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Perceptions of low and high flow water risks in the Cordillera Blanca, Peru

GEO 511 Master's Thesis

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Photo on the title page: The Palcacocha glacier lake in front of the Palcaraju and Pucaranra glacierised mountains. Source: photo by Alexander Luna, ongoing project with the title YURAQ JANKA | CORDILLERA BLANCA.

Abstract

Climate change has manifold impacts on different regions in the world. High mountain environments are particularly sensitive to climate change. Melting glaciers, destabilising effects on mountain slopes and changing precipitation increase the occurrence of natural hazards. In addition, melting glaciers let glacial lakes grow in number and volume, aggravating the risk of glacial lake outburst floods (GLOFs). Moreover, the whole hydrological regime is changing, resulting in water scarcity. These circumstances considerably enhance risks for populations living in these areas. Corresponding adaptation measures have been shown to fail when the risk assessment did not fully consider the risk perception of all stakeholders. This study analyses local residents' and experts' perceptions of high and low flow water risks in the Quillcay catchment, Cordillera Blanca (Peru). The Quillcay catchment is located in a highly dynamic environment, influenced by several climate change impacts such as GLOFs and water scarcity. A transdisciplinary investigative approach, involving qualitative semi-structured and expert interviews, is used in the case study. The qualitative analysis shows differences between the perceptions of the two groups. The interviewed local residents perceived water scarcity as the most important risk by far and ascribed only minor importance to GLOFs. On the other hand, the experts perceived water scarcity to be only slightly more important than GLOFs, while some of the experts did not even consider water scarcity as a problem in the catchment. Since experts' perceptions affect practice significantly, this results in a lack of adaptation measures to address water scarcity. It is, therefore, suggested that the perception of local residents as well as social, cultural, economic and political dimensions are considered to a greater extent in risk assessment and in the consequent implementation of adaptation strategies.

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Abbreviations

ALA Huaraz	Autoridad Local del Agua (Local Water Authority)
ANA Huaraz	Autoridad Nacional del Agua (National Water Authority)
CENEPRED	Centro Nacional de Estimación, Prevención y Reducción del Riesgo de Desastres (National Centre for Disaster Risk Estimation, Prevention and Reduction)
COSUDE	Cooperación Suiza de Desarrollo (Swiss Development Cooperation)
EWS	Early warning system
GLOF	Glacier lake outburst flood
INAIGEM	Instituto Nacional de Investigación en Glaciares y Ecosistemas de Montaña (National Institute for Glacier and Mountain Ecosystem Research)
INDECI	Instituto Nacional de Defensa Civil del Perú (National Institute of Civil Defence of Peru)
MINAM	Ministerio del Ambiente del Perú (Ministry of the Environment of Peru)
PNH	Parque Nacional Huascarán (Huascarán National Park)
PUCP	Pontificia Universidad Católica del Perú (Pontifical Catholic University of Peru)
Predes	Centro de Estudios y Prevención de Desastres (Centre for Disaster Studies and Prevention)
UGRH	Unidad de Glaciología y Recursos Hídricos (Glaciology and Water Resources Unit)

1 Introduction

Rapidly retreating glaciers form many new glacial lakes and let existing ones grow. Avalanches and rock falls also occurr more often due to destabilising effects on mountain slopes. The combination of these climate change impacts increases the potential occurrence of GLOFs in high mountain areas. When an avalanche or a rock fall hits a glacial lake, it can cause a flood wave that overtops the lake and runs down the valley, causing large scale destruction along its path. In 2010, such a flood wave from glacial lake no. 513 threatened residents from Carhuaz, Cordillera Blanca (Peru). Fortunately, it was a small flood and there were no fatalities. To protect people from a future glacial lake outburst flood, an early warning system was implemented at the lake to warn the local population in the case of an outburst. At the end of November 2016, the rainy season should already have started, but no rain was in sight. Farmers desperately waited for the rain to sow their potatoes. The longer the absence of rain lasted, the more a rumour spread that the scientific instruments of the early warning system were holding back the rain. Eventually, this rumour mobilised a group of incensed residents who went up to the glacial lake and dismantled the early warning system. A few days later, it started to rain (Willer 2017).

Were these farmers simply superstitious? Or did an particular Andean rationality contribute to this belief? Or were political dissents decisive for the mobilisation of people?

A prior in-depth study could have shed light on the local conditions. Consideration of all dimensions including technical, institutional, social, cultural and political aspects might have prevented such an incident. Indeed, there were studies made on the local conditions and workshops were conducted in which inhabitants were informed about the project. But they all focused on the GLOF risk, and did not consider what people were most worried about: water scarcity.

1.1 Research gaps

So far, research on climate change and subsequent glacier retreat has mainly focused on the physical impacts such as glacier runoff change. However, less attention has been paid to the impacts of glacier retreat for human populations living in high mountain areas, nor have investigations in this topic often integrated natural-human approaches. If glacier retreat and the subsequent decline in runoff is only regarded as an environmental problem driven by globally rising temperatures, research on these effects fail to recommend effective adaptation strategies, because it neglects the social drivers of the problem. Thus, the scientific work has predominantly been done within disciplinary boundaries. To address this shortcoming appropriately, a transdisciplinary approach is required, involving different academic disciplines as well as non-scientists. Increasingly, scientists call upon integrative transdisciplinary approaches combining different disciplines as well as local perspectives (Bury et al. 2011; Carey et al. 2017; Carey, Huggel, et al. 2012; Castree et al. 2014; Drenkhan et al. 2015; Negi et al. 2016; Polk et al. 2017). Carey et al. (2017) emphasise the importance of the integration and acceptance of a diverse range of local knowledge. Not only academic knowledge, but also indigenous knowledge, women's voices and local farmers' observations should be integrated. In this process, natural and social sciences should interact and collaborate on equal terms (Carey et al. 2016, 2017; Klenk and Meehan 2015; Wainwright 2010). Jurt el al. (2015) recommended that local perspectives should be addressed from inside the communities to better understand their responses to climate change. In addition, the knowledge of local residents such as farmers can give important insights into local conditions under climate change and its impacts that are often overlooked or unknown by scientist from outside (Byg and Salick 2009). Within the existing research on physical impacts of climate change at high altitudes, en emphasis has been placed on high flow risks such as floods or GLOF while low flow risks such was water scarcity have been treated less. Moreover, hardly any research has focused on the integrated assessment of both the impacts of low and high flow hazards. Furthermore, research on the perception of high mountain glacial low and high flow water risks is scarce. Most previous studies in this area are on local perceptions of climate change (e.g. Byg and Salick 2009; Heikkinen 2017; Jurt et al. 2015; Kaul and Thornton 2014; Shijin and Dahe 2015), while few have focused on the perception of glacier related high flow hazards like GLOFs and, even less on glacier related low flow hazards such as water scarcity.

To summarise, the following research gaps can be identified: (1) human impacts of climate change, (2) transdisciplinary approaches which include the consideration of different knowledge as well as perspectives from inside, (3) local insight into climate change impacts, (4) low flow risks, and (5) the perception of these.

1.2 Research objective and questions

The aim of this study is to contribute to the identified research gaps by investigating how local residents and experts perceive low and high flow water risks in the Quillcay catchment, Cordillera Blanca (Peru). The insights should help to compare the perceptions of local residents and experts and understand the differences or similarities between the groups. This in turn should contribute to the improvement of future adaptation strategies in the field. On the basis of the previous considerations, the study's research questions are formulated as follows.

The main research interest is stated in the first question and the further questions contribute to the principal question. The second, third and fourth questions extend the topic while the fifth to the eighth questions are intermediate steps to answer the superior questions.

> *"How do local residents and experts perceive low and high flow water risks of the Quillcay catchment?"*

>> *"To what extent do the perceptions of local residents and experts differ?"*
>>
>> *"How can differences or similarities between local residents' and experts' perceptions be explained?"*
>>
>> *"To what extent do differences in perceptions between local residents and experts entail consequences?"*

>>> *"Which low or high flow water risks do local residents and experts perceive in the Quillcay catchment?"*
>>>
>>> *"Which low or high flow water risk do local residents and experts perceive as the most important one?"*
>>>
>>> *"How do experts define risk?"*
>>>
>>> *"To what extent do experts' definitions of risk resemble to international risk concepts (e.g. IPCC (2014))?"*

1.3 Structure

The work is structured in 9 chapters in the following way.

Chapter (2) presents the study area of the Quillcay catchment. It is located in the high mountains of the Cordillera Blanca, Peru. Its climate, hydrology, glacier hazard history, and the local economic activities are illustrated.

Chapter (3) and (4) give an overview of the current state of research in natural and social science. Chapter (3) starts with introducing the risk concepts of the study and then summarises natural science studies about climate change and its impacts in high mountain areas. Chapter (4) compiles different social science theories and current research on risk perception.

Chapter (5) explains the qualitative methods used in the present study. They consist of snowball sampling (Patton 1990), episodic (Flick 2000) and expert (Bogner et al. 2002, 2009) interviews, and content analysis (Mayring 2007). In addition, it presents the sample of the local residents and the experts.

Chapter (6) presents the qualitative results of the research. The topics discussed are the role of water, the perception of low and high flow water risks, and the definition of risk.

Chapter (7) analyses and discusses the results, and in doing so, answers the research questions. It is divided into three parts. Firstly, it starts with a short summary of the results and relates them to physical science literature. Secondly, it illustrates the risk perceptions observed in the two sample groups, and presents explanatory approaches to the observed patterns. Thirdly, it relates the results to social science theories. In addition, it reflects on the contribution to the scientific debate, the limitations of the study and finally presents an outlook on future research and recommendations for practice.

Chapter (8) concludes the main findings.

This research contributes to the SNSF and DFG funded project '*AguaFuturo*: Integrated Water Resources Modelling: Future Risks and Adaptation Strategies - a case study in the Andes of Peru', a joint project of University of Zurich, University of Stuttgart and University of Oregon.

2 Study Area

Figure 1 Callejón de Huaylas valley and the city of Huaraz. The lower unglaciated Cordillera Negra to the west (left) and the snowy peaks of the Cordillera Blanca to the northeast (right) with its highest peak Huascarán (6768 m a.s.l.). Source: photo by the author.

2.1 Location

The present study focuses on the Quillcay catchment, which is situated in the tropical high mountains of the Cordillera Blanca in northern Peru (see Figure 3). The catchment is characterised by the urban centre of the city of Huaraz and the surrounding settlements and villages uphill to the east. It comprises the settlement of Nueva Florida and the villages Llupa, Coyllur and Yarush (see Figure 2). At an elevation of 3052 m a.s.l, Huaraz is the largest city in the Callejón de Huaylas and the capital of the region Ancash. The Callejón de Huaylas is a valley extending from south to north in the highlands of the Andes. It is embedded between the glaciated Cordillera Blanca to the east and the lower unglaciated Cordillera Negra to the west, which separates it from the Pacific ocean. The Cordillera Blanca is the largest and highest mountain range in Peru and hosts the largest area of tropical glaciers worldwide (Mark et al. 2017; UGRH 2014a). The peak of the mountain Nevado Huascarán (6768 m a.s.l) represents the highest peak of the Cordillera Blanca and Peru (see Figure 1).

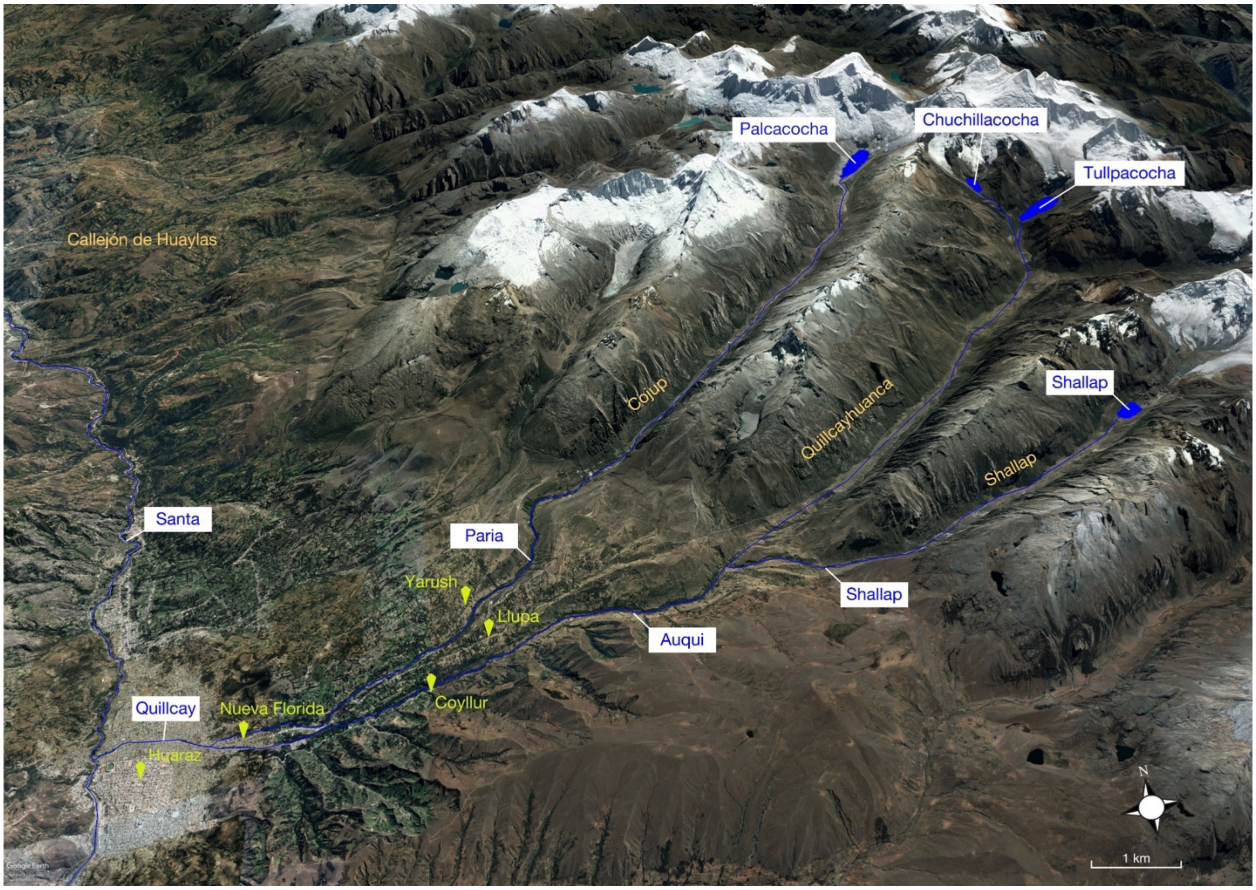

Figure 2 The Quillcay catchment. It is a subcatchment of the Callejón de Huaylas and consists of the microcatchments Cojup, Quillcayhuanca and Shallap. Source: Google Earth 2018, edited by the author.

Figure 3 Location of Huaraz. (left) Huaraz in Peru and the northwest of South America; (right) Huaraz in the Callejón de Huaylas with the snowy peaks of the Cordillera Blanca to the east. Source: Google Earth 2018, edited by the author.

2.2 Hydrology

The Cordillera Blanca constitutes the watershed between the continental slopes of the Pacific and the Atlantic. The Callejón de Huaylas, also known as Santa valley, hosts the Santa river which originates uphill from Huaraz, flows along the whole valley and disembogues in the Pacific ocean accomplishing a course of 300 km. The Santa river is the largest and most important river in the area. It has a crucial economic role, since most hydropower and large-scale agricultural activities depend on its water (Drenkhan et al. 2015). Quillcay is a subcatchment of the Santa catchment, and is formed by three microcatchments: Shallap in the southern part, Quillcayhuanca in the centre and Cojup in the north (see Figure 2). Shallap and Quillcayhuanca form the basin of the Auqui river and the Paria river flows through Cojup. The Auqui and Paria rivers merge together to form the Quillcay river, after which the subcatchment is named. The Quillcay river flows from the convergence in Nueva Florida through Huaraz and confluences with the Santa river. The Paria and Auqui rivers have different water quality properties. The Paria has good water quality with an approximately neutral pH of 6.8 on average, whereas the Auqui is naturally contaminated, containing acidic water with an average pH of 4.0 (see Figure 4). The water exhibits aluminium, manganese and dissolved iron concentrations (EPS Chavín S.A. 2006). EPS Chavín, the company that provides the water supply for Huaraz, is located at the Paria river, where it captures water which requires less treatment. The source regions of the rivers are the snowy peaks east of Huaraz, which drain their melt water into the glacial lakes at the headwaters. Palcacocha is the glacial lake at the beginning of the Cojup microcatchment (see Figure 5), the lakes Tullpacocha and Cuchillacocha are located above Quillcayhuanca and the lake Shallap on top of the Shallap valley.

Figure 4 The Auqui river in the Quillcayhuanca catchment. The yellowish colour reveals the contamination. Source: INAIGEM (2016).

Figure 5 The Palcacocha glacial lake. The two glaciated mountains Palcaraju and Pucaranra are located in the background. In the foreground the siphoning system which drains the lake is visible. Source: photo by the author.

2.3 Climate

In the tropical latitude of the Peruvian Andes, the annual average temperature does not vary much throughout the year, but precipitation is characterised by pronounced seasonal patterns. The annual hydrological cycle is divided into a rainy season from October to April (austral summer) and a dry season from May to September (austral winter) (Bury et al. 2013; Gurgiser et al. 2016; Mark et al. 2010). In the Santa catchment, precipitation varies between approximately 700-1000mm/year, with most of the rainfall during the wet season (Garreaud et al. 2009).

2.4 Glacier hazard history

The Cordillera Blanca has a long history of glacier hazards, involving many fatalities. In the last 150 years, at least 24 GLOFs have killed about 6000 people and roughly 20,000 people have been killed by at least six avalanches. In 1941, Huaraz was hit by a major GLOF that destroyed a third of the city including its centre and killed 5000 people (see Figure 6) (Ames Marquez and Francou 1995; Carey 2005; Portocarrero 1995; Zapata Luyo 2002). The GLOF emerged through an ice avalanche impact into the moraine dammed glacial lake Palcacocha (see Figure 5). The last time a flood wave from Palcacocha, caused by a landslide from the lateral moraine, threatened residents along the Paria and Quillcay rivers was in 2003. Fortunately no damage occurred that time (Carey 2005; Vilímek et al. 2005).

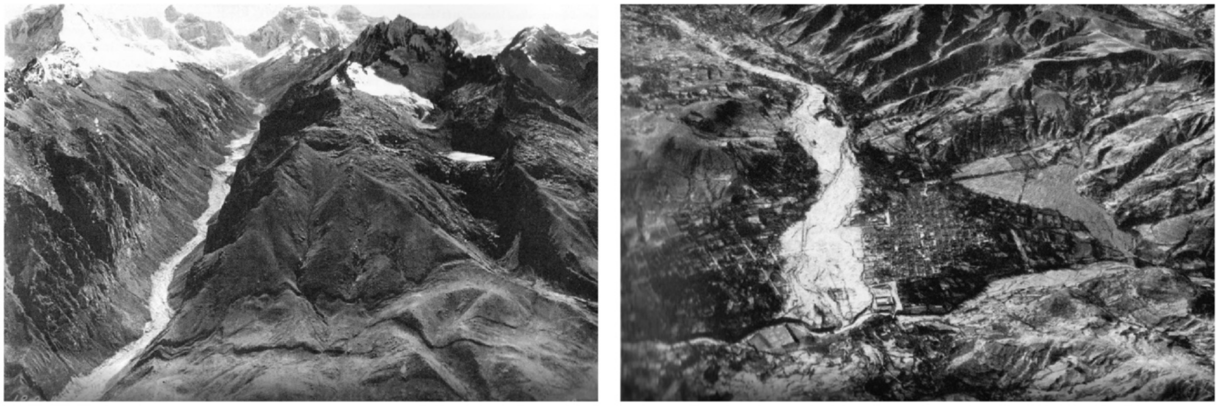

Figure 6 GLOF traces. (left) Cojup catchment after the GLOF in 1947; (right) Huaraz and Nueva Florida after the GLOF in 1947. Source: Photo Servicio Aerofotográfico Nacional.

Figure 7 Infrastructure at GLOF risk. (left) Boulevard beside the Quillcay river in the city centre; (right) housing in the confluence of Paria and Auqui river in Nueva Florida. Source: photos by the author.

To prevent further disasters from Palcacocha lake, an artificial dam was built at the glacial lake in 1974. The artificial dam strengthens the natural one and increase the freeboard by 7 m. Since the emptying of the lake in 1941, the lake level and hence the lake volume have steadily risen until the present day. In 2016, the lake contained a volume of approximately 17 million m^3, more than at the moment of the outburst when it was estimated to 12 million m^3. Current modelling shows that the freeboard of the artificial dam is no longer enough to retain a potential flood wave caused by an impact into the lake. in 2011, a siphoning system was installed at the lake to counteract this circumstance. It reduces the volume of the lake by draining additional water and thus increases the freeboard (UGRH 2017). To this date, an early warning system is in the planning stage. Moreover, outburst floods could also originate in the Tullpacocha and Cuchillacocha glacial lakes. For these reasons, Huaraz and the surrounding settlements are permanently exposed to GLOF risk. Furthermore, the areas destroyed in 1941 were reconstructed and a rapid uncontrolled urbanisation process started to occupy additional territory in the hazard zone. Nowadays, large parts of Huaraz including the centre and surrounding settlements are at high risk of GLOFs because they are located within the reach of the flow path of a potential outburst flood (see Figure 7). This especially applies to the now densely populated settlement of Nueva Florida, which was uninhabited in 1941 and completely overrun by the GLOF (see Figure 6 and Figure 7). Huaraz and the neighbouring municipality of Independencia count approximately 120,000 inhabitants of which almost half are exposed to GLOF risk (Proyecto Glaciers+ 2016).

2.5 Demography

Broadly speaking, the population in the Callejón de Huaylas consists of urban Spanish-speaking mestizos who are of mixed Spanish-indigenous ancestry and rural indigenous people who speak Quechua. The relation of the Cordillera Blanca's population to the capital Lima and its leadership has never been favourable. There exists a long history of highland populations occupying a marginalised position in Peruvian society in comparison with coastal residents. There is evidence to suggest that the coastal region and population is privileged by the governing Spanish descendant elite since the establishment of Lima in 1536. Still today, people from the Peruvian Andean highlands are disadvantaged through political neglect and stereotypical perceptions. They are considered to be underdeveloped because of their inaccessible landscape, and indigenous inhabitants are seen as 'backward'. Highland inhabitants, in turn, feel snubbed and neglected by the racist, in their view, government from Lima (Carey 2005; Mallon 1992; Orlove 1993; Poole 1997).

2.6 Economy

Small-scale agriculture is traditionally the most widespread subsistence activity in the Peruvian Andes (see Figure 8). To date, most indigenous highland inhabitants are still small-scale farmers for their own subsistence. This type of farming, which is spread over elevations between 3000 and 4000 m a.s.l., is rain-fed in the wet season and primarily depends on glacial melt water during the dry season (Bradley et al. 2006; French et al. 2016; Mark et al. 2010). The crops cultivated in these areas are potatoes, corn and grain such as wheat, which are primarily produced for self-subsistence and surpluses are sold on the markets in Huaraz (Gurgiser et al. 2016). The money earned is used to buy food products that cannot be cultivated in this environment like rice, sugar and different types of vegetables and other consumer items. In recent years and decades, the

Figure 8 Small-scale agriculture in Llupa. Source: photos by the author.

Andean agriculture has increasingly being faced with the impacts of climatic changes. There exists evidence that rain-fed agriculture has been deteriorating and crop losses have increased due to changing and unpredictable precipitation patterns, including a delayed wet season onset, enhancing torrential rainfall events and dry spells during the rainy period (Gurgiser et al. 2016; Sanabria et al. 2014). Towards the lower parts of the Santa catchment, the agriculture changes. Mostly high-value export crops are cultivated in large-scale agricultural projects, such as CHAVIMOCHIC and CHINECAS (Carey et al. 2014). Rapid economic growth in activities like mining, ecotourism and production of export crops has led to a diversification of subsistence activities and urban migration. These changes, which are locally highly uneven, increase the demand of water resources (Bury et al. 2013; Drenkhan et al. 2015; Mendoza Nava 2015; Painter 2007).

3 Climate change and its impacts

The following chapter focuses on changing climate and resulting impacts. First, it introduces risk concepts and definitions and then illustrates climatic changes and its impacts in high mountains.

3.1 Risk concepts and definitions

The study bases on the risk concept stated in the 5th Assessment Report of the Intergovernmental Panel of Climate Change (IPCC) (2014a, 2014b). Additionally, risk definitions of Peruvian institutions working with risk management are presented since they are relevant for this study as interviews of these institutions were conducted.

3.1.1 IPCC

According to the risk concept of IPCC created in 2014, risk is a function of hazard, vulnerability and exposure (see Figure 9) (IPCC 2014a, 2014b).

$$\text{Risk} = f\,(\text{hazard, vulnerability, exposure})$$

A potential natural hazard alone is not yet a risk. But as soon as it exists in the presence of exposed and vulnerable human populations, it constitutes a risk. Consequently, a glacial risk exists not only because of geophysical dynamics in high mountains but also because human populations are present in places that potentially could be affected and are vulnerable to the hazard. Hence, if people are vulnerable but not present in a place that could be affected, there exists no risk and if people are exposed to a glacial hazard but are prepared enough to not be affected, there is no risk either. IPCC (2014a, p. 5) defines the components of the risk concept as follows.

Hazard

"The potential occurrence of a natural or human-induced physical event or trend or physical impact that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources" (IPCC 2014a, p. 5). In this work, the term hazard is used to refer to climate-related physical events or trends and their physical impacts.

Vulnerability

"The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt" (IPCC 2014a, p. 5). In the context of the Peruvian Andes, certain parts of the population are more vulnerable than others. For example, a higher vulnerability can be assigned to Quechua-speaking subsistence farmers living in rural areas and poorer communities living in new settlements along the margins of rivers where GLOFs can pass (Carey 2010; Oliver-Smith 1999).

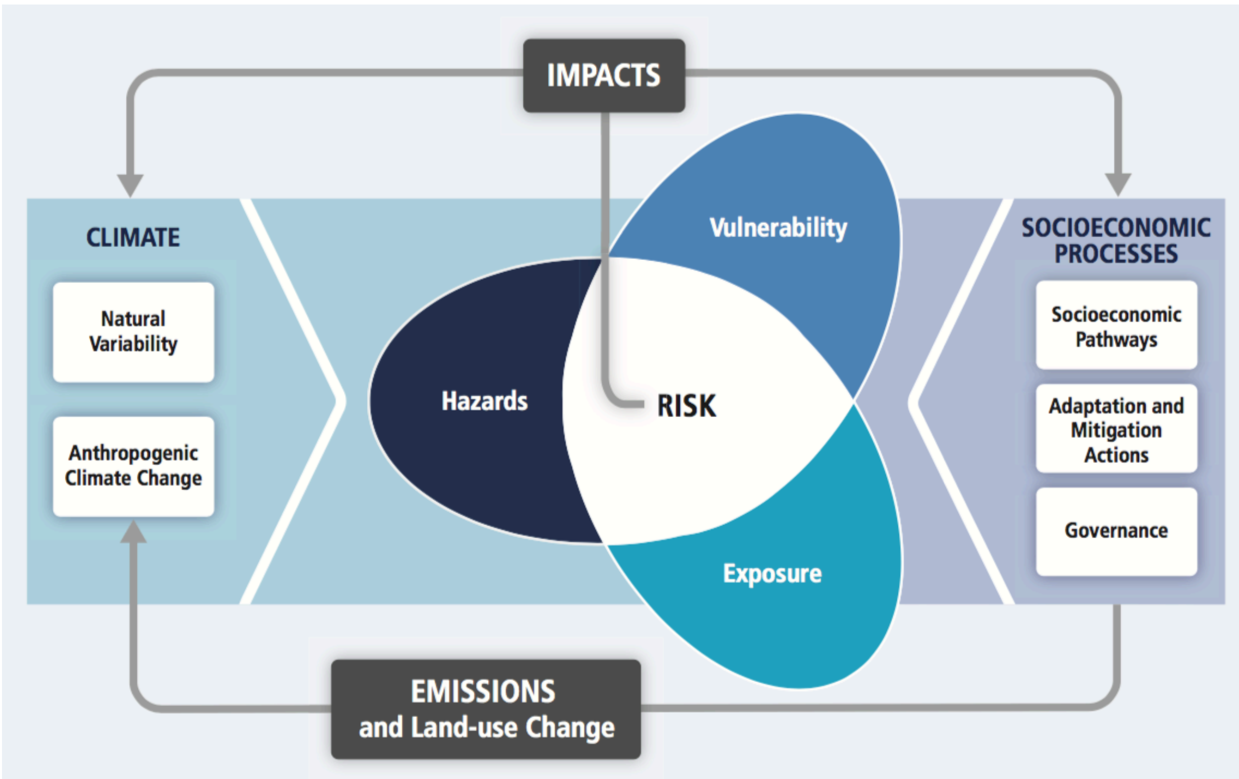

Figure 9 The risk concept of IPCC. Risk results from the interaction of climate-related hazards with the vulnerability and exposure of human and natural systems. Changes in both the climate system (left) and socioeconomic processes including adaptation and mitigation (right) are drivers of hazards, exposure, and vulnerability. Source: IPCC (2014a).

Exposure

"The presence of people, livelihoods, species or ecosystems, environmental functions, services, and resources, infrastructure, or economic, social, or cultural assets in places and settings that could be adversely affected" (IPCC 2014a, p. 5). Differences in vulnerability and exposure are not determined by climatic factors. They are determined by multidimensional social, economic and cultural inequalities which are often produced by uneven development processes (IPCC 2014a).

Risk

"The potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. Risk is often represented as probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur. Risk results from the interaction of vulnerability, exposure, and hazard" (IPCC 2014a, p. 5). In this study, the term risk refers to the risks of physical climate-change impacts. The focus lies on the potential consequences of a risk i.e. the threat posed by a risk. Within this it emphasises the individual attribution of values. There is less focus on the probability of occurrence. The composition of risk from hazard, vulnerability and exposure is a presupposed thought but not treated in depth.

3.1.2 Peruvian institutions

In Peru, the concept of risk is defined on a national level by CENEPRED, the national centre for disaster risk management, and INDECI, the national institute of civil defence of Peru. Both institutions share the disaster risk management process. The current definition is stated in the manual for risk assessment of natural phenomena created in 2014 (CENEPRED 2014). In this manual, risk is a function of hazard and the vulnerability of exposed elements. More specific, hazards are identified by evaluating the factors intensity, magnitude, frequency or period of recurrence (return period), and the level of susceptibility to phenomena of natural origin. The vulnerability is defined by an analysis of exposure, fragility and resilience.

$$R_{ie} \mid_t = f\,(H_i, V_e) \mid_t$$

R = risk

f = function

H_i = Hazard with an intensity greater than or equal to $_i$ during an exposure period $_t$

V_e = Vulnerability of an exposed element $_e$

The risk definition is formalised in the national law no. 29664, which was developed in the year 2011. The definitions are based on scientific work from Cardona (1985) and Fournier d'Albe (1985) among others. In comparison to the risk concept of IPCC, this concept does not state exposure as a separate component but includes it into vulnerability.

Initially, a distinction between the terms *hazard* and *risk* was intended in the whole research including the interviews. However, the first contact with people at the study site revealed that a distinction between the terms was not useful since they did not distinguish them. Instead, they used both terms interchangeably. Moreover, the term *hazard* does not exist in this exact formulation in Spanish. In Spanish, the term ‚peligro' is used for hazard, but 'peligro' can also mean *danger* in general. *Risk* on the other hand is 'riesgo' in Spanish and can clearly be demarcated. To adapt to the interviewees' language, the terms were also used interchangeably by the interviewer with a preference for 'peligro' or *hazard* respectively, to avoid influencing the interviewees' answers. For these reasons, hazard, risk and danger are also used interchangeably in this work to display results as accurately as possible.

3.2 Climate change and its impacts in high mountains

One fifth of the continents are covered with mountain systems. High mountains are crucial for direct and indirect life support of many people worldwide because they provide important ecological services. They are a key element of the hydrological cycle and constitute the source region of many of the world's major rivers. The environment of high mountains is especially sensitive to climatic changes. Snow, ice and permafrost react sensitively on changes in atmospheric conditions such as the increase in temperature due to their proximity to melting conditions. Moreover, mass movements are most intense on steep mountain slopes (Haeberli and Beniston 1998). Globally rising temperatures also cause changes in precipitation in high mountains. These changes in combination with snow and ice melt result in an increasing runoff variability and finally in a change of water resources. Consequently, ecological and social systems downstream are affected (Bury et al. 2011). The tropical glaciated mountain ranges in Peru are particularly sensitive to impacts of climate change (Bury et al. 2011; Carey 2005). At the same time, they play an essential role for the freshwater supply of the adjacent semi-arid lowlands because they store and release water from snow, ice, and lakes.

3.2.1 Temperature increase

The mean temperature of each of the last three decades has successively been higher than any preceding decade since 1850. In the Northern Hemisphere, these three decades were very likely the warmest 30-year period of the last 800 years and likely the warmest of the last 1400 years. On global average, surface air temperature has increased by 0.12 °C per decade between 1951 and 2012 (IPCC 2014b). In comparison, temperature has increased by 0.13 °C per decade from 1950 to 2010 in the tropical Andes, which is above the global average. Especially low-latitude and high-altitude regions such as the tropical Andes are exposed to rapid global warming. This is probably due to more humid air that reduces the lapse rate. This is why it is generally warmer in high altitudes closer to the equator than further north or south. Moreover, scenarios of future temperature development in the Andes predict continuing pronounced warming rates (Bradley et al. 2006; Buytaert and de Bievre 2012; Vuille et al. 2003, 2008, 2015; Vuille and Bradley 2000).

3.2.2 Precipitation change

During the last century, precipitation has increased in mid-latitude regions of the Northern Hemisphere. However, no clear uniform trends could be identified for other latitudes (IPCC

2014b). Precipitation patterns are also not uniform in the Andes either. For the area of the Cordillera Blanca and further north, a slight increase in precipitation could be observed whereas towards south a slight decrease (Haylock et al. 2006; Vuille et al. 2003). Although the total amount of precipitation has not changed significantly in the Andes and the Cordillera Blanca, the frequency of extreme precipitation is changing. Most gauging stations in Peru show increases in heavy precipitation events, however at the same time few stations also show decreases (Haylock et al. 2006). This suggests a heterogeneous pattern in precipitation changes. On a global level, there are more regions where the number of extreme precipitation events has increased than decreased (IPCC 2014b). In the Callejón de Huaylas, a high interannual variability in precipitation patterns was found (Gurgiser et al. 2016). The onset dates of the rainy season, the number of torrential rain events per agricultural year, and the occurrence of dry spells after the onset of the rainy season vary strongly among different years. But no fundamental changes in the amount of precipitation could be observed. It should be mentioned that the potential effects and trends in frequency of heavy rainfall events could not fully be addressed due to the lack of data (Gurgiser et al. 2016). These observations indicate that the minor changes in precipitation patterns are unlikely to have importantly contributed to the observed glacier recession (Rabatel et al. 2013; Vuille et al. 2003). The 5th assessment report of the Intergovernmental Panel on Climate Change (IPCC) lists extreme precipitations as a key risk of climate related risks for the future. In Central and South America, extreme precipitations are stated to cause flooding and landslides in urban and rural areas.

3.2.3 Glacier retreat and related hazards

Glaciers are continuously shrinking almost worldwide (IPCC 2014b). The first decade of the 21st century shows the most negative mass balances on a global scale since the beginning of observations, followed by the last decade of the 20th century (Rabatel et al. 2013; Vuille et al. 2008; Zemp et al. 2015). In the tropical Andes, glaciers are particularly vulnerable to climate change. They are rapidly shrinking in surface area, length and volume. Since the Little Ice Age maximum, the current rate of glacier retreat in the tropical Andes is unprecedented (Rabatel et al. 2013). The increasing recession trend has started in the late 1970s. The glaciers in the tropical Andes show a more negative mass balance (retreat rate) than the average glacier monitored in the rest of the world. Especially glaciers that are entirely located below 5400 m a.s.l. are likely to disappear in the coming years to decades. Since they do not have a permanent accumulation zone and are generally small glaciers, they are more vulnerable to changing climate conditions. Yet, they represent the majority of all glaciers in the tropical Andes (Rabatel et al. 2013). Rabatel et al. (2013) assume that the observed glacier retreat can be attributed to the increase in atmospheric temperature and Vuille et al. (2018) state that the recession is closely linked to the observed increase in surface air temperature at high altitudes in the region.

99% of all tropical glaciers worldwide are located in the tropical Andes (Kaser 1999). They spread over Venezuela, Colombia, Ecuador, Peru and Bolivia (Rabatel et al. 2013). Peru hosts 71% of all tropical glaciers whereby the Cordillera Blanca represents the largest area of tropical glaciers worldwide. Glaciers in Peru shrunk by 43% from 2’042 km^2 in 1970 to 1’171 km^2 in the 2014. In the Cordillera Blanca, they shrunk by 27% from 723 km^2 in 1970 to 528 km^2 in 2014 (UGRH 2014a). According to the 2014 glacier inventory, 755 of the total 2679 glaciers of Peru are found in the Cordillera Blanca (representing 41%). The glaciers are ranging from an altitude of 4249 m a.s.l. to 6701 m a.s.l. whereby the minimum altitude of the vast majority is below 5400 m a.s.l. (see Table 1).

Glaciers in the Cordillera Blanca, Peru	Range of Minimum Altitude [m a.s.l.]	Number
	4000 - 4500	18
	4501 - 5000	459
	5001 - 5500	273
	5501 - 6000	5
Total		755

Table 1 Distribution of glaciers according to ranges of minimum altitudes in the Cordillera Blanca, Peru. Source: UGRH (2014a).

The recession and the thinning of glaciers lead to an increase in glacier related hazards. GLOFs, rock/ice avalanches, rock falls, and landslides at gradually destabilising slopes have become more frequent since anthropogenic global warming has started. As glaciers thin, they are becoming more instable and susceptible to fractures. This leads to an increased potential of ice avalanches. Rock/ice avalanches, rock falls, and landslides are occurring more often due to destabilising effects on mountain slopes. Steep mountain slopes react belatedly on the disappearance of the glaciers that previously supported them. Additionally, the rising temperatures degrade permafrost and icy peaks. GLOFs are the most prominent glacial hazard in terms of damage potential (Osti and Egashira 2009; Richardson and Reynolds 2000). The tropical Andes and the Cordillera Blanca have repeatedly been the scene for those glacial hazards where GLOFs and ice/rock avalanches were the most devastating hazards (Carey 2010; Emmer et al. 2014; Evans et al. 2009; Harrison et al. 2018; Vilímek et al. 2005).

3.2.4 Glacial lakes

As glaciers are melting, new glacial lakes form and already existing ones grow. The inventory of glacial lakes counted 830 glacial lakes in the Cordillera Blanca of which 204 have appeared recently (UGRH 2014b). Moreover, many more lakes are to come into existence in the future. As the glaciers are retreating, overdeepened parts of the glacier bed are exposed and filled up with glacial melt water resulting in the formation of new glacial lakes. In Peru, 201 potential future glacial lakes >1 ha (10^4 m^2) were identified of which 31 are located in the Cordillera Blanca (Colonia et al. 2017). The new lakes constitute a potential for water supply, hydropower production and tourism (Haeberli, Buetler, et al. 2016) but at the same time also pose a threat to downstream living populations (Haeberli, Schaub, et al. 2016).

Firstly, future glacial lakes can contribute to the water supply of downstream populations. This might be an important supplement in the future since water resources in high mountains in the form of short- and long-term snow and ice are vanishing (Seibert et al. 2014). When needed, the water stored in glacial lakes could partially replace the decreasing melt water. However, the storage capacity of the potential future lakes is minor in comparison to the capacity of the still existing amount of snow and ice (Linsbauer et al. 2012). Furthermore, major investments in infrastructure would be needed that additionally hinder the endeavour. Secondly, the future lakes also provide potential for hydropower production. Hydropower energy production is favourable because of its highly flexible energy storage. However, its planning is problematic since energy prices are fluctuant (Biot 2015). Thirdly, tourism can benefit from glacial lakes as a potential compensation for the change of landscape diversity due to glacier retreat (Espiner and Becken 2014). High mountain landscapes are transforming rapidly as a result of vanishing glaciers and degrading permafrost. Within decades, new landscapes will evolve presenting bare bedrock, loose debris, sparse vegetation, numerous new lakes and steep slopes with slowly degrading permafrost (Haeberli, Schaub, et al. 2016). Lastly, multipurpose projects for glacial lakes are promising. They integrate aspects of water supply and risk management (Haeberli, Buetler, et al. 2016).

Despite the benefits of emerging glacial lakes, they increase the hazard potential of GLOFs. The growth of glacial lakes in number and volume combined with the accumulation of rock/ice avalanches, rock falls, and landslides increases the GLOF risk considerably (Haeberli, Schaub, et al. 2016).

3.2.5 GLOF

Glacial lake outburst floods (GLOFs) are the most important glacial hazard in terms of damage potential (Osti and Egashira 2009). They have killed thousands of people worldwide, and caused severe impacts on infrastructure of downstream communities and on long-term economic development (Harrison et al. 2018). In the Cordillera Blanca, GLOFs and avalanches have killed nearly 30,000 people since 1941 (Carey 2005). Climate change has shown an influence on the frequency of GLOFs. The number of worldwide GLOF events has increased simultaneously with the glacier's recession since the beginning of the 20th century. Since 1860, 165 moraine failure triggered GLOFs have worldwide occurred, of which 28 in Peru (Harrison et al. 2018).

Process

In what follows, the process of glacial lake outburst floods is described (see Figure 10). It focuses on GLOFs triggered by moraine dam failure or overtopping flows or a combination of both (Clague and Evans 2000; Harrison et al. 2018; Huggel et al. 2004; Richardson and Reynolds 2000; Worni et al. 2012). The failure of moraine-dams is the most common trigger of glacial lake outburst floods (Harrison et al. 2018).

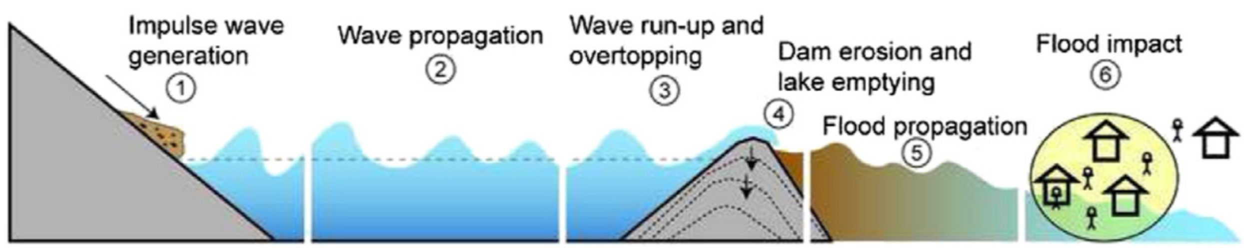

Figure 10 Sketch of a typical GLOF process chain caused by an impact into the lake. Source: Worni et al. (2014).

(1) An impact on a glacial moraine dammed lake generates an impulse wave. The impact is caused by avalanches (snow, ice, rock or mixed), rock fall, debris flows or landslides from degrading icy peaks, destabilising mountain slopes or moraines. Moraine dammed lakes result from periods of glacier recession when glacier tongues thin, stagnate in flow and recede. They typically form between the glacier tongue and the end moraine.

(2) The impact wave is propagated along the lake.

(3) The wave runs up the dam and overtops it. Alternatively, the overtopping flow can also be triggered by heavy rainfall or a sudden influx of water from upstream sources that rise the lake level until it overflows.

(4) The overtopping flow successively erodes the dam until the lake empties. In this process, the material of the dam is crucial for the stability. Dams that consist of loose moranic material are susceptible to erode with overtopping flows. Moraine dams are formed by rock debris transported by glaciers. There are other types of dams where the outflow process is different, such as ice dammed lakes, bedrock dammed lakes, landslide dammed lakes and combinations of the just mentioned types.

(5) The flood wave is propagated downwards. Along the path, the consistency of the flood changes: initially, it mainly consist of water and on the way, it incorporates debris and transforms to a debris flow. If there are shallow parts on the way down, the debris flow deposits debris and continues with more water than debris.

(6) The debris flow impacts downstream settlements, infrastructure and fields along the flow path.

GLOFs can occur at any time of the year, independent of the season. Harrison et al. (2018) identified the weather as a potential trigger of GLOFs. Warm summer weather or heavy winter snow may trigger ice avalanches into the lake. They found that GLOFs triggered by ice avalanches or rock falls predominantly occur during summer. However this result should be treated with caution as their data are incomplete. According to Richardson and Reynolds (2000), who researched in the Himalayas, the main trigger of the failure of moraine dammed lakes are ice avalanches, followed by seepage and rock avalanches.

Measures

There exist structural and non-structural measures to mitigate impacts from GLOFs or prevent the lake outburst from happening at all (see Figure 11 and Figure 12). Structural measures can be measures at the lake such as dam strengthening including artificial dams, and control of the lake level by lake drainage through open cuts or tunnels. These measures should prevent an outburst flood from happening (Emmer et al. 2018). Further, there exist structural measures along the flow path such as retention basins and deflection dams that should mitigate the GLOF impacts. Non-structural measures include early warning systems (EWS). To function, an EWS presupposes understanding of the risk, hazard monitoring, risk communication, and preparedness of people including response capacity. In case of a GLOF event, early warning systems trigger an alarm at the glacial lake which is passed on to responsible authorities who are in charge to decide whether to evacuate or not. If so, citizens should be prepared to response to the alarm and seek flood safe places (Hegglin and Huggel 2008). In the Cordillera Blanca, approximately 40 glacial lakes have been equipped with such GLOF preventing or mitigating measures (Emmer et al. 2018).

Figure 11 Examples of structural and non-structural GLOF measures. (top left) A failed moraine dam equipped with an open cut; (top right) an outlet of a drainage tunnel; (bottom left) a retention basin; and (bottom right) a transmission tower of an early warning system. Source: Emmer et al. (2018) except for the retention basin which is a photo by the author.

Figure 12 Artificial dam at Palcacocha lake, Cordillera Blanca (Peru). (left) View towards the glacial lake and the glaciated mountains; (right) view towards the valley. Source: photos by the author.

3.2.6 Water resources in high mountains

Naturally changing water resources are intertwined with social, economic, cultural, legal and political factors. On the one hand, climatic changes determine the supply of water and on the other hand, human components influence access, allocation and demand of water. As a result, the actual availability of water for people is a combination of both factors.

Water supply

Water resources in high mountains are governed by water surface stores like glaciers and wetlands. Additionally, precipitation contributes to the total runoff depending on the season. The storage capacity of these surface stores is small and they are dominated by seasonal precipitation and melting patterns (Buytaert and de Bievre 2012). Recent studies have revealed that the role of groundwater stores is significant during the dry season (Baraer et al. 2015; Glas et al. 2018). Changes in precipitation and decline in glacierised areas alter hydrological systems in high mountains and consequently affect water resources for downstream populations and ecosystems in terms of quantity and quality (IPCC 2014a). The loss of glacier volume implies changes in the water storage capacity of high mountains. Consequently, the seasonality of melt water runoff starts to shift and affects mountain settlements, the lower valley and surrounding lowlands to the Pacific coast (Seibert et al. 2014). Over 80% of the freshwater resources available for downstream populations and ecosystems in the semi-arid lowlands originate in mountains (Messerli 2001). Therefore, changes in water supplies in the tropical Peruvian Andes strongly impact entire Peru.

The changes of water resources are reflected in the increasing annual variability and an eventual decrease in volume of runoff (Mark et al. 2015; Vuille et al. 2018). The transition from a glaciated to a deglaciated catchment includes an initial increase in glacier melt water runoff due to enhanced glacier melt. After a maximum is reached (so called ‘peak water’), runoff starts to decrease. During the dry season, glacier melt water represents a buffer for lacking precipitation. The decreasing glacier melt runoff results in a reduced buffering capacity which leads to the increasing annual variability in runoff. In the Cordillera Blanca, peak water is shown to have already passed meaning that water resources are yet diminishing (Baraer et al. 2012; Bury et al. 2013). This situation is particularly problematic during the dry season when precipitation is missing and a large part of the discharge is glacier melt water. In the Santa river, the melt water contribution during the wet season is 30% on average whereas from May to September, the melt water constitutes up to 67% of the total runoff (Condom et al. 2012). With ongoing glacier recession, the water resources management in the region will increasingly become challenging, especially during the dry season when people rely on glacier melt water.

Water quality

Vanishing glaciers also affect water resources in terms of quality (Fortner et al. 2011; Mark et al. 2015). Water quality is degrading due to increasing amounts of sediment loads in streams and mining (Guittard et al. 2017). Melt water dissolves metals of newly exposed rock surfaces. The highly acidic and metal-containing water flows through small streams and accumulates in the Santa river. It poses a threat to human, animal and agricultural use. Moreover, water quality is affected by anthropogenic contamination. Mining activities in the Callejón de Huaylas and the absence of proper sewage treatment systems additionally pollute water (Mark et al. 2017).

Water demand

Population growth, economic growth, increasing water-related energy demand, agricultural expansion, political constellations and water rights shape water a changing demand (Vuille et al. 2018). Demographic changes in Peru trigger a growing urban and domestic water use. The Peruvian population is currently growing by 1.1% per year (INEI 2014). Migration from rural to urban areas additionally increases water use since in cities, water is easier accessible. Many households, especially in rural areas, do not have access to permanent water supply and the needed infrastructure is projected to further increase water use (Drenkhan et al. 2015). The growth of water-intensive industries such as mining leads to an additional rise of water use. Both, the growing population, and the growing industry and economy increase the demand for electricity from hydropower plants. In agriculture, the expansion in area and the shift towards export-orientated crops further enhance the water demand. Export orientated crops such as avocado and asparagus require higher amounts of water than native alfalfa or potatoes. The increase in cultivated area occurs predominantly in agricultural projects of the coastal desert of Peru which require intense irrigation (e.g. CHAVIMOCHIC and CHINECAS) (Bury et al. 2013). For CHAVIMOCHIC, the largest agricultural project of Peru, irrigation water is extracted from the Santa river that drains the Cordillera Blanca into the Pacific ocean next to the project area. But even in rural mountainous areas, the water demand is predicted to grow since rising temperatures extend cultivated land uphill (Hole et al. 2011). Furthermore, rights to water allocation and access in mountainous regions are distributed based on historical practices and cultural values. At the same time, political power relations play an influential role (Drenkhan et al. 2015). All depicted processes are predicted to continue or even intensify in the future and therefore the increase in water demand will continue.

Water availability

Predictions show that in the future, water demand will likely outpace water supply. Buytaert and de Bievre (2012) analysed the supply and demand of water for larges cities in the Andes that are primarily supplied with glacier melt water. They argue that regardless of the future development of climate induced changes in water supply, the increasing demand of water by population growth will be the decisive factor for water availability. Further authors state that the water demand influenced by allocation practices and power relations is likely to outweigh climate change driven water supply (Carey et al. 2017; Drenkhan et al. 2015; Jurt et al. 2015; Mark et al. 2017; Vuille et al. 2018). The combination of reducing supply and increasing demand results in serious water shortages i.e. water scarcity. Especially in the dry season when rain is missing, people increasingly suffer from shortages in drinking and irrigation water (Carey et al. 2017; Drenkhan et al. 2015).

3.2.7 Water scarcity

Water scarcity is the combination of naturally determined water supply and human induced water demand in the situation when water demand exceeds water availability (EU 2007). UN-WATER (2006) and FAO (2007) define water scarcity as "the point at which the aggregated impact of all users impinges on the supply or quality of water under prevailing institutional arrangements to the extent that the demand by all sectors, including the environment, cannot be satisfied fully" (Van Loon and Van Lanen 2013, p. 1484). This definition emphasises water scarcity as being a result of the interaction of all different kind of water users including the environment. As it depends not only on the supply but also on the demand of water, it has a strong social component inherent. In contrast, droughts, which are often connoted with water scarcity, are a natural hazard. According to Tallaksen and Van Lanen (2004), drought is defined as "a sustained and spatially extensive period of below-average natural water availability" (in Van Loon and Van Lanen 2013, p. 1484) and following EU (2007), droughts are considered natural phenomena. So, even without an environmental drought, water scarcity can occur when demand exceeds supply (Van Loon and Van Lanen 2013). In the Cordillera Blanca, water scarcity occurs during the dry season, aggravating towards the end from July to September. A delayed onset of the rainy season and dry spells during the early phase of the rainy season, when farmers rely on rain water for sowing, also lead to water scarcity (Gurgiser et al. 2016).

In this work, *water scarcity* and *drought* are not distinguished because the interviewees used the terms interchangeably. For both phenomena, the term *water scarcity* is used. However, in quotations, both words might appear since interviewees used them both.

Consequences

Water scarcity entails several consequences on society such as water conflicts (Drenkhan et al. 2015). The conflicts are shown to be primarily social rather than about the available quantity of water. The conflicts often concern unequal allocation of water, power relations and rising demands of water (Carey, French, et al. 2012). In the Cordillera Blanca, these issues are manifested in the conflicts about glacial lakes that are seen as an important water resource by different stakeholders. Local residents fight against hydropower companies that aim at controlling the lake for increasing their energy production. If the companies manage to control the discharge volume, they benefit from a more favourable energy production. At the same time, the local residents discern spiritual value in these lakes, which they want to preserve. For this and because they distrust the companies' and institutions' risk management performed at the lakes, hey want to maintain control over the lakes. Moreover, conflicts arise or aggravate due to institutional weakness and inability to allocate water among stakeholders such as the local residents and the hydropower companies (Carey, French, et al. 2012; Drenkhan et al. 2015; French et al. 2015). The role of water governance is crucial within this issue and is particularly promising when as many water users as possible are included into the process of decision-making (Condom et al. 2012). In 2009, Peru has issued a new water law that recognises the rights of native and peasant communities for traditional and customary water use. For the first time, the law mentions environmental and ecological flow. However, explicit and long-term management strategies are missing.

3.2.8 Low and high flow water risks

The risks mentioned in the sections above can be divided into two categories: low and high flow water risks. Low flow water risks consider risks where the water amount is insufficient like aridity and water scarcity. High flow water risks refer to risks where the amount of water is more than sufficient such as rain storms, debris flows and GLOFs (Van Loon and Van Lanen 2013). In this study, water scarcity and GLOFs are sometimes used as examples referring to the entirety of low and high flow water risks, respectively.

Complementary, risks can also be divided into sudden and slow onset risks. Sudden onset risks describe risks where the onset is sudden, as the name implies (e.g. flash floods and rock falls). On the other hand, slow onset risks emerge slowly (e.g. water contamination and city smog) (Wang and Liu 2018).

4 Risk perception

This chapter introduces risk perception theories and illustrates conducted research on the topic.

4.1 Different perspectives on risk perception

In the following chapter, different steps in the evolution of risk perception theories are presented. Risk perception research has its origin in psychology. Other important contributions come from geography, sociology, political science and anthropology. In the initial phase of risk perception research, risks were analysed as independent phenomena (Jurt 2009).

4.1.1 Technical-scientific approach

The research has started to change with the psychometric paradigm (Slovic 1987). The psychometric paradigm originates from psychology and represents the technical-scientific perspective on risk perception. This perspective implies a realistic position which views risks as taken-for-granted phenomena that are scientifically measurable (Lupton 1999). In the psychometric paradigm, risk perception is dependent on knowledge, experience and values of an individual (Jungermann and Slovic 1993). Therefore, risk perception is 'inherently subjective' (Gebrehiwot and van der Veen 2014). Individuals' understandings and evaluations of risks lead to a subjective assessment of the risk probability and its possible consequences. The probabilities and consequences are individually evaluated in a quantitative way that is based on the characteristics of the risk itself. Further, the individual risk perception shapes the attitudes towards risk management strategies (Slovic 1987). Within this approach, a layperson's perception differs significantly from an expert's perception (Fischhoff et al. 1978).

The technical-scientific approach has been criticised by social scientists. They comment on the neglect of the social and cultural contexts in which risks are perceived. The constructivist and cultural theory approach are two responses to that.

4.1.2 Constructivist approach

Another important approach in risk perception research is the constructivist approach. Opposed to the technical-scientific approach, which emphasises the role of the individual, the constructivist approach includes the social and cultural context in which risks are perceived. This approach implies a constructivist position that takes risks as socially constructed. On the background of a series of catastrophes in the 1970s and 1980s (e.g. Chernobyl in 1986), Beck (1986) describes the transition from an industrial society into a risk society. In a risk society, the production of wealth entails the production of human made risks such as environmental pollution.

4.1.3 Cultural theory approach

A further relevant approach is the cultural theory approach. Douglas and Wildavsky (1982) emphasise among other aspects the embeddedness of risks in the cultural and social context. For them, risk does not represent a probability calculation but a strategy for dealing with dangers and otherness. Cultural theory suggests that risk perceptions are determined by the social affiliation to the individual's group or organisation. By this, a notion of collectiveness of risk perceptions is stated (Douglas and Wildavsky 1982).

4.1.4 Vulnerabilities

Vulnerability directly influences the perception of risk. Authors describe different crucial factors for a person's vulnerability. Hewitt (1983) describes how asymmetrical power relations can determine the vulnerability more than the geophysical features of a place. Blaikie et al. (1994) emphasise socio-economic constraints as determining vulnerability. According to them, living in an area at risk does not happen because inhabitants lack knowledge but rather due to economic constraints. They mention further aspects influencing vulnerability such as gender, age, class, ethnicity, and caste. Further, Altieri and Nicholls (2013) suggests vulnerability as the capacity to adapt.

4.1.5 Knowledge

In the debate about different knowledge of natural hazards and risks, the dichotomy between laypersons' versus experts' knowledge is most prominent. The laypersons' knowledge is often described as traditional, indigenous and 'other' to the modern, Western expert knowledge. McCarthy et al. (2007) show that quantitative as well as qualitative approaches have used to compare these two categories. In doing so, they often assessed the experts' knowledge as 'right' and the laypersons' knowledge as 'erroneous' or deficient. The two types of knowledge are represented as being opposed and the categorisation has been taken for granted. Authors like Agrawal (1995), Barth (2002), and Cruikshank (2005) have called to overcome this dichotomy. Further, the overemphasising of expert knowledge is criticised (Dessai et al. 2004; Slovic 2000).

4.1.6 Risk networks

Jurt (2009) calls upon a more encompassing risk perception. The risk perception should go beyond the mere consideration of the natural hazard and include social, cultural, economic, and political risks. The context of the risk perception is crucial. In the process, the focus lies on the interconnection of these risks, i.e. the risk networks. Thus, not only the causes and consequences of a natural hazard should be considered but its embeddedness in further risks too. Since the risks are interconnected, they influence each other and an enhancement or a diminishment of one risk has an impact on the perception of the other risks. The initial risk can either be the natural hazard or another kind of risk. Jurt (2009, p. 105) illustrates the risk networks with the following example of her research. The network consist of the risks of avalanches, decline of tourism and migration:

> "Bernadette, the owner of a small guest house, is worried about the avalanches that threaten the access roads to Sulden [Jurt's study site]. She considers the avalanches to be a very high risk, not only for Sulden but also for the municipality as a whole, for whenever something happens, tourists may be afraid to come to Sulden in the future and tourism could experience a considerable forfeit. In a municipality like Sulden, which according to Bernadette survives only because of tourism, this could have severe consequences, such as among others less tax income for the municipality, fewer jobs, and thus more factors to enhance one of the crucial risks for the survival of the municipality: migration."

This example shows that the enhancement or diminishment of one risk, in this case the natural hazard of avalanche, can affect the perception of further risks, here economic, social and cultural risks. It is important to consider that the risk networks are ideal types of risk constellations that do not necessarily represent a specific person's perception.

The call for a more encompassing risk perception derives from her insights into risk perceptions. These reveal that on a scale of countries, small regions and even villages, people face similar patterns of natural hazards but do not necessarily perceive them similarly. For this reason, natural hazards should not just be seen as a product of natural processes but embedded in natural and social systems.

4.2 Perception of low and high flow water risks

Research about risk perception has primarily focused on the following topics illustrated by Dahal and Hagelman (2011, p. 154): "Diseases such as cancer (e.g. Katapodi et al. 2005; Peters et al. 2006), technological hazards such as water pollution (e.g. Langford et al. 2000) and gene technology (e.g. Siegrist 1999), and natural hazards such as earthquakes (e.g. Lindell and Prater 2002), floods (e.g. Wong and Zhao 2001), hurricanes (e.g. Peacock et al. 2005), snow (e.g. Earney and Knowles 1974), wildfires (e.g. Zakaria 2001) and flash-floods (e.g. Wagner 2007)." Yet, research on the risk perception of low and high flow water hazards such as water scarcity and GLOFs remains scarce. Few studies are dedicated to the perception of these hazards only (e.g. Dahal and Hagelman 2011; Murtinho et al. 2013). They partly appear in other studies, for example about the perception of climate change impacts (e.g. Byg and Salick 2009; Kaul and Thornton 2014; Shijin and Dahe 2015;

Mark et al. 2017), the perception of natural hazards in general (e.g. Jurt 2009) or analyses about water resource use (e.g. Walker-Crawford et al. 2018).

4.2.1 Perception of water scarcity and GLOFs

Murtinho et al. (2013) showed that water scarcity is perceived to a greater extent in regions with seasonally more variable precipitation patterns than in regions with less annual precipitation. Mark et al. (2010, 2017) identified a perception of overall declining water resources. The residents of the Santa catchment state scarcity in drinking and mainly irrigation water. Also industrial water users mention an overall decrease in water availability as well as an increasing inter-annual discharge variability. Heikkinen (2017) reported the perception of a decrease of river discharge connected to shortages in drinking and irrigation water of a tributary of the Santa catchment. Surveyed people explain changing water resources by deforestation and changing precipitation patterns (Murtinho et al. 2013), a shortening of the rainy season (Heikkinen 2017) and the melting of the glaciers (Heikkinen 2017; Jurt and Buchecker 2005).

Dahal and Hagelman (2011) found that despite the probability of a GLOF, the risk perception of people living beneath the endangered glacial lake is low. People of Nepal’s high mountains are aware of the hazard, but only few are worried about the risk. This suggests that they underestimate the risk. The repeated inaccurate predictions and subsequent warnings of an outburst are stated as the main reason for the low risk perception. Additionally, a mitigation project at the lake lets people assume that they are protected. Furthermore, some people prefer to leave the control over the GLOF risk to a higher religious power.

Findings of Walker-Crawford et al. (2018) support the perception of a low GLOF risk. Their study in the Cojup and Quillcayhuanca microcatchments, Cordillera Blanca (Peru) demonstrated that water scarcity is by far the most important risk to the local residents, both in terms of perceptibility and the consequences they face through it. In comparison, the risk of GLOFs is perceived differently. For some it is similarly worrying as water scarcity, but for others the probability of occurrence and the consequences are less severe. In some cases, GLOF risk is even reported as almost non-existent. Many local residents do not mention GLOFs spontaneously, which supports these findings.

4.2.2 Perception of climate change impacts

The emergence of low and high flow water hazards is influenced by different components of changing climate such as glacier retreat and changing precipitation patterns. People’s perceptions of those help to better understand the perception of low and high flow water risks which is why some findings are briefly presented.

Shijin and Dahe (2015) report that a great majority perceives that temperature tended to increase. Studies reveal that the vanishing glaciers are perceived as the most striking climate change impact (Heikkinen 2017; Jurt 2009; Mark et al. 2017; Shijin and Dahe 2015). Jurt (2009) reports that glacier retreat is perceived as enhancing other natural hazards like inundations, mudflows, and landslides. People are concerned about the disappearing glaciers because they are of cultural and spiritual value to them. Thus, their disappearing affects their way of life (Heikkinen 2017; Jurt 2009; Shijin and Dahe 2015). Declining precipitation is the second most perceived climate change impact (Heikkinen 2017; Murtinho et al. 2013; Shijin and Dahe 2015). In addition, an increase in heavy rain events was perceived (Gurgiser et al. 2016; Heikkinen 2017; Jurt 2009). Further, a shortening (Heikkinen 2017) or delaying (Shijin and Dahe 2015) of the rainy season was also stated. Moreover, people perceived that the weather has become more extreme whereby heat, cold and heavy precipitation are provoking more natural hazards (Jurt 2009). The perception of a decreasing river discharge could also be found (Carey et al. 2017; Heikkinen 2017; Shijin and Dahe 2015). Mark et al. (2017) also reported on perceptions of declining or disappearing springs. Most perceptions vary on a very local scale and are considerably related to the village people live in (Byg and Salick 2009; Jurt 2009).

Overall, the local perceptions are consistent with measured data except for declining precipitation. In all studies, data show no significant decrease in precipitation (Heikkinen 2017; Murtinho et al. 2013; Shijin and Dahe 2015). Shijin and Dahe (2015) explain that the reason for this circumstance might be that the persistent drought conditions of recent years in the study region influenced residents' perceptions of precipitation.

4.3 Importance of risk perception

Perceptions of risks are important for the adaptation to climate change since they influence the way people respond to it. Therefore, people's risk perceptions should be better understood because they can enhance the effectiveness of risk management by improving adaptation strategies (e.g. Dahal and Hagelman 2011; Huggel et al. 2008; Murtinho et al. 2013; Negi et al. 2016; Siegrist and Cvetkovich 2000; Treby et al. 2006). In this process, diverse interests, circumstances and socio-cultural contexts should be recognised as well as indigenous, local, and traditional knowledge should be included (IPCC 2014a). Risk perceptions also matter because local responses to the respective risk depend on them. For these reasons, risk management strategies which do not consider local risk perceptions are prone to fail (Huggel et al. 2008). Regardless of the theoretical approach, Renn (1998) and Renn et al. (2011) suggest to apply multidisciplinary and participatory approaches in risk management which should involve all stakeholders. To develop adequate adaptation strategies, Dessai et al. (2004) advise to consider both scientific expert assessments as well as social or individual perceptions. Additionally, a variety of social and individual perceptions should be included since Jurt el al. (2015) found that perceptions of local populations are as heterogeneous as the local populations themselves.

4.4 Risk perception: meeting point between physical and social science

Risk and risk perception research is a field where social and physical science meet. In fact, this situation could be an opportunity to approach each other but instead, it is rather characterised by controversy (Renn 1998). As a result, social and physical scientists adopt different approaches. Both parties have their own approaches to the topic and focus on different components. As mentioned above, social scientists criticise the technical-scientific approach which is based on probabilities and assesses risks as taken-for-granted phenomena that are scientifically measurable (e.g. Lupton 1999). They state that it neglects that risk perception is socially constructed. On the other hand, technical experts argue that risk management should not be determined by the possible misperception or ignorance of the public (Sapolsky 1990). However, in the last decade new approaches towards a more integrative risk management were presented. They call upon the inclusion of different disciplines including their tools as well as local knowledge and perceptions (Bury et al. 2011; Carey et al. 2017; Carey, Huggel, et al. 2012; Castree et al. 2014; Drenkhan et al. 2015; Polk et al. 2017).

5 Methodology

This study pursues a qualitative research approach. A qualitative approach is suitable for addressing research questions which aim to investigate imaginings, experiences and perceptions (Cohen and Crabtree 2006). Understanding is the epistemological principle of qualitative research (Flick 2000). It focuses on the understanding of a subject's view, and thus helps to describe how a subject perceives the world or an aspect of it (Flick et al. 2007). The openness of a qualitative approach allows it to be adapted to changing situations and to be fully responsive to the research object, in this case interviewees.

The approach includes the following methods: Snowball sampling (Patton 1990) was applied to get access to interviewees. Episodic interviews (Flick 2000) and expert interviews (Bogner et al. 2002, 2009) were conducted for data acquisition. Content analysis (Mayring 2014) was applied to analyse the data.

5.1 Sampling

To compile the study's sample, snowball sampling (Patton 1990) was applied. Snowball sampling is a sampling in which the sample is chosen with regard to the purposes of the study. It facilitates in-depth during the research because it helps locate "information-rich key informants or critical cases" (Patton 1990, p. 176). Initially, individuals familiar with the topic were asked with whom it would be useful to talk. Then, these individuals recommended further interesting interviewees for the sample. Following this scheme, the 'snowball' got bigger and bigger. In a first step, still in Switzerland, the supervisor Christian Huggel, who knows the study area quite well due to his own long-standing research in the area, was asked for contacts. Those people were then contacted in Huaraz and asked for further contacts, and so on. To compile a heterogeneous sample, or in other words not to enlarge the 'snowball' with just one specific group of interviewees, it was important to start the snowball sampling with at least two interviewees who were as different as possible. This process step is important if a spectrum of opinions is targeted, because diverse views on the topic are desired. Besides that, new topics arose during the interviews which seemed important to address. Therefore, further interviewees were identified according to newly raised topics. To ensure a heterogeneous sample and by this a differentiated perspective on the subject, two different groups of interviewees were identified in the first place: *experts* and *local residents*. In a second step, the sample was refined within the groups by considering the type of work in the case of the experts and the place of residence for the local residents. However, the possible selections were restricted due to the recommendation-based process.

Both groups of the study's sample live in an environment influenced by water related risks. The experts even deal with those risks in their occupational activity. The local residents were chosen from four different villages and there experts from twelve institutions or organisations. Five sixths of the interviewees were male. The age of the interviewees ranged from 30 up to 85 years. Some of the local residents and the experts had experienced the earthquake in 1970, none of them had experienced the GLOF in 1941. Table 2 and Table 3 give an overview of the interviewees.

5.1.1 Local Residents

In this work, the term *local residents* stands for people from the rural area of Huaraz, who do not live in the city but in the neighbouring settlements and villages at higher elevations. In the text, the local residents are designated with the term 'informant'. They were chosen according to their place of residence. Initially, the subsistence activity of the local residents had secondary importance. The place of residence was decisive for the selection of the local residents because depending on the position of their village or their house, they are exposed to GLOF risk to a greater or lesser extent. Table 2 gives an overview of the interviewed local residents. They are sorted in descending order according to the distance of their place of residence to Huaraz.

Place of Residence	**Designation in Text**
Yarush	Informant 1
	Informant 2
Coyllur	Informant 3
	Informant 4
	Informant 5
Llupa	Informant 6
	Informant 7
	Informant 8
	Informant 9
Nueva Florida	Informant 10
	Informant 11

Table 2 List of interviewed local residents.

Within the Quillcay subcatchment, the interviewees were chosen from the Cojup and the Quillcayhuanca microcatchment. They come from Yarush, Coyllur, Llupa and Nueva Florida. Yarush is furthest away upstream the Paria river in the Cojup catchment. Llupa is closer to Huaraz, located in the same catchment, while Nueva Florida is a settlement connected to the municipality of Huaraz. Coyllur is situated at a similar distance from Huaraz as Llupa but in the Quillcayhuanca catchment by the Auqui river. Yarush, Coyllur and Llupa are constructed above the river gorge. They are thus mostly protected from an impact of a glacial outburst flood since the flow path is below in the gorge. On the contrary, Nueva Florida is built around the confluence of the two rivers Paria and Auqui in the midst of a potential GLOF flow path. All local residents are small-scale farmers except for informant 3 (Coyllur) who works in the NGO Care in Huaraz together with expert 17. Informant 3 occupies a double role as he lives in a village but works in a NGO. In this study, his perception as a local resident was addressed. Some local residents also pursue additional part-time occupations (e.g. carpenters, construction workers, who assist construction sites in the villages and in Huaraz, mountain guides and other staff accompanying mountain tours). One informant is also mayor. Informant 6 (Llupa) is the only female local resident interviewed.

5.1.2 Experts

In this study, the term *experts* stands for representatives of institutions with one exception of an independent expert who is not affiliated to any institution (expert 16). The experts are designated as 'experts' in the text. As the study aimed at investigating the perception of water related risks, experts were interviewed who work in this field. This includes water and risk management, and project or other experience in this topic. They come from different backgrounds including technical, social, mixed technical and social as well as administrative. They experts were chosen from different governmental and non-governmental institutions as well as from independent and scientific backgrounds. The organisational level of the institutions varies from local over regional to national and international. Locally and regionally operating institutions are located in Huaraz, the national and international ones in Lima. The focus lies on experts from Huaraz and their knowledge of the local context while experts from other places might amplify the perspective and add additional aspects. Therefore, most experts are from Huaraz and were interviewed in Huaraz. Only the representatives of COSUDE, MINAM, CENEPRED, PUCP and one representative of INDECI were met in Lima. The representative of Predes was met and interviewed in Cusco. Table 3 provides an overview of the interviewed experts and Figure 13 illustrates the relationship of the governmental institutions.

Level of Organisation	Field of Activity	Insititution	Designation in Text
International	Administrative	COSUDE	Expert 1
			Expert 2
National		MINAM	Expert 3
	Technical	CENEPRED	Expert 4
			Expert 5
		INDECI	Expert 6
			Expert 7
			Expert 8
			Expert 9
Local		ALA Huaraz	Expert 10
			Expert 11
Regional		UGRH	Expert 12
	Technical & Social	INAIGEM	Expert 13
			Expert 14
		PNH	Expert 15
None		None	Expert 16
National	Social	CARE	Expert 17
Local		Wayintsik	Expert 18
National		Predes	Expert 19
		PUCP	Expert 20

Table 3 List of interviewed experts.

5.1.2.1 Governmental institutions

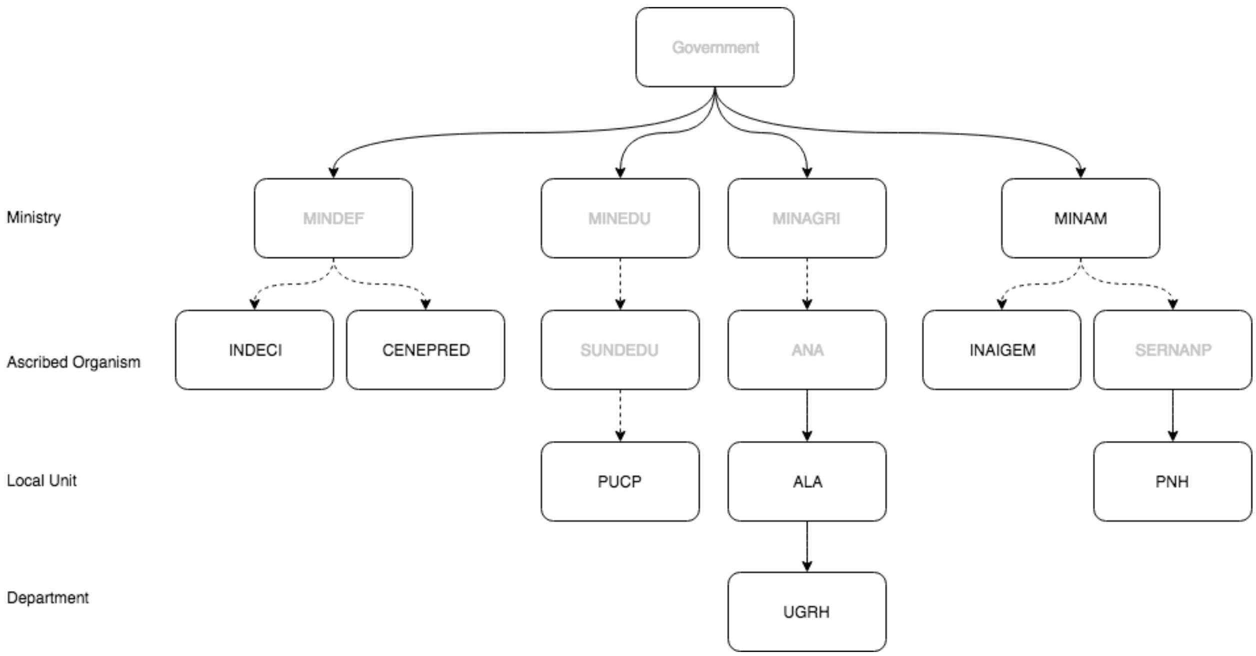

Figure 13 Governmental institutions. Institutions in black font were interviewed. Institutions in grey font are displayed to show the organisation and hierarchy of the governmental institutions. Solid lines signify direct influence and dashed lines represent indirect influence. 'Ascribed organisms' belong to a ministry but are mostly independent, e.g. they take their own decisions and make their own budgeting. Local units and their departments directly depend on the hierarchically superior institution except for the PUCP.

MINAM

Ministerio del Ambiente del Perú (Ministry of the Environment of Peru)

The ministry of the environment compiles the rules and guidelines for executive institutions in the area of environmental issues like INAIGEM. It is therefore mainly busy compiling normative documents.

CENEPRED

Centro Nacional de Estimación, Prevención y Reducción del Riesgo de Desastres (National Centre for Disaster Risk Estimation, Prevention and Reduction)

CENEPRED is an 'ascribed organism' of the Ministry of Defence (MINDEF). It works on a national level to advise national, regional and local governments in the incorporation of disaster risk management into development planning. Within disaster risk management, CENEPRED focuses on the processes of estimation, prevention and risk reduction, and reconstruction (see

Figure 14). For example, it compiles the manual for the evaluation of risks originated by natural phenomena, which is valid throughout Peru for the assessment of natural disaster risks such as floods or droughts. The inclusion of preventive processes in the Peruvian governmental disaster risk management has a relatively young history as CENEPRED was only founded in 2011. For this reason, the preventive management might be not very decentralised yet and consequently preventive measures are still lacking on a regional and local level.

INDECI

Instituto Nacional de Defensa Civil del Perú (National Institute of Civil Defence of Peru)

INDECI also belongs to the MINDEF as an 'ascribed organism'. It is in charge of the reactive disaster risk management on a national level (see Figure 14). It advises national, regional and local governments in preparedness, response and rehabilitation of disaster risks. Its aim is to protect the life and heritage of individuals and the State. For instance, INDECI organises the earthquake and tsunami drills. Since it exists longer than CENEPRED, INDECI is more represented in the country down to a local level and also better known throughout the population.

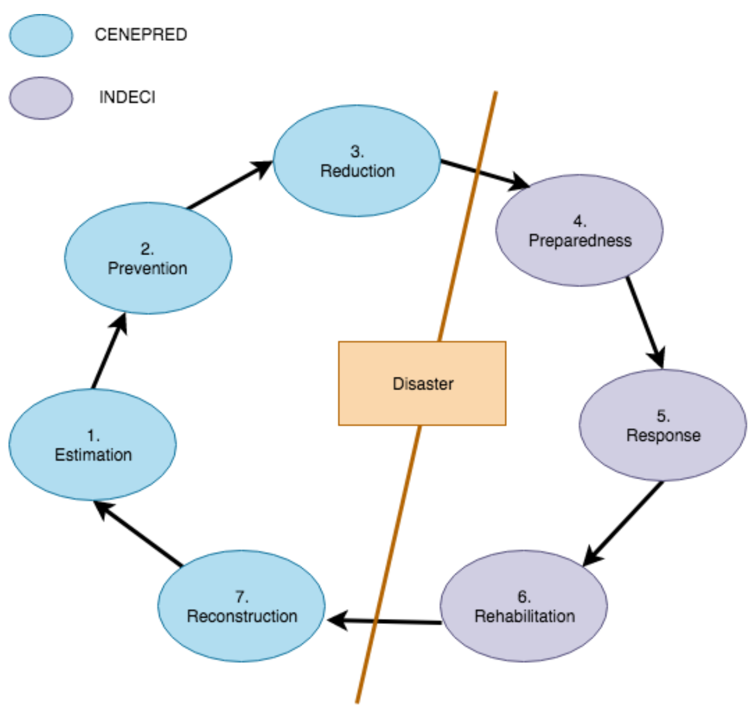

Figure 14 Disaster risk management process. Different steps of the disaster risk management process are shared by CENEPRED and INDECI. CENEPRED focuses on the prevention of disaster risks and INDECI on the response to disaster risks. (Figure adapted from CENEPRED (2016)).

ALA Huaraz

Autoridad Local del Agua (Local Water Authority)

ALA Huaraz is the local unit of the National Water Authority (ANA - Autoridad Nacional del Agua) which are both part of the Ministry of Agriculture and Irrigation (MINAGRI). ALA's field of responsibility is the management, conservation and protection of water resources in the different catchments around Huaraz. Within water resources management, it aims at sustainable development with a shared responsibility between government and society. Moreover, it promotes the national programme of ANA *culture of water*, which should encourage a more sustainable use of water resources on a level of households by recognising the economic, social and environmental value of water. For example, ALA is responsible for the granting of water use rights.

UGRH

Unidad de Glaciología y Recursos Hídricos (Glaciology and Water Resources Unit)

UGRH is a department of ALA Huaraz and thus also belongs to the MINAGRI. It is specialised in glaciology and water resources and focuses on glaciers and glacial lakes. It is responsible for the assessment of the availability of water resources in the glaciers and lagoons. URGH is based in Huaraz but is responsible for the entire Peruvian Andes. For example, it issues the inventory of all Peruvian glaciers and glacial lakes.

INAIGEM

Instituto Nacional de Investigación en Glaciares y Ecosistemas de Montaña (National Institute for Glacier and Mountain Ecosystem Research)

INAIGEM is an 'ascribed organism' of the MINAM. As the name implies, INAIGEM's area of activity is glacier and mountain ecosystem research. It was founded in 2014 and is headquartered in Huaraz with a second base in Cusco. As an example, it conducts the monitoring of the Palcacocha glacial lake.

PNH

Parque Nacional Huascarán (Huascarán National Park)

Huascarán National Park is a natural protected area in the Cordillera Blanca, which is administered by the National Service of Natural Areas Protected by the State (SERNANP). PNH is the local office of SERNANP that manages the national park. It belongs to the MINAM and is based in Huaraz. It was founded in 1975 and recognised in 1985 as a UNESCO World Heritage Site and Biosphere Reserve.

PUCP

Pontificia Universidad Católica del Perú (Pontifical Catholic University of Peru)

PUCP is a private university in Lima. It is privately funded with support of the Catholic church. It depends on National Superintendence of Higher University Education (SUNDEDU - Superintendencia Nacional de Educación Superior Universitaria) in terms of quality supervision and the awarding of certificates.

5.1.2.2 Non-governmental organisations and other institutions

CARE Perú

CARE is an international non-governmental organisation that is represented with CARE Perú in Peru. The interview was made with one representative of the office of CARE in Huaraz, which has been set up due to the collaboration with the project *Proyecto Glaciares+*. *Proyecto Glaciares+* is a joint project of CARE, University of Zurich and COSUDE, the Swiss Development Cooperation. Therefore, CARE in Huaraz focuses on management of glacier originated risks such as the GLOF from Palcacocha. But CARE Perú has a broader background of activities.

Wayintsik

Wayintsik is a local non-governmental organisation from Huaraz. Its mission is to strengthen the capacities of high mountain rural communities by innovating methods and empowering their resources. The members of Wayintsik seek to educate high mountain rural communities to be self-sustainable and make sustainable use of their natural resources. For instance, they conduct projects in the improvement of guinea pig keeping which is a locally traditional food and income source for rural communities.

Predes

Centro de Estudios y Prevención de Desastres (Centre for Disaster Studies and Prevention)

Predes is a national non-governmental organisation that focuses on the study and the prevention of natural disasters. It promotes the incorporation of prevention into development seeking to transform development in a more sustainable process. They aim at reducing people’s vulnerability to natural hazards. Predes has a history of 35 years in disaster prevention and is therefore a pioneer in this area, only to be followed by CENEPRED later.

COSUDE

Cooperación Suiza de Desarrollo (Swiss Development Cooperation)

COSUDE depends on and is financed by the Swiss Agency for Development and Cooperation (DEZA - Direktion für Entwicklung und Zusammenarbeit). It conducts projects in Peru in cooperation with Peruvian non-governmental organisations. In case of the *Proyecto Glaciares+*, COSUDE works together with CARE Perú.

5.1.3 Anonymity

Scientists recommend to anonymise interviewees because qualitative data usually contains very sensitive information (Kuckartz 2016). In addition to this, Backhaus and Tuor (2008) mention that anonymisation depends on the research topic. In this study, institutions' names are declared. But the experts themselves are anonymised. For the sake of the topic, it is important to know the institutions names since the study's aim is to clarify the circumstances of different institutions' perspectives of low and high flow water risks. The local residents are anonymised but the village in which they live is declared. The place of residence is important to better understand their risk perceptions since the perception may vary on a local scale, even from village to village (Jurt et al. 2015).

5.2 Data Acquisition

To acquire the data, episodic interviews (Flick 2000) were conducted with the local residents and expert interviews (Bogner et al. 2002, 2009) with the experts. The aim of the interviews was to represent the whole spectrum of opinions and perceptions on the research topic. The focus of the research lies on the expert interviews while the episodic interviews allow to complement and contrast the data from the expert interviews. This procedure enabled methodological triangulation, a combination of different methods. It aims at enhancing data quality by taking a different perspective on an issue (Flick 2004, 2009). Twenty seven interviews were conducted of which 23 were individual interviews and four were interviews with two interviewees. Three interviewees were met twice, for the actual interview and for further conversations on the topic. This resulted in a total number of interviewees of 31. The interviews lasted between 20 minutes up to three hours with an average time of 50 minutes. On average, the interviews with the experts lasted twice as long as the interviews with the local residents. All interviews were personal interviews with meeting places in offices, coffee places, private homes, on the street, and in the field. All interviews were hold in Spanish.

5.2.1 Episodic Interview

To assess the perception of hydrological risks of the local residents, episodic interviews after Flick (2000) were conducted. In this research, a mixture between episodic and focused interview was used. Focused interviews investigate subjective perspectives and views of a social group. Episodic interviews are suitable when the focus of the research lies on investigating subjective knowledge and experiences of a social group. They differentiate between semantic and episodic knowledge. Episodic knowledge is based on personal experiences of concrete situations whereas semantic knowledge bases on more abstract an generalised knowledge that emerges through these experiences (Flick 2000).

5.2.2 Expert Interview

Expert interviews after Bogner et al. (2002, 2009) were also conducted with the experts of the research topic. Expert interviews give insight into technical, process and interpretative knowledge of an expert. Technical knowledge refers to the knowledge typically known as expert knowledge. Process knowledge is based on practice and experience of processes and interactions. Interpretative knowledge represents the subjective interpretation of relevancies, rules and point of views (Bogner and Menz 2009). For this study, all types of expert knowledge are relevant. Concerning the interpretative knowledge, reflections of Bogner and Menz (2009) are important to consider. They emphasise the importance of expert knowledge. Expert knowledge has social relevance "because it affects practice to a significant degree" (Bogner and Menz 2009, p. 54). Experts have the possibility to enforce their interpretations in their field of action. Bogner and Menz (2009, p. 55) clarify this by stating:

> "An expert's knowledge, his or her action orientations and so on, also (and this is decisive) point to the fact that she or he may become hegemonic in terms of practice in his or her field of action (for example, in a certain organizational-functional context). In other words, the possibility exists that the expert may be able to get his or her orientations enforced (at least in part). As the expert's knowledge has an effect on practice, it structures the conditions of action of other actors in the expert's field in a relevant way."

These considerations are insofar important as expert's interpretative knowledge has significant influence on decisions. For example, the development of adaptation strategies in the area of water and risk management. Therefore, the focus lies on the interpretative knowledge in this study. Further, it is important to consider that the distinction of the interviewed expert between *expert* and *private person* is hard to achieve and methodologically not recommended (Bogner et al. 2002). In addition, attention has to be paid on the 'interaction effect' between interviewer and interviewee. The interviewee reacts on the interviewer and may respond according to his or her imaginations about what the interviewer might expect to hear (Bogner et al. 2002). Moreover, the expert might want to convey a specific strategic agenda (Meuser and Nagel 2009).

5.2.3 Interview Guideline

The tools for both interview types was a semi-structured interview guidelines that include stimuli. The guideline contained conversation topics and more concrete questions which are arranged in thematic blocks. The thematic blocks were:

(1) *Perception of water* which allowed a first approach to the topic by assessing the interviewees' general perception of the role of water.

(2) *Perception of water related risks* focused on the perception of risks related to water. In a first step, the aim was to identify all water related risks the respondents are aware of. In a second step, the most important risk was determined with the intention to ascertain whether water scarcity or GLOFs worry the participants more.

(3) *Adaptation strategies for water related risks* aimed at assessing the measures that the interviewees consider to encounter the risks.

(4) *Risk perception of others* tried to shed light on how the interviewees perceive other interviewees' risk perception.

Even though the terms *risk* and *hazard* were used interchangeably to adapt to interviewees' language, preferably *hazard* was used to avoid prejudicing the participants' responses as far as possible. For each sample group, an individual guideline was prepared. It included the same thematic blocks, but questions were prepared differently to adapt to the type of communication of the group. The guideline helped to keep track of discussed topics and provided stimuli when needed. The semi-structured form provided a flexibility that allowed to react on inputs from the interviewees. Furthermore, the open questions allowed the interviewees to go into depth where it mattered to them. Inputs from the interviews were taken to adjust and improve the guideline during the process of data acquisition. As an example: at the start of data acquisition, the terms high and low flow water risks were used in the second interview block, adopted from the research questions. But it turned out that both local residents and experts did not understand what was meant with these terms. So, the guideline had to be improved and the interviewees' intuitive classification of risks according to seasons was adopted. The interview guideline is attached in the appendix.

To answer the main research question, the emphasis was put on the first and the second topic during the interviews and the data analysis. This is why those topics are principally dealt with in the results section.

Transcription

To analyse the data later, most interviews were recorded and transcribed. There were circumstances under which recording was not appropriate. In this cases, notes were taken during and after the interview. The process of transcription is an indispensable step to analyse and interpret data (Flick 2006). Here, a smoothed, partially summarising version of transcription was chosen as it enhances comprehension of the data. Flick (2006) recommends only to transcribe as much and as precise as necessary. Too detailed transcription can result in illegibility (Kuckartz 2016). Most of the transcription was outsourced to research assistants in Peru due to the amount of data compared to the availability of time.

5.3 Data Analysis

For the analysis of the interview data, summarising content analysis after Mayring (2007) was adopted. The summarising content analysis aims at reducing the data material to obtain a manageable amount of data while preserving the essential contents. Therefore, this method is suitable for this study since a large amount of data has been gathered and a reduction of the material as well as a separation of essential information from unessential was required. To achieve this reduction, a category system was developed to categorise or 'code' the data material. The definition of these categories is the main characteristic of the reduction of the data material. To define the categories, an abductive approach was adopted. Abduction is "a creative inferential process aimed at producing new hypotheses and theories based on surprising research evidence" (Timmermans and Tavory 2012, p. 167). It relies on the social and intellectual position of the researcher and existing theoretical frames. In a first step, categories were deductively formed beforehand whereby the research questions, theoretical knowledge and further knowledge gained during data acquisition were leading the way. In a second step, during the process of coding, further categories were inductively formed directly out of the interviewees' statements in the data material. This process is also called *in-vivo-coding* (Kuckartz 2016). After a part of the data material was coded, the category system was reviewed whether it fit the research aim and was subsequently revised. The process of inductive coding and reviewing was iterative until the desired reduction was achieved. The data analysis focused on the main topics that had emerged during the interviews. After the coding, the main topics of the interviews represented in the most important codes were taken to construct the results. In this process, it was important to focus on the essential aspects while not omitting other aspects important for the entirety of the research topic (Mayring 2007). The software used to code was MAXQDA described by Kuckartz (2016).

6 Results

This chapter illustrates the interview results by following the thematic steps of the interview guideline. First, it presents the local residents' and the experts' perception of water in general, second and most important, it depicts their perception of water related risks and third, it shows the interviewees' definition of risk. The chapter is entirely based on statements of the interviewees. The results are presented according to the topics arisen during the interviews. To clarify, different or similar groups of perceptions are distinguished where they exist. The focus lies on the distinction between the local residents' and the experts' perceptions.

6.1 Role of water

Perceptions of the role of water are manifold. When being asked what comes to their mind when talking about water[1] (translated from Spanish, for original: see footnote), the interviewees spontaneously mention a range of different topics. The notions vary from water being beneficial for life to water being detrimental for life up to water being mortal. The associations include abstract ideas as well as everyday representations. In what follows, different voices on the role of water are illustrated.

Informant 7 (Llupa) emphasises the benefits of water by commenting on its use in agriculture, animal farming and household:

> "Water is used for watering, plants, potatoes. Well, water is good for everything. It serves to drink, cows drink, donkeys, sheep, pigs bath, when they feel hot from running they go and bath. That's what water is good for. Also from the tap, we drink, for shower, for that the tap serves."[2]

[1] "¿Si hablamos de agua, que es lo primero que le viene a la mente?"

[2] "Agua sirve para regar, plantas, papas. Agua sirve para todo pues. Sirve para tomar, toman vacas, burros, ovejas, chanchos se bañan, cuando tienen calor corriendo van y se bañan. Para eso vale el agua. El caño también igualito tomamos, para ducha, para eso mantiene el caño."

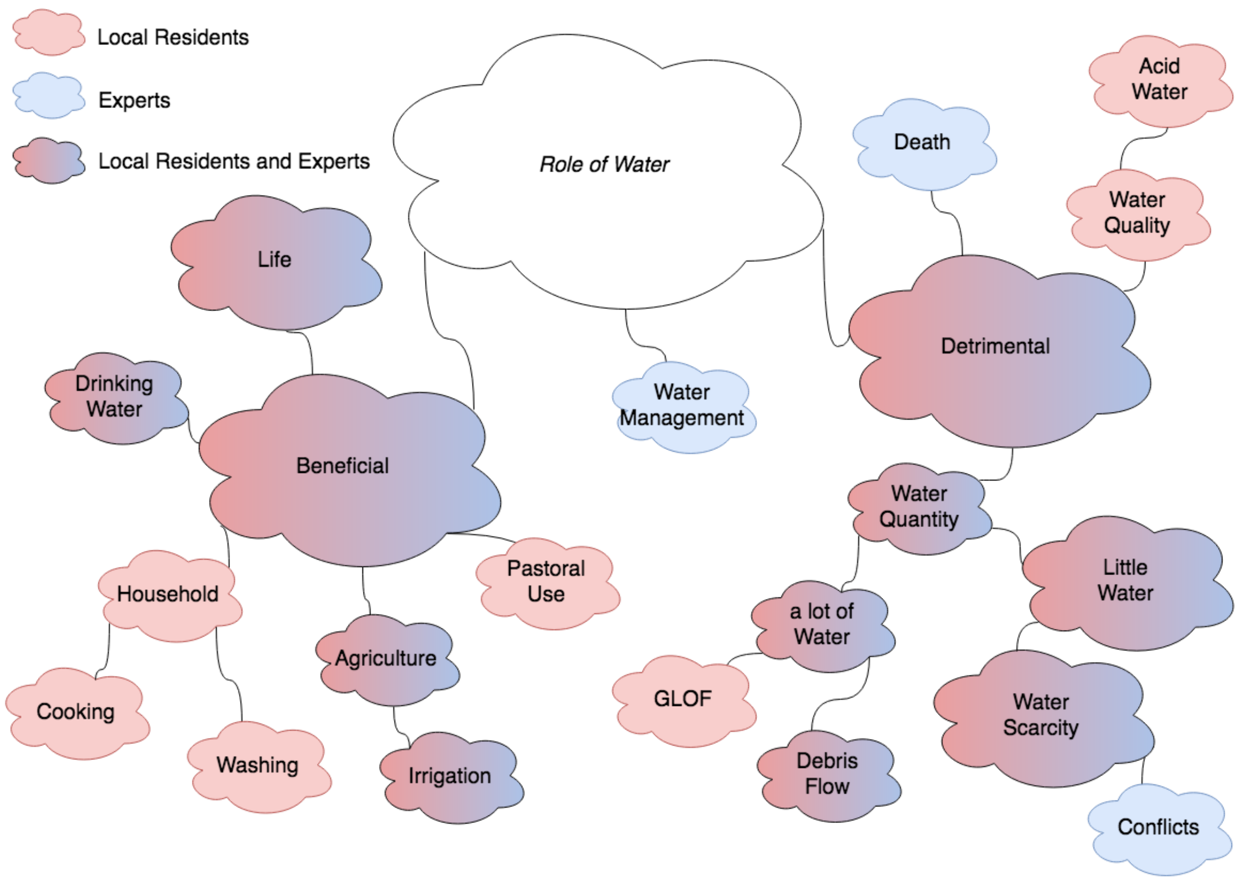

Figure 15 Perceptions of the role water as mentioned by the interviewees. Red colour stands for the local residents' perceptions, blue stands for the experts' perceptions, and red and blue mixed indicates that both the local residents and experts report about that term. The size of a cloud indicates how often the term is mentioned overall; the bigger the could the more mentions. Note: the figure shown here is not to be interpreted as the general result of the study, but as a first impression of the topic.

Opposed to that, informant 9 (Llupa) focuses on the destructive potential of water by stating:

> „Speaking of water, since we are from the same area we know, sometimes so much rain can cause debris flows. Why? Because there is a lot of rain and a lot of lakes in Llupa. They are also taking care of the Palcacocha lake, which is a danger to Huaraz."[3]

Also expert 14 (INAIGEM) mentions detrimental aspects of water:

> „Generally, when I'm asked about water, it comes to my mind that it's going to be scarce, that it's going to generate many conflicts in the future, that's what comes to my mind."[4]

[3] "Hablando de agua, como somos de la misma zona que conocemos, a veces tanta lluvia puede producir huayco. ¿Por qué? Porque hay mucha lluvia y mucha laguna en Llupa. También están cuidando la laguna Palcacocha, que es un peligro para Huaraz."

[4] "Generalmente cuando me preguntan por el agua viene a mi mente que va a ser escasa, que va a generar muchos conflictos a futuro el agua, eso es lo que viene mi mente."

On the other hand, water is both, beneficial and detrimental for expert 19 (Predes):

> "Water comes to [my mind] as a source of life, but also a source of destruction. Both."[5]

Further, the local residents address water quality as being detrimental and the experts mention the importance of water management. The notions of water being detrimental prevail the notions of water being beneficial, both for local residents and experts. The experts predominantly mention water scarcity whereas the local residents mention water scarcity and water quality equally. Figure 15 illustrates the different perceptions of the role of water that were raised by interviewees. The connections between the individual terms were established retrospectively, meaning they were not indicated as such by the interviewees but interpreted by the interviewer. The mention of water management can neither be assigned to the beneficial nor to the detrimental aspects of water. This is why it forms a category of its own.

6.2 Water related risks in the Cordillera Blanca

The local residents and the experts raise various water related risks of the Cordillera Blanca and the Quillcay catchment when being asked which hazards related to water come to their mind[6]. Depending on the season, they tell about different risks. They mention heavy and torrential rain, floods, debris flows, landslides, rock falls, GLOFs, frost and water scarcity. The most mentioned risk of the rainy season is GLOF and of the dry season water scarcity. More experts comment on GLOFs whereas more local residents comment on water scarcity. The following sections illustrate the perception of water related risks according to the seasons.

6.2.1 First mentioned risk

The following tendencies are seen in the interviews regarding the risks that interviewees first mention (see Figure 16). Spontaneously, glacial lake outburst flood is the most mentioned risk by the local residents and experts. The second most mentioned risk for the experts is water scarcity whereas for the local residents it is debris flows. Further, they mention heavy rain, water quality, the El Niño phenomenon and conflicts. Water quality is mentioned by all local residents of the village Coyllur. Most experts from technical institutions mention GLOF as the first risk whereas social, and social and technical experts rather mention water scarcity first. It is to remark that most interviewees mention the first risks before being explicitly asked for risks. As shown above, respondents already refer to risks related to water when asked about the role of water in general.

[5] "Se me viene el agua como fuente de vida, pero también fuente de destrucción. Las dos cosas."
[6] "¿Qué peligro con agua le viene a la mente?"

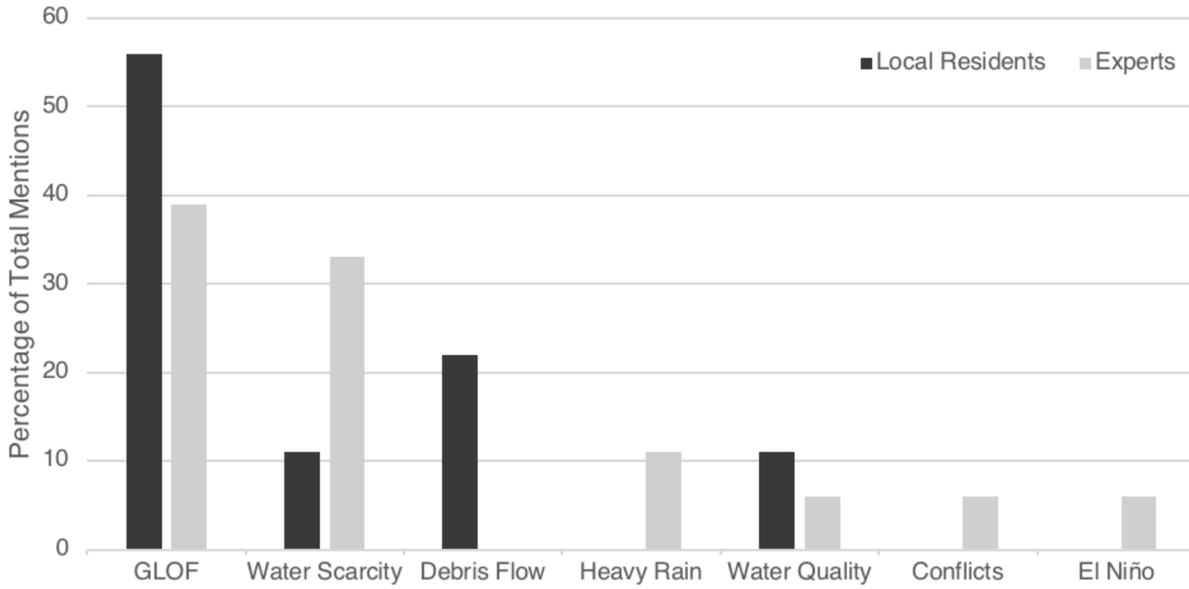

Figure 16 First mentioned risks of the local residents and experts, indicated in percentage of total mentions. The number of mentions is 9 for the local residents and 18 for the experts, therefore no significance can be shown with this illustration.

6.2.2 Rainy season

The rainy season in the Cordillera Blanca evokes various water related risks in the respondents; similar to the first mentioned risks but more detailed. The local residents and experts mention heavy and torrential rain, floods, debris flows, landslides, rock falls and GLOFs.

Both groups perceive heavy rain as a risk and at the same time as a trigger of further risks. A majority of the interviewees state that heavy rain during the rainy season is problematic. On the one hand, due to its direct impacts and on the other hand, because it is the main source of water related risks during that time of the year.

> "The most damaging are the heavy rains. That's the most important thing here in Ancash. ... Other events are triggered from the rains."[7] (Expert 7, INDECI)

Direct impacts of rain

Both groups mention that heavy or torrential rains directly increase river discharge and cause destruction at river banks where often stabilisation is missing. This also impacts roads next to the river that become impassable and need repair work. The intense precipitation and the increased runoff affect agriculture. Especially fields at steep slopes are affected by soil washing and erosion

[7] "Lo más dañino son las fuertes lluvias. Eso es lo más resaltante aquí en Ancash. … A partir de las lluvias se desencadenan otros eventos más."

and sometimes fields even start to slide. The high water level of the river can carry away crops that grow next to the river. Hail is also mentioned to impact crops in rainy season. Informant 6 (Llupa) states that:

> "Sometimes when it rains a lot, the torrential rain affects the crops ... When the water increases, it takes the crops along that are on a slope, near the stream and the river ... ."[8]

Further, torrential rain also affects the water quality and thus drinking water. When there is intense precipitation, rivers carry loads of sediments and other contaminations that affect the water catchment and distribution systems. This is the case in the mountainous regions as well as in the coastal regions of Peru where water resources come from rivers that originate in the mountains. Informant 4 who lives in Coyllur reports:

> "Because of the excess of rain that may exist in the catchments, a lot of water is accumulated and the flow of the river increases and sometimes, as the road goes along the side of the river, all this stretch is affected. The river goes up the road and there is no vehicular or pedestrian traffic, and the consumption of the supposedly drinking water that is also from the river, is completely obstructed. For example, last night, because of the constant rain that has fallen the previous day, the water collection has collapsed and now there is no water".[9]

The effects of heavy rainfalls during the rainy season aggravate when there is an El Niño or a La Niña phenomenon occurring. Expert 12 (UGRH) explained that during El Niño rainfalls at the coast are intensified whereas during La Niña rainfalls in the sierra are intensified.

Cascading impacts of rain

Heavy rain has not only direct impacts, but also cascading effects. The interviewees explain that if there are several successive days of heavy rain, gravitational and fluvial processes such as debris flows, landslides and rock falls are likely to occur in the Cordillera Blanca. The inhabitants of the valley are familiar with these risks since almost every rainy season road ways get blocked due to such events. Especially when roads from or to Lima are blocked, it is problematic because it is the main route of transport for people and commodities. Floods are said to be less common

[8] "A veces cuando llueve mucho, el torrencial cuando cae afecta a los cultivos … Cuando aumenta el agua, se los lleva el agua a los cultivos que están en pendiente, cerca de la acequia y el río … ."

[9] "Por el exceso de lluvia que pueda haber por las quebradas, se carga bastante agua y aumenta el caudal del río y algunas veces, como la carretera va por el costado del río, todo ese tramo afecta. El río se sube a la carretera y no hay, no hay tránsito vehicular ni peatonal, y el consumo de, supuestamente del agua potable, también es del río y se obstaculiza completamente. Por ejemplo ayer de noche, por la constante lluvia que ha ocasionado el día anterior, se ha colapsado la captación del agua y ahorita no hay agua."

the region, they are mainly impacting the Pacific coast of Peru. In the Quillcay catchment itself, landslides and rock falls are less important, only minor events are reported. Expert 15 (PNH) explains that the catchment is geologically not very active compared to others in the region which might be a reason why it is not so vulnerable to these mass movements. Only informant 8 (Llupa) comments that his parents have a field on a slope in the catchment which tends to slide when it rains heavily. Then, it is dangerous to go there to pasture. Yet, debris flows are mentioned by many local residents and some experts. Informant 1 (Yarush) states that torrential rain can cause debris flows near his house because there is a river and steep slopes.

6.2.2.1 GLOF

However, the most mentioned risk related to water of the rainy season in the Quillcay catchment is the glacial lake outburst flood. Almost all interviewees living in and around Huaraz mention the Palcacocha lake as being a threat to Huaraz: "the dangerous lake comes"[10] (informant 7, Llupa). The perceptions of the GLOF itself vary strongly among the interviewees. There are different perceptions about how a GLOF occurs (process), how likely it is to occur (probability) and how strong it would be i.e. how far it would travel (magnitude).

The experts explain that a GLOF could occur when seismic activity detaches blocks of ice and rock from the mountains above Palcacocha lake and fall into the lake. Expert 7 (INDECI) is more specific and explains that avalanches impacting the lake would cause waves that overtop the dam of the lake and then cause the GLOF. Some mention that the origin of the detaching ice is hanging glaciers. Others mention that a GLOF can occur when the dam brakes. The experts and the local residents refer to the events of 1941 when the GLOF in Huaraz occurred and 1970 when the earthquake and subsequent avalanche of Yungay happened. Some local residents also mention the connection of ice and glacial lake outburst floods but give no further explanations. Informant 8 (Llupa) mentions that the excess of deglaciation could increase the water level of the lake so it could collapse. The local residents and experts state that the threat of a GLOF is especially high in the rainy season, when there is torrential rain on successive days. They expect that Palcacocha lake then fills up and the probability of an overflow and a subsequent outburst is higher.

> "If there is excessive rainfall, there will also be an increase in the volume of water in the lakes. And that can also [trigger cascading processes]. Since the dam of the lakes is not safe, there can be an outburst."[11] (Expert 8, INDECI)

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[10] "viene laguna peligrosa"

[11] "Si hay lluvia excesiva también va a haber un incremento del volumen del agua de las lagunas. Y eso también puede desencadenarse. Como no es seguro el dique de las lagunas, puede haber un desembalse."

There are diverse opinions on the probability of a GLOF event. All experts and some local residents are afraid that a GLOF could occur again. Most state that the probability is highest in the rainy season but some also say that a GLOF could occur at any time and that the risk is permanent. Expert 12 (UGRH), who works with glaciers and lakes on a daily basis, comments that he is permanently worried because he is familiar with past events and thus is aware about their destructive potential. Moreover, he has seen these events continuing in recent years and is therefore sure that further events are to come. Expert 8 (INDECI) talks about the properties of the Palcacocha lake and in doing so points out that it has not been defined yet whether the natural dam below the dam construction consists down to the lake bed of rock or of moraine material. It would be very important to know that because this property significantly contributes to the probability of an outburst. Others, mainly local residents, are more sceptical and are not convinced that there is an actual risk. They state that the glaciers have retreated far enough that an ice avalanche would not reach the lake anymore. On the other hand, for expert 18 (Wayintsik), "a GLOF is something remote, which may not even pass"[12]. Informant 7 (Llupa) explains that only God knows when the lake will come. Informant 10 (Nueva Florida), who owns a house in Nueva Florida, explains that he does not believe that the lake still comes. However, it could come if God wants it to come:

> "Informant 10: Palcacocha? Yes, they say it can come but I don't think so, (...) before there was more danger, but not now, the glacier is too high [far away], it can't fall any more, there is no danger. (…). In 1941, the Palcacocha lake came and passed through here, destroying all of Huaraz.
>
> Interviewer: Don't you worry that it might come again?
>
> Informant 10: No, I don't think so. It's not coming anymore. If God, the one in heaven, wants, it can come ..."[13]

There are different opinions as well concerning the magnitude and the reach of the event. Informant 4 (Coyllur) says that depending on the amount of water, an outburst flood could reach the main plaza of Huaraz and informant 6 (Llupa) says that the flood would affect the whole centre of Huaraz. Expert 15 (PNH) does not believe that a future event could be as strong as the

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[12] "un aluvión es algo remoto, que tal vez ni pase"

[13] "Informante 10: Palcacocha? Sí, dicen que puede venir pero no creo, (…) antes más sí había peligro, pero ahora no, el glaciar está muy arriba, no puede mas caer, no hay peligro. (…). En 1941 vino la laguna Palcacocha y paso por acá, destruyó todo Huaraz.
Entrevistadora: Usted no se preocupa que podría venir otra vez?
Informante 10: No, creo que no. Ya no viene. Si Dios, el arriba, quiere, puede venir …"

one in 1941 because according to him the conditions are not existent. Informant 6, who lives in Llupa, explains that an outburst flood would not affect themselves because they are living on the upper side of the gorge and hence out of reach. Informants 1 and 2, who live in Yarush, point out that even though they might not be hit by the GLOF, they are affected because they depend on Huaraz for the purchase of certain foods that they do not grow themselves.

Measures

Few experts and even fewer local residents address adaptation measures for GLOFs. They mention several structural and non-structural adaptation measures which should be taken to face a potential GLOF from Palcacocha lake. Lowering the lake level is the most mentioned structural measure. Expert 16 (independent) explains that if the level of the lake is lowered, a potential avalanche into the lake would not be able to cause a flood wave which is high enough to overtop the dam. Therefore, a lowering of the water level of Palcacocha would prevent a GLOF from happening. In doing so, there are different suggestions. Expert 17 (CARE) says that the already existing siphoning system is able to lower the lake level when needed. Expert 16 (independent) suggests to make a large cut into the dam and lower the water level by 20 metres. Expert 7 (INDECI) states that a better dam is needed since the natural dam is of moraine material and the artificial dam is old and not high enough to retain the modelled flood wave. Informant 5 (Coyllur) is the only local resident who comments on structural measures. He suggests to construct walls at both sides of the river to prevent a GLOF from impacting Huaraz and the nearby villages. Expert 17 (CARE) would like to remove people who are living in the hazard zones but since this is not easily possible, he emphasises the importance of non-structural measures.

Expert 16 (independent) argues that reducing the vulnerability is most promising since that would lower the risk level despite the high hazard potential. Other experts state the need for prevention, education, sensitisation, preparation. Regarding preparation, experts 16 (independent) and 17 (CARE) mention the importance of an early warning system. Until the construction work of the dam will be done, an early warning system is needed to warn the population if a GLOF would occur. For the success of an EWS, the population should be educated and sensitised so that they know how to react when the alarm is triggered. *Expert 9 (INDECI) reports that it is important to always be prepared in case of an event. Thus, everyone should have an emergency backpack ready and know the evacuation routes to run away and bring oneself in safety*. Expert 13 (INAIGEM) tells that leaders who guide and convince people are needed.

In the process of GLOF adaptation, the challenge of the political authorities is mentioned. Authorities are said to only remember the existence of the Palcacocha lake, once the rainy season has started and after they forget about it again. As a result, discussions about the execution of adaptation projects can only be held at that time of the year, which considerably narrows the opportunity for action. The rest of the year, the authorities do not want to know about Palcacocha.

6.2.3 Dry season

Water scarcity is the most reported risk of dry season by the local residents and experts. Some local residents also mention frost to occur during the dry season, which is problematic because it affects plants in agriculture. Expert 15 (PNH) explains the situation of water scarcity in the Cordillera Blanca:

> "In the particular case of tropical glaciers, we have relatively abundant water in the rainy season, when it rains and we have the contribution of the glaciers in greater quantity, but in the dry season is where you feel there is a need for water, right? (...) And that is because the glaciers contribute less and obviously because it is the season in which it does not rain a drop. But it is already tangible that the communities and populations, the water supply now is not as regular as it was in the past.“[14]

6.2.3.1 Water scarcity

Almost all local residents and the majority of the experts state that water scarcity is a problem in the Quillcay catchment. Some experts and a local resident who live in Nueva Florida say that so far it has only been a problem in the Cordillera Negra since it has no ice for water supply during the dry season and therefore water is scarcer there. The Cordillera Blanca, however, is not yet affected because it still has glaciated areas. Few experts say that water scarcity is not a problem in either locations.

Most of the interviewees, who state that water scarcity is a problem in the Quillcay catchment, say that it is already problematic these days whereas others say that it will become a problem in the future. Almost all local residents report that there is not enough water anymore in the dry season. The amount of water that comes from rivers has decreased over the last years. It is not sufficient anymore to irrigate fields in the dry season and to supply drinking water for Huaraz. Also the springs, from which drinking water is taken in the villages, are said to now dry out during the dry season. Informant 6 (Llupa) illustrates that:

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[14] “En el caso particular de los glaciares tropicales, el agua lo tenemos en relativa abundancia en esta época de lluvias, cuando llueve y tenemos el aporte de los glaciares en mayor cantidad, pero en época seca es donde se siente que hay necesidad de agua ¿no? (…) Y eso es porque los glaciares aportan menos y obviamente por ser época que no llueve ni una gota. Pero ya se siente que las comunidades y las poblaciones, el abastecimiento de agua ahora mismo no es tan regular como era antiguamente.“

"[For] ten years there has already been a scarcity of water. Scarcity of rain. That in the times of June, July and August the rivers dry up. It‘s not like before that you reach your highest flow in June and July. But now it doesn't run much, the big river, the main river, the Paria river now [in the rainy season] arrives with high volume but in June and July it will almost run as a quarter of the normal, third of the normal. It's not like before. Less than half of it. More than less than half."[15]

Just informant 4, who lives in Coyllur, considers water scarcity as being only a problem in the future. Among the experts, the views are more heterogeneous. Most experts also state that the problem already exists in the Quillcay catchment but many say it will only be a problem in the future. Few experts say that water scarcity is no problem. Among them are expert 7 and 8 (INDECI) who state that there has always been water in the Quillcay river and therefore water scarcity does not exist. His colleague, expert 8 (INDECI) confirms that there is no water scarcity in the Quillcay catchment since there has always been water:

"Expert 7: (...) it hasn't often been registered that there was water scarcity. In the case of EPS Chavín, it [the company] hasn‘t said, there hasn‘t been rationing. It doesn't exist, does it?

Expert 8: Not for this part, but for the part of the Cordillera Negra, last year there was [water scarcity].

Expert 7: But not here in the catchment. In other words, the EPS, what I haven‘t seen and haven‘t heard of is that it [the company] makes a rationing of water for human consumption. Because there is water and we have always seen that where the Paria river joins the Quillcay river there has always been water. There has always been water.“[16]

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[15] "[Desde] diez anos mas atras ya hay escasez de agua. Escasez de lluvia. Que en los tiempos de junio, julio y agosto los ríos se secan. No es como antes que llegas tu caudal más alto en mes de junio y julio. Pero ahora casi no corre mucho, el río grande, el río principal, el río Paria ahorita [en epoca de lluvias] llega con volumen alto pero en junio y julio casi correra como cuarta parte de lo normal, tecera parte de lo normal. Ya no es como antes. Menos de la mitad. Más de menos de la mitad.“

[16] "Experto 7: (…) no se ha registrado mucho que haya escasez de agua. En el caso de EPS Chavín, no ha dicho, no ha habido racionamiento. No existe ¿no?
Experto 8: Para esta parte no, pero para la parte de la cordillera negra, el año pasado sí hubo [escasez].
Experto 7: Pero acá en la cuenca no. O sea, la EPS, lo que no he visto y no he escuchado de que haga racionamiento de agua para consumo humano. Porque hay agua y siempre hemos visto que, por donde se une el río Paria con el río Quillcay siempre ha habido agua. Siempre ha habido agua.“

Drivers

The interviewees mention various natural and social drivers which lead to water scarcity. Figure 17 illustrates the variety of drivers raised by the interviewees while the connections between the individual mentions were established retrospectively, meaning they were not indicated as such by the interviewees but interpreted by the interviewer. Some experts and local residents explain that in the dry season there is not enough water anymore because climate has changed and glaciers melt. Informant 11 (Nueva Florida) illustrates:

> "Almost all the people have concerns about water. And also climate change. It's not like before, too much heat, water scarcity, deglaciations, because before the glaciated mountains were full [of ice] and now they are already totally black. That's why there's not even water anymore."[17]

Others just explain that the lake is draining less water which is why the runoff has decreased without giving further information on potential causes. Expert 17 (CARE) explains that towards the end of the dry season in July and August, the Palcacocha lake, even though it has a large volume, does not naturally discharge water anymore. Additionally, the decrease in runoff or even the drying out of springs is caused because "the mountain dried and didn't drain anymore water and so there was no more water"[18] (informant 8, Llupa). Expert 12 (UGRH) explains that the river water originates in the dry season from the mountains. It consists of glacier melt water and underground water that is fed by rain during the rainy season. The underground water only lasts for the months of May, June and July but no longer in August and September which results in water deficit. Some local residents say that the lack of rain causes water scarcity.

[17] "Casi todo el pueblo tenemos preocupaciones del agua. Y también del cambio climático. No es como antes, mucho calor, escasez de agua, desglaciaciones, porque anteriormente todo lleno eran los nevados y ahora están totalmente negro ya. Es por eso que ya no hay ni agua."

[18] "la montaña se secaría y ya no drenaba agua y ya no había agua"

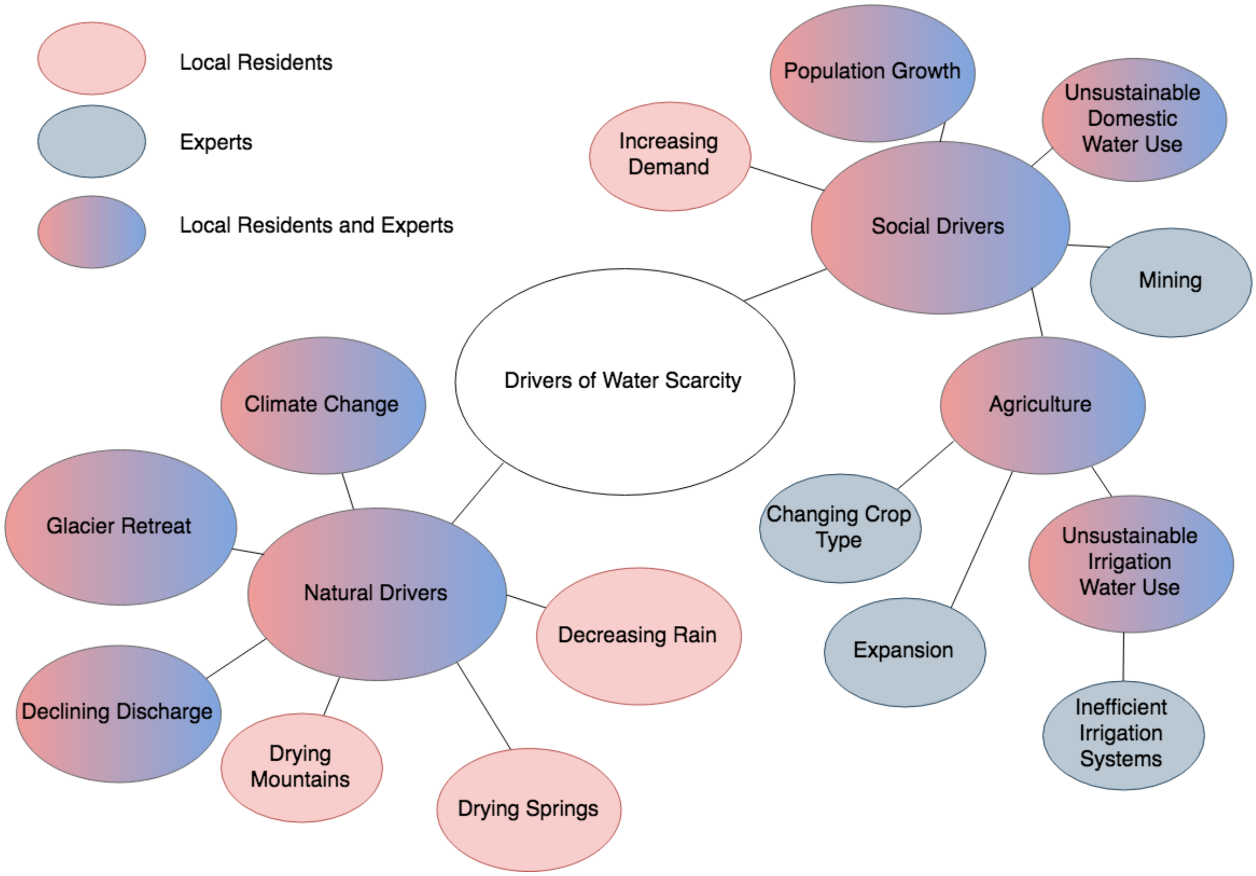

Figure 17 Natural and social drivers of water scarcity as mentioned by the interviewees. Red colour stands for the local residents' mentions, blue stands for the experts' mentions, red and blue mixed indicates that both the local residents and experts report about that term. The size of an oval indicates how often the term is mentioned overall; the bigger the oval the more it was mentioned.

The social conditions for water scarcity are manifold. The interviewees mention water use and demand as influencing the amount of available water. Expert 8 (INDECI) explains that in local agriculture water is poorly used and gets lost due to unsuitable irrigation systems. He adds that the farmers use most of the water available during the dry season and leave little for domestic use. Informant 3 (Coyllur) and informant 8 (Llupa) report that water use is also a problem in villages. Certain households use too much drinking and irrigation water which is why there is less water left for other households. Households, located next to the river or canals, are using all the water and then there is none left for the others. Informant 8 (Llupa) tells that during the years 2015 and 2016 it did not rain and the demand of irrigation water was so high that even though there was still water available, it was not enough to satisfy the demand. Further, several interviewees mention population growth as a condition which influences water scarcity. Expert 20 (PUCP) summarises the situation as follows:

> "The scarcity of water is related to the increase of population, and it is also related to the increase of the productive space, of the agricultural expansion, or the type of cultivated crops (...) [and] the technologies of irrigation have also changed."[19]

Consequences

For the interviewees, water scarcity involves a whole chain of consequences (see Figure 18). Shortages in water supply are the direct impact of water scarcity. Expert 12 (UGRH) explains that the amount of water, which naturally originates from Palcacocha lake, is no longer enough to satisfy the demand of the city of Huaraz in the dry season. Therefore, additional water is extracted from the lake with the siphoning system during this season. The local residents report that they do not have enough drinking and irrigation water during the dry season. Especially towards the end of the dry season in the months of August, September and October, water supply in the villages above Huaraz is not guaranteed anymore. Informant 8 (Llupa) experienced the following during an end of the dry season when it should have started to rain but it did not:

> "People were getting desperate. (...) There was still water but there was so much demand, or in other words, everyone wanted to irrigate, so it was not enough. And of course, when your fields are close to the channel, you can irrigate but those who are not close to the channel couldn't. When there is no rain there is a scarcity of water because everyone wants to irrigate and there isn't enough water. What also happened was that the drinking water dried up. The village takes water from the spring, but then the mountain dried up and no longer drained water and so there was no water. We had to connect to a channel to have water in the houses but it was already turbid."[20]

However, not only villages suffer from water shortages. The city of Huaraz has also already been forced to ration water. Expert 12 (UGRH) reports that during the dry season there have been periods when water had to be rationed by sectors. But since 2011, when a siphoning system was installed at Palcacocha lake, the problem for Huaraz could be solved for the moment. The siphoning system allows to drain additional water from Palcacocha lake when needed.

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[19] "La escasez de agua está relacionado con el aumento de población, y ademas esta relacionado con el aumento del espacio productivo, de la expansion agricola, o el tipo de cultivos que estan haciendo (…) [y] las tecnologías del riego también han cambiado."

[20] "La gente estaba llegando a desesperarse. (…) Todavía había agua pero tanto hubo la demanda, o sea todo el mundo quería regar, entonces no era suficiente. Y claro que cuando están cerca al canal los terrenos puedes regar pero los que no están cerca al canal no se podían. Cuando no hay lluvia hay escasez de agua porque todo el mundo quiere regar y no hay suficiente agua. Lo que pasó también fue que el agua potable se secó. El pueblo toma agua del manantial, entonces la montaña se secaría y ya no drenaba agua y ya no había agua. Tuvimos que conectar de un canal para que haiga agua en las casas pero ya era turbio."

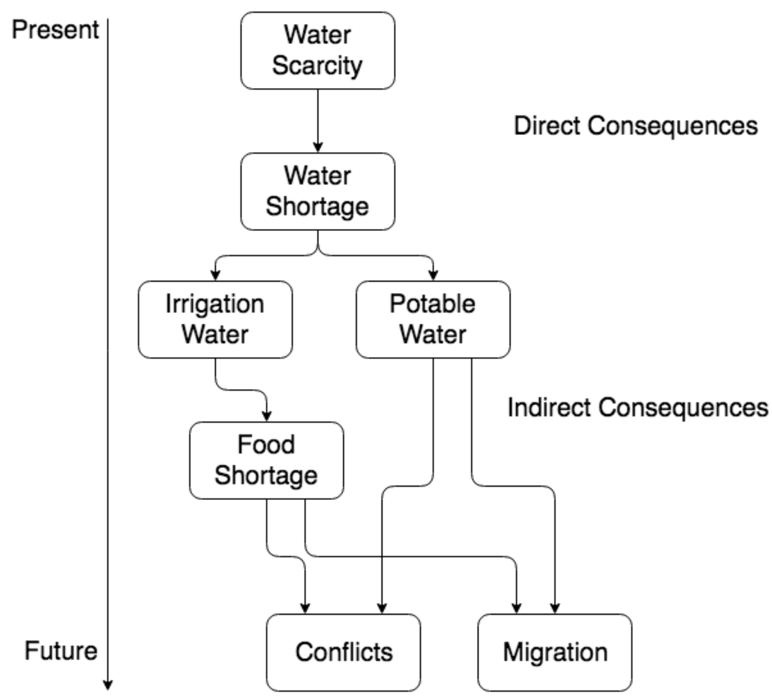

Figure 18 Direct and indirect consequences of water scarcity mentioned by the interviewees. Note: the actual link between individual consequences may be more complex in reality. Not all terms were mentioned by all interviewees.

When it comes to indirect impacts of water scarcity, the interviewees tell mainly about the future. Predominantly the local residents address indirect impacts of water scarcity whereas few experts remark on this. The local residents explain that if they have not enough water to irrigate their fields, they will not be able to seed and therefore will not harvest. This will result in food shortage for them and on the market where they sell and buy their products. Also for animal farming, the lack of water will be problematic. Therefore, many voices mention that they are worried about the food and drinking water supply in the future. Informant 4 (Coyllur) states:

> "The [ice of the] glaciated mountains are distancing themselves, they are disappearing. This means the ice is disappearing. Right? This worries me, at some point we're not going to have rivers anymore, we're not going to have lakes anymore. We will no longer have the water source. (...) Even now the rains are no longer fixed rains. There are years of good presence of rains and there are years of scarcity, there is drought. (...) So that, is going to have the effect that we are not going to be able to sow, we are not going to be able to live in peace."[21]

[21] "Nuestros nevados se están distanciándose, se están desapareciendo. Eso quiere decir que está desapareciendo el hielo. ¿No? Eso me preocupa, en algún momento ya no vamos a tener ríos, ya no vamos a tener lagunas. La fuente de agua ya no vamos a tener. (…) Inclusive, ahora las lluvias ya no son lluvias fijas. Hay años de buena presencia de

Water scarcity and possibly resulting food and drinking water shortage entail further indirect consequences. Some experts mention migration. Expert 17 (CARE) states that people abandon rural areas because agriculture is no longer profitable, among other reasons due to water scarcity. Furthermore, several conflicts are mentioned which are illustrated as follows.

Conflicts

The interviewees tell about different conflicts. On the one hand, regarding the allocation between rural agricultural use and urban domestic use and on the other hand, concerning the allocation of drinking and irrigation water in rural areas. The experts tell about social conflicts existing in the Quillcay catchment. They state that local residents are facing social conflicts regarding water use due to water scarcity. Informant 3 tells that people blame each other for using too much water during the dry season in his village Coyllur. Some households, which are closer to the water resource, use so much water that there is not any left for people living further away. Expert 11 (ALA) reports that the water distribution among local residents is poor and at the same time states that when irrigating, farmers use the water poorly and waste it. Expert 14 (INAIGEM) predicts conflicts in the future regarding water use between agriculture and domestic use. According to him, agriculture uses 80% of the water resources in entire Peru and when the consumption of drinking water increases, farmers will start to complain which results in conflicts. Expert 16 (independent) tells that due to water scarcity, social conflicts about water use will arise in the future on a national up to a global level. According to him, the problem of water scarcity will result in a 'war about water' which will be worse than any war because people will be fighting for water and thus for their lives. Also informant 7 (Llupa) has an apocalyptic view on the end of water scarcity:

> "We just look at the glaciated mountain. (...) And when [the ice of] the glaciated mountain is finished, that lake is going to dry up too. What water is going to come? Eventually, when the water is going to run out, blood is going to come. That's what the gospels say, that blood will come when the lake is finished. And blood we're going to drink, so it says."[22]

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lluvias y hay años de escasez, hay sequía. (…) Entonces eso, va a repercutir a que no vamos a poder sembrar, no vamos poder vivir tranquilos."

[22] "Miramos no más el nevado. (…) Y cuando se acabe el nevado va a secar esa laguna también pues. ¿Qué agua ya va a venir? Última hora cuando el agua ya se va a acabar, sangre va a venir. Así dicen los evangelios, que sangre va a venir cuando se acabe la laguna. Y sangre vamos a tomar, así dice."

Measures

Few experts and few local residents report about adaptation measures for water scarcity. The most mentioned adaptation measures for water scarcity is the construction of reservoirs. In total, Both, the local residents and the experts state that water reservoirs made of cement should be built to collect and store water in the rainy season which can be released when needed in the dry season. Other suggestions from the local residents are the construction of small artificial lakes for the same purpose and the construction of water channels to lead irrigation water to their fields. However, informant 11 (Nueva Florida) says that when water is lacking there cannot be done anything than waiting for the rain. Further suggestions for water scarcity measures come from the experts, especially expert 12 (UGRH) gives detailed explanations. He and others mention reservoir dams, the diversion of water, the usage of the siphoning system at Palcacocha lake to drain additional water and water rationing. Expert 12 (UGRH) emphasises the natural storage of water in wetlands and moranic material, whose presence favours the water supply in the Cordillera Blanca compared to the one of the Cordillera Negra where such structures are non-existent. Expert 14 (INAIGEM) also mentions the role of the ecosystem in the future water resource management. Expert 13 (INAIGEM) suggests to make regulations on water use, to consume less for drinking and showering and to look for water in another place. Furthermore, some experts consider multipurpose projects as a valuable solution. The adaptation to GLOFs and water scarcity should be combined in one project of which the protection to risks as well as the water supply could benefit simultaneously.

Yet, the adaptation to water scarcity is said to be hindered by the authorities. According to the interviewees, the authorities are not aware of the water scarcity problem and are therefore not doing anything in this area. In addition, the lack of an organisation of rural water users does not help to improve the situation either.

6.2.4 Water quality

When talking about water scarcity, some experts and local residents of Coyllur and Nueva Florida come up with water quality and state that in the Quillcay catchment it is causing more problems than water scarcity. In fact, it is most problematic in the Quillcayhuanca catchment. In contrast to water scarcity, which is problematic in the dry season, the problem of water quality is all-season. Expert 14 (INAIGEM) states that the quantity of water is not yet problematic in the Cordillera Blanca but the quality of water already is. Many interviewees report that the water of Auqui river in the Quillcayhuanca catchment is unusable because it is acidic.

"The water that exists in Quillcayhuanca is sufficient to supply the use of the population, the agricultural use, for pisciculture, but the problem is in the quality. In quantity we have enough, but in quality much of the water is not suitable, hence, there comes the problem of water."[23] (Expert 12, UGRH)

They report that the quality of the Auqui river begun to deteriorate in the 1970s. Before then, there were trout in the river. Nowadays, the pH of the water is between 3.5 and 4. Expert 12 (UGRH) explains that the reason for the contamination is the leaching of minerals in the mountains above lake Cuchillacocha and Tullpacocha due to glacier retreat. Bedrock that before had been covered with ice is now exposed and naturally occurring minerals in these rocks are eroded and find their way into the water bodies below. The impact of the minerals on the water is visible when watching the Auqui river. All stones in and around the river bed are coloured in orange. The residents of the Quillcayhuanca catchment use the water of the Auqui river for agriculture, watering of animals and domestic use including drinking water.

"Interviewer: So, if we talk about water, what's the first thing that comes to your mind?

Informant 3: The first thing is the river, right? And in the context where I live, in the Auqui River. Water, Auqui River. And when that comes to mind, I know that the river is polluted and in the settlement where I live, which is Coyllur, we take that water from the river that is not suitable for human consumption. And a total chain is coming, isn't it? The water, the river, I remember, the river is dirty, we drink that."[24]

Informant 3 (Coyllur) and the other residents of Coyllur report on the bad quality of the Auqui river and its impacts for people, animals and agriculture. They tell that the acidic water destroys irrigated plants and that children are more often sick than before. In contrast, the water quality of the Paria river in the Cojup catchment is good. It is there where EPS Chavín is located, the company which provides water supply for Huaraz. At this location, the water only needs a minimum treatment whereas if it would be taken from the Auqui river, the treatment would need to be much higher. Apart from the water contamination caused by natural processes, there is also mentioned that water gets contaminated due to anthropogenic processes. The interviewees report

[23] "El agua que existe en la quebrada Quillcayhuanca es suficiente para abastecer el uso poblacional, el uso agrícola, para uso piscícola, pero el problema esta en la calidad. En cantidad tenemos suficiente, pero en calidad gran parte del agua no es apto, entonces por ahí viene el problema de agua."

[24] "Entrevistadora: Entonces, si hablamos de agua ¿qué es lo primero que te viene a la mente?
Informante 3: Lo primero el río pues, ¿no? y en el contexto donde yo vivo, en el río Auqui. Agua, río Auqui. Y cuando eso viene a mi mente, sé que el río está contaminado y la población donde yo vivo, que es Coyllur, tomamos esa agua del río que no es apto para consumo humano. Y se viene una cadena total ¿no? El agua, el río, me acuerdo, el río está sucio, tomamos eso."

that people in the Quillcay catchment throw waste into the river which pollutes the water and makes it unfit for consumption. Furthermore, the Santa river gets contaminated by mining and human residues. Mining residues are deposited without any protection beside the river and the city of Huaraz has no sewage treatment plant.

6.2.5 Most important risk

The mentions of the most important water related risks show different tendencies for the local residents and for the experts (see Figure 19). They were asked which hazard is the most severe for people[25] and responded as follows. The experts mention GLOFs and water scarcity similarly often as the most important risk in the Quillcay catchment. On the other hand, local residents mention water scarcity as the most important risk by far most . Some local residents and experts share the opinion that it is not possible to say whether GLOFs or water scarcity would affect people more i.e. both are equally important risks. Few members of both groups mention water quality, heavy rain, conflicts and earthquake, even though it is not water related.

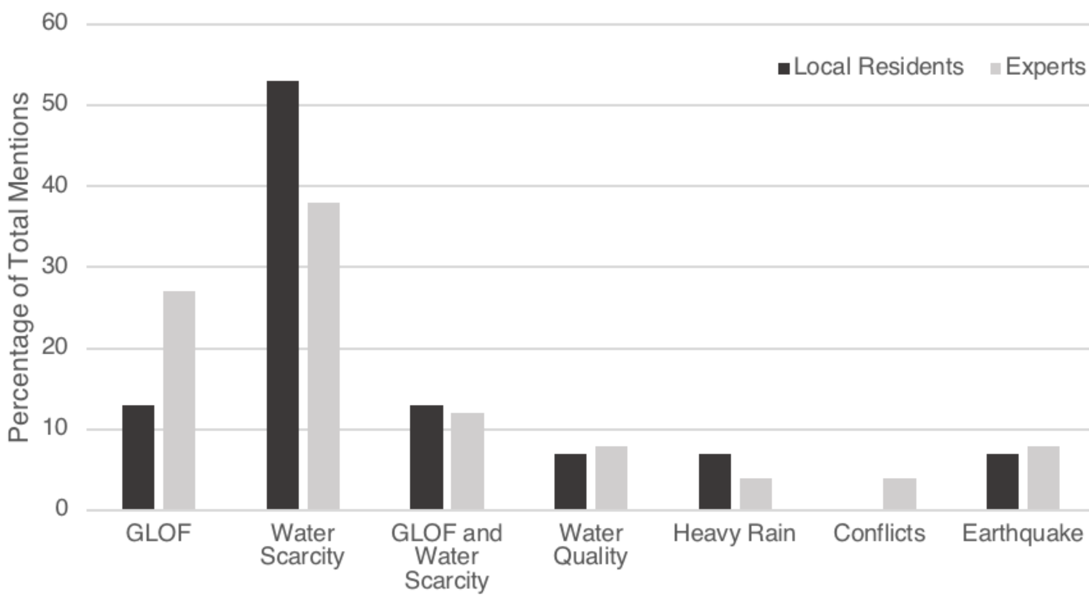

Figure 19 Most important risks mentioned by the interviewees, indicated in percentage of total mentions. The number of mentions is 15 for the local residents and 26 for the experts, therefore no significance can be shown with this illustration.

Some interviewees reason why which risk is more important or why it is not possible to determine that. Expert 15 (PNH) is one of the interviewees who represents the view that both risks threaten people and both have negative impacts on them but each in a different way. Therefore, both risks should be addressed simultaneously. A main difference is the probability of occurrence: A GLOF

[25] "¿Cuál es el peligro más grave para la gente?"

could happen the day after or only in 100 years whereas the water problem is occurring year after year.

Those who state that GLOFs represent a higher risk than water scarcity draw on the simpler mitigation of water scarcity. Expert 10 (ALA) explains that water scarcity is less problematic than a GLOF because it can be mitigated with engineering techniques, such as the allocation of water. Of the same tenor is expert 13's (INAIGEM) statement:

> "The [water problem] is less. The amount of water can be regulated. You have to drink less water, bath less, look for water elsewhere, look for a solution."[26]

The interviewees who claim that the water scarcity threatens people more than GLOFs argue exactly opposing. They state that the mitigation of GLOF events is more feasible than that of water scarcity. Expert 16 (independent) explains that the impacts of a GLOF event could be recovered in between few years whereas the problem of water scarcity only worsens with time.

> "The worst is the water [problem] because the GLOF kills people, destroys houses, but after 10 years or 15 years it can be fixed, but not the water thing. The water [problem] will continue to grow and the problem will grow. It's going to get worse every time."[27]

Expert 19 (Predes) remarks that it depends on different aspects whether water scarcity or GLOFs are more problematic. She says that the effect of each risk depends on the area and she also emphasises the reach of the risk:

> "I think it depends [which danger is the worst for the population]. If we think about the issue of GLOFs, those who are most affected are generally almost urban populations, in their homes, right? But if we think about the issue of drought, those who are strongly affected in their livelihoods are the peasant communities, because it affects their production and therefore it will generate hunger and they will not have to eat. So, the issue of GLOFs is specific. It can be a microcatchment and it affects the houses that are there; but the drought is general, it affects a larger population, and since it is not violent, nobody gives it importance."[28]

[26] "El [problema del] agua es menos. En la cantidad de agua se puede hacer regulaciones. Hay que tomar menos agua, bañar menos, buscar el agua en otro lugar, buscar una solución."

[27] "El peor es el [problema del] agua porque el aluvión mata gente, destruye casas, pero después de 10 años o 15 años se puede arreglar, pero lo del agua no. El agua va a seguir creciendo y creciendo el problema. Cada vez va a ser peor."

[28] "Yo creo que depende [cuál peligro es la peor para la población]. Si pensamos en el tema de aluviones, quienes se afectan más fuerte son generalmente poblaciones casi urbanas, en sus viviendas ¿no? Pero si pensamos en el tema de sequía, quienes se afectan fuerte en sus medios de vida son las comunidades campesinas, porque afecta su producción

Even though, the question aimed at investigating whether water scarcity or GLOFs are more important, the interviewees raised water quality as the risk that is more important than GLOFs or water scarcity. Expert 14 (INAIGEM) explains the situation as follows:

> "What worries me is that the biggest problem is being generated not by the risks of events [for example GLOFs] but by the decrease in the volume and quality of the water, the quality is the most serious thing there is."[29]

6.3 Risk definition

The interviewees conceptually address water related risks of the rainy season and those of the dry season differently. When they talk for instance about debris flows or GLOFs, they speak of actual hazards or risks[30]. In contrast, they often do not use the terms risk or hazard when they talk about water scarcity. They rather say '*the water problem*'[31].

The experts were asked for the risk definition that is used in their institution[32]. The given definitions differ significantly. Experts 6, 7 and 8 (INDECI), expert 12 (UGRH) and expert 16 (independent) define risk in the following way:

Risk = hazard * vulnerability[33]

Expert 17 (CARE) and expert 19 (Predes) define it similarly whereas experts 10 and 11 (ALA) do refer to the risk definition of INDECI and state that they use their definition without giving further details. Without defining risk, experts 13 and 14 (INAIGEM) state that a technical definition of risk is not useful in practical work or in collaboration with local residents.

y por consiguiente eso les va a generar hambre y no van a tener que comer. Entonces, el tema de los aluviones es específico. Puede ser una microcuenca y te afecta las viviendas que están ahí; pero la sequía es general, te afecta a mayor población, y como no es violento nadie le da importancia."

[29] "Lo que a mí me preocupa es que el mayor problema se está generando no por los riesgos de eventos [por ejemplo aluviones] sino por la disminución del volumen y la calidad del agua, la calidad es lo más grave que hay."

[30] peligros o riesgos

[31] 'el problema del agua'

[32] "¿Como ustedes definen riesgo institucionalmente?»

[33] Riesgo = peligro * vulnerabilidad

7 Discussion

This chapter discusses the main findings of the study and answers the research questions. It is divided into three main parts. The first part (Chapter 7.1) summarises the results by following the structure of the results section. It sets them into context with physical science literature by comparing the interviewees' perceptions with measured data. The second part (Chapter 7.2) illustrates the risk perceptions according to the two sample groups and presents explanatory approaches to the observed patterns. The third main part (Chapter 7.4) connects the results to social science theories. Throughout the discussion, the focus lies on the comparison between the perceptions of the two sample groups, *local residents* and *experts*, regarding the two core risks, GLOF and water scarcity.

7.1 Perception of low and high flow water risks

7.1.1 Role of water

The question after the general role of water reveals the ambiguous meaning of water for the local residents and for the experts. On the one hand, they perceive water as beneficial for life. On the other hand, slightly more statements indicate that water is perceived as detrimental for life. Additionally, some experts even relate it to death. These findings suggest that the role of water is ambiguous with a prevailing perception of water related to threat. These perspectives can be visualised with the respondents' places of residence and living conditions. Water has a decisive role for the maintenance of life in a high mountain environment such as the Cordillera Blanca, where water resources depend on seasonally fluctuating glacier melt water and precipitation. This especially holds for small-scale farmers whose source of life highly depends on this water. This dependence on water may be an explanation for the frequent mentioning of water benefits. On the other hand, high mountains also pose seasonal and permanent water related risks for downstream settlements why it is comprehensible that the interviewees focus on this issue. It is unclear why the connotation of threat prevails. However, the fact that the sole notion of water evokes risk connotations shows that water is directly connected to risks and lets assume that water related risks play a crucial role in the everyday life of the interviewees.

7.1.2 Low and high flow water risks

When addressing the question about water related hazards, the interviewees mention a variety of risks. Depending on the season, they mention different risks. The interviewees mention the majority of risks in the rainy season. This might reflect that most water risks in the Cordillera

Blanca are related to rain and therefore appear in the rainy season. GLOF is the most mentioned hazard of the rainy season whereas water scarcity is the most mentioned of the dry season. More experts comment on GLOFs whereas more local residents comment on water scarcity. Broadly speaking, the risks related to water that the interviewees tell about reflect the high mountain environment in which they live in.

Seasons

In the interviewees' perception of water related risks in the Cordillera Blanca, the seasons play a significant role. All mentioned risks related to water are assigned to either the rainy or the dry season. When talking about water related risks in the interviews, the local residents and experts usually started telling about risks of either the rainy or the dry season depending on the first risk that came to their mind. After that, the interview had to be guided towards the other season to receive information about those risks. This circumstance lead to a change of course of the study. The initial plan of the study was to structure the interviews and the results according to high and low flow water risks. As the interviewees did not respond well on this division, the structure of the seasons was adopted.

7.1.3 GLOF

The most mentioned risk of the rainy season in the Quillcay catchment is the outburst flood of the glacial Palcacocha lake. Almost all interviewees agree on the threat 20 km above Huaraz during rainy season. However, the detailed perspectives on the process, probability and magnitude of a GLOF vary. The experts explain more detailed about the GLOF process than the local residents. About the probability, there exists one common perspective: The rainy season increases the risk of a lake outburst considerably and thus the risk is highest during the rainy season. The potential travel distance and impact of a GLOF from Palcacocha is also disputed.

The respondents' explanations on the process of GLOFs largely correspond to the process described in literature (Clague and Evans 2000; Harrison et al. 2018; Huggel et al. 2008; Richardson and Reynolds 2000; Worni et al. 2012). Both versions of how an outburst flood can occur are mentioned, namely the impact of a rock/ice avalanche on the lake surface and the rise of the lake level. However, the almost exclusive assignment of the GLOF to the rainy season does not correspond to the actual risk. Indeed, heavy rain is able to rise the glacial lake level and therefore create a potential situation for an overflow and a subsequent outburst. However, ice avalanches, which are the main reason for GLOFs (Richardson and Reynolds 2000), can occur independent of the season. Moreover, Harrison et al. (2018) identified the weather as a possible influence on the probability of glacial lake outbursts. Warm summer weather or heavy winter snow may trigger avalanches that cause GLOFs. However, no interviewee raises GLOFs when referring to the dry season.

7.1.4 Water scarcity

The local residents prominently mention water scarcity, almost all of them state that water scarcity is a problem in the Quillcay catchment. Most data about the conditions and consequences of water scarcity were gathered in the interviews with the local residents. The experts also mention water scarcity, but not all state that it is a problem in the Quillcay catchment. Some say it is problematic in the Cordillera Negra and few say it is not a problem at all. They do not give specific information about the topic except for expert 20 (PUCP) who researches in the field of social anthropology in the Peruvian Andes. So, water scarcity is perceived as being spatially distributed. The interviewees mention different natural and social drivers that cause water scarcity. Furthermore, several local residents do not address water scarcity by themselves. They only start to explain the problem once it was raised by the interviewer.

The perceived water scarcity is in line with measured data since water availability in fact is decreasing (Buytaert and de Bievre 2012). On the one hand, water resources are declining due to vanishing glaciers and more variable precipitation patterns. Also other authors report about local observations of irregular or disappearing springs in the Quillcay catchment (Bury et al. 2011; Mark et al. 2010). Especially in the dry season, the reduced water supply becomes apparent (Mark et al. 2015; Vuille et al. 2018). On the other hand, water demand is increasing due to similar reasons that the interviewees mentioned such as population growth and agricultural change (Drenkhan et al. 2015; Vuille et al. 2018). Authors raise additional reasons for increasing water demand that are not addressed by the interviewees, namely political constellation, power relations, water rights and allocation practices. Authors argue that factors like population growth, water allocation practices and power relations are going to outweigh the climate change driven water supply (Buytaert and de Bievre 2012; Carey et al. 2017; Drenkhan et al. 2015; Jurt et al. 2015; Mark et al. 2017; Vuille et al. 2018). However, the interviewees rather focus on natural drivers of water scarcity when talking about the phenomenon. They seem to have a very local view on the problem as they report the declining water resources on their direct environment (e.g. vanishing glaciers). To see all involved components, a broader perspective on the topic would be needed. Solely, the perception of decreasing precipitation, which considerably contributes to water scarcity, does not correspond to measured data. In the Callejón de Huaylas, Gurgiser et al. (2016) found a high interannual variability in precipitation. There is strong variation among different years regarding the onset dates of the rainy season, the number of torrential rain events per agricultural year and the occurrence of dry spells after the onset of the rainy season. But no fundamental changes in amount of precipitation could be observed. In the region of the Andes that include the Cordillera Blanca, heavy precipitations events are showed to be enhancing and even a slight increase in precipitation could be observed (Haylock et al. 2006; Vuille et al. 2003). Nevertheless, scientific observations corresponds to the perceived increase in variability of rainfall.

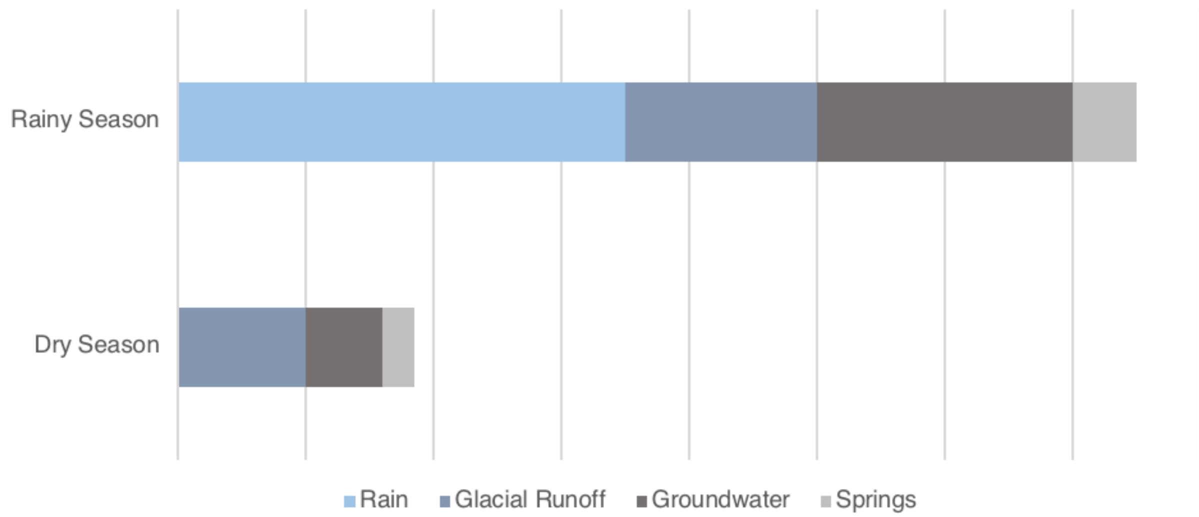

Figure 20 Water supply in the Cojup microcatchment. Source: interviews, Condom et al. (2012), Glas et al. (2018), Somers et al. (2016).

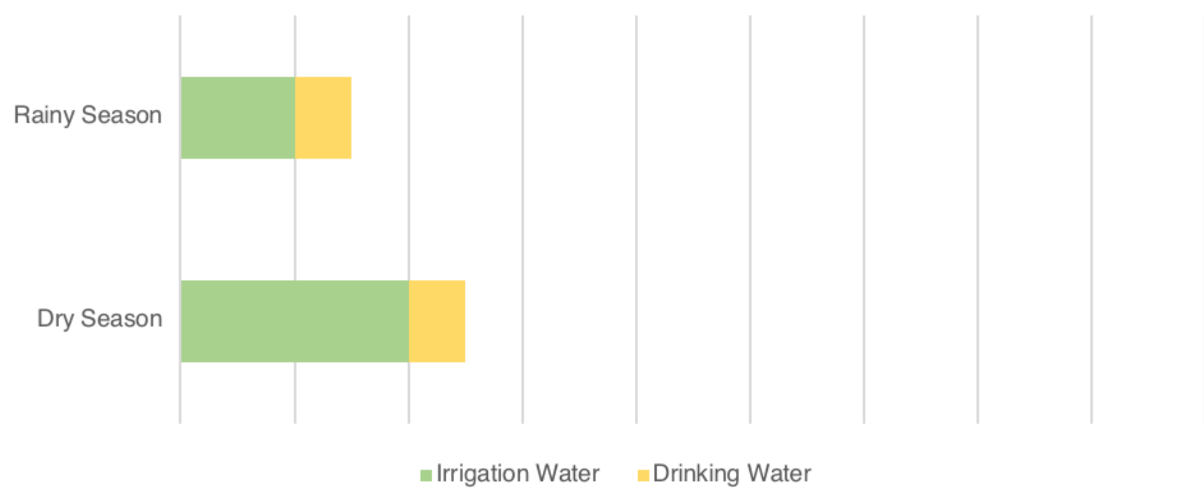

Figure 21 Water demand in the Cojup microcatchment. Source: interviews, Condom et al. (2012), Glas et al. (2018), Somers et al. (2016).

To visualize the water supply and demand in the Cojup microcatchment, a qualitative analysis was made (see Figure 20 and Figure 21). It shows the situation in the rainy and the dry season.

The different components of supply and demand are illustrated in relative shares. The demand for irrigation water derives from small-scale farming only. For other catchments the situation may differ. The analysis is based on a combination of information from scientific literature and interviews (Condom et al. 2012; Glas et al. 2018; Somers et al. 2016).

Social consequences

The consequences of water scarcity are all of social character since water scarcity itself is defined through a social component. As direct consequences of water scarcity, the respondents report shortages in drinking and irrigation water. Among the indirect consequences of water scarcity are shortages in food supply, social conflicts and migration. When the interviewees remark on the direct impacts of water scarcity, they narrate about the past, the present and the future whereas when they come to tell about indirect impacts they mainly narrate about the future. This circumstance could be a hint that the consequences of water scarcity are not fully in place and the indirect consequences are yet to come. This shows the temporal aspect of water scarcity, which represents an additional dimension to the spatial one.

Especially interesting is a deeper look into conflicts. The interviewees report already existing conflicts in the Quillcay catchment during the dry season due to water scarcity and state that the conflicts will increase in the future. The experts and local residents tell about disputes among rural water users whereas some experts complain about the unsustainable water use of local agriculture. Two conflicts exist: one between the rural allocation of drinking and irrigation water and another between the rural agricultural and the urban water use. As becomes evident, conflicts exist among rural people and between urban and rural people. They are not merely about the amount of water but rather about its allocation. It does not seem clarified who is allowed to use how much water in which time frame. This lack of clarity results in mutual accusations and consequently in conflicts. In this context, it is to remark that the respondents' representation of conflicts and the corresponding depiction of these in the results section might be too simplistic. Conflicts arise due to different factors, not just environmental conditions like water scarcity but also historically grown and current power relations, political structures and the mentioned (missing or unclear) water management practices. Similar findings are found in literature as authors state that water conflicts are rather of social kind concerning unequal allocation, power relations and rising demand than about the environmentally reduced quantity of water (Carey, French, et al. 2012; Drenkhan et al. 2015)

7.1.5 Water quality

Some interviewees tell that degrading water quality is even more problematic than the decreasing water quantity in the Quillcay catchment. The problem is reported by the local residents, who live in Coyllur and Nueva Florida, and the experts working with water risk or water management (ALA, CARE, INAIGEM, PNH, URGH). They also state that in particular the Quillcayhuanca microcatchment is affected. In this microcatchment, water scarcity is also perceptible during the dry season but the acidic water harms people, animals and agriculture all year round. Therefore, even though they have sufficient water in terms of quantity during the wet season, the poor quality makes it impossible for them to receive an adequate water supply. Mark et al. (2017) describe the natural contamination of Santa river tributaries like the Auqui river. The water of these streams contains naturally sourced dissolved metal concentrations deriving from newly glacier free rock surfaces.

The previous chapters give answer to the research question *"Which low or high flow water risks do local residents and experts perceive in the Quillcay catchment?"*. The local residents and experts perceive low and high flow water risks according to the seasons of their environment, namely the rainy and dry seasons. For the interviewees, heavy rain, floods, debris flows, landslides, rock falls and GLOFs belong to the rainy season, and frost and water scarcity to the dry season. The classification of the mentioned risks to low or high flow water risks follows the classification according to the seasons except for frost that is neither the one nor the other.

7.1.6 Risk definition

The risk definitions showed that ambiguities exist among the experts regarding the definition of risk. The explicit risk definitions are given by a minority of the experts. All these experts have a technical background (INDECI, URGH, independent). These experts' definitions follow the risk concept of CENEPRED (2014) and INDECI since they also include the components hazard and vulnerability. In comparison, the concept of IPCC (2014) additionally lists an exposure component which in the experts' and CENEPRED's definition is included into the vulnerability component resulting in a 'vulnerability of an exposed element' component.

Experts and CENEPRED (2014)	Risk = hazard * vulnerability $_{\text{of an exposed element}}$
IPCC (2014)	Risk = hazard * vulnerability * exposure

These considerations exclude the majority of the experts. They either gave vague definitions (CARE, Predes), referred to INDECI without giving further explanations (ANA) or rejected any technical definition (INAIGEM). In principal, little data could be collected about the risk definitions because the experts did not elaborate much on the subject. This suggests that most experts are not clear about the precise risk definition of their institution, which might impact the assessment and management of risk including the design of adaptation strategies.

This chapter answers the research question about the experts' risk definitions and their resemblance to the international risk concept of IPCC (2014). It shows there is no homogenous definition of risk among the experts. Few define risk according to CENEPRED (2014) while most define it vaguely or not at all. The definition of those who defined risk precisely resembles the concept of IPCC except for the exposure component that is included in vulnerability.

7.1.7 Perception of climate change

Observations of climate change were implicitly mentioned when the interviewees told about high and low flow water risks. In connection with the mentions of GLOFs, the interviewees also reported about glacier retreat, growing glacial lakes in size and number, and increasing heavy rain events. In the context of water scarcity, they reported rising temperatures, declining amount of rain, increasing torrential rain events, retreating glaciers, changing water resources such as decreasing river discharge, drying out of springs, and deteriorating water quality. The phenomenon of climate change was designated as such by most local residents and experts. This suggest that the interviewees are aware of it. However, it cannot be conclusively stated to what extent the perceptions include the global reach of the phenomenon. This is not always the case, as findings of Byg and Salick (2009) demonstrate. They showed that people are aware of changing climate impacts like rising temperatures but do not ascribe them to a wider global phenomenon. Instead, they assume that changes are local. Frequently mentioned causes also involve moral issues including bad behaviour of outsiders like tourists.

The reasons for climate change are not a focus of this study and were therefore not explicitly asked for. However, informant 6 (Llupa) explains that climate has changed because of environmental pollution caused by mining and industry. Informant 7 (Llupa) and expert 9 (INDECI) do not explain the causes of climate change but of polluted water: People pollute water by throwing plastic and other waste into the rivers.

7.1.8 Consistency with measured data

These study's findings suggest that people's perceptions of water related risks do not entirely correspond to scientific observations. This is shown in the perception of decreasing precipitation which in fact is fluctuating if not slightly increasing as measured data show. Further, the fact that both the local residents and experts clearly assign the risk of GLOFs to the rainy season underscores that.

Possible reasons for the erroneous perception of overall decreasing precipitation are the coexisting phenomenon of water scarcity during the dry season and the possibly romanticised picture of the past. Shijin and Dahe (2015), who researched in high mountain areas of Tibet, support the present findings as they identified similar patterns in people's perception of climate change. They found that local residents perceive precipitation as having declined significantly whereas measured data show a fluctuation with a slight increase in precipitation. Their explanation attempt for this circumstance is that the persistent drought phenomenon of recent years in the studied region influenced local residents' perceptions of precipitation. This might also be true for local residents in the Quillcay catchment. In recent years, dry seasons with scarce water became more frequent. Further, scientists have raised that people's reports of past events or conditions may be romanticised because they may recall idealised images of how things were or should have been. Indeed, experimentally based studies show that the recall of past events may be influenced by expectations (e.g. DiMaggio 1997; Freeman et al. 1987). Hence, scientists are sceptical about the reliability of non-scientists' observations (Berkes 2002; Huntington 2000). Heikkinen (2017) interviewed smallholders of the Quillcay catchment and also found that overall they perceive a reduction in precipitation that causes them loss of crops. Comparing to measured data, she also concludes that the losses in agriculture might rather be due to the increasing irregularity of rainfall than to the lack of precipitation. However, she also reported that most of the climatic observations of local residents conform with measured data.

The reason for the almost sole assignment of GLOFs to the rainy season remains unclear. One possibility is that people think GLOFs occur when it is raining because the GLOF event in 1941 occurred in December during the rainy season. But the interviews showed that people do no longer have that GLOF event very present, which may exclude this reason. A second possibility is that GLOFs are associated to the rainy season because they are also high flow water risks which are usually correctly connected with the rainy season (e.g. debris flows). A further possibility could be that GLOFs are associated to the rainy season because they derive from lakes containing large amounts of water. The large amount of lake water is connected with the large amounts of precipitation in the rainy season.

7.2 Risk perception according to the sample groups

The results show that the risk perception differs between and within the two sample groups *local residents* and *experts*. In what follows, a closer look is taken at the specific differences between and within the two groups and explanatory attempts to these circumstances are presented.

The interviewees' descriptions of water related risks show tendencies regarding how much and how detailed each group narrates about which risk. Regarding the rainy season risks, both the local residents and experts perceive heavy rain as a direct and indirect risk. But the local residents are more worried about torrential rain and its direct impacts whereas experts are more focused on the cascading processes. Concerning GLOFs and water scarcity, the experts comment more in terms of quantity and detail about GLOFs while the local residents report more and also more precisely about water scarcity. This suggests that GLOFs are more of a concern for experts whereas water scarcity rather worries local residents. Poor water quality is primarily mentioned by the local residents from Coyllur who are most aware of the problem while few experts comment on the issue. The question after the most important risk allows to identify clearer differences between the groups which partly support the general tendencies. The experts assess GLOFs and water scarcity similarly often as the most important risk whereas local residents mention water scarcity by far the most. Further, water quality, heavy rain, and conflicts are also mentioned as the most important risk. Few local residents and experts share the opinion that GLOFs and water scarcity are equally important risks.

However, these statements do not apply to all members of a group to the same extent since the groups are very heterogeneous. Within the group of the local residents, there are members whose perceptions rather correspond to the general tendency of the expert group and vice versa. Furthermore, the general tendency of each groups' perception does not extend over the whole findings. In particular, the first mentioned risk reveals contradictory results.

This chapter responds to the research question *"To what extent do the perceptions of local residents and experts differ?"*. It demonstrates that the perceptions of the local residents and the experts differ to a great extent. There are differences in the perception of the direct and cascading impacts of rain, GLOFs, water scarcity and water quality. The local residents perceive direct impacts of rain more severe than cascading impacts and vice versa for the experts. The local residents perceive water quality as a higher risk than the experts. However, both groups are very heterogeneous and the described differences do not apply to all members of a group to the same extent.

7.2.1 Sample groups

The expert group is more heterogeneous than the local residents group. This can be seen in the results of the first mentioned and the most important risk. A possible reason for this might be the more diverse background of the experts. The experts work in institutions with different fields of activity such as technical work, social orientated activities, and mixed forms. These fields are very likely to influence the perception of risks as it probably makes a difference whether the experts are in contact with the local residents or not during their work. Moreover, there were differences observed within the institutions. The interviews with two different experts from each ALA, INAIGEM and INDECI have shown that they do often not agree on each other. In comparison, the local residents' perceptions are more similar. This might be explained by their main occupation since they all are farmers. But still, differences exist within the local residents group. This could be explained by their different part time jobs such as mountain guide or carpenter that can extend their risk perception. Moreover, they live in different villages that are differently influenced by environmental conditions. This is very clear in the case of the bad water quality that only affects residents from Coyllur or partly Nueva Florida. Further, there also exist different perception within villages. Due to the steep topography, the perception of water scarcity depends on the elevation within a village. Villagers who live at a higher elevation closer to the mountains and hence to water resources are able to withdraw the amount of water wanted while people who live further down are faced with the consequences. The heterogeneity of perceptions between and within the two interviewee groups suggests that the heterogeneity is generally high. The findings of Jurt el al. (2015) support this view. They state that perceptions of local residents are as heterogeneous as the local residents themselves.

Initially, the research questions were set up to clearly separate the perceptions of local residents from those of experts. Though, a finding of the study is that the perceptions cannot clearly be separated into two groups.

7.2.2 Knowledge debate

Explanatory approaches for the impossibility to clearly separate the perceptions into two groups can be found in the debate about risk knowledge. Knowledge of natural hazards has often been divided into the opposing groups of experts and laypersons declaring the experts knowledge as the 'right' and the laypersons' as the 'erroneous' knowledge (McCarthy et al. 2007). The results of this study show that the categorisation is not uniformly applicable and that the dichotomy should be overcome as several authors suggest (Agrawal 1995; Barth 2002; Cruikshank 2005). The critique on the overemphasising of expert knowledge (Dessai et al. 2004; Slovic 2000) is also valid here as some experts have shown not to represent environmental and social circumstances. For instance, they ascribe the GLOF risk primarily to the rainy season and few do not recognise water scarcity as an issue in the Quillcay catchment. Instead, most local residents are familiar with the situation of the environmental and social conditions. Especially when talking about water scarcity, the local residents seem to be better informed than many experts. The expected divergence between the experts' and laypersons' knowledge did not show to be the case.

Furthermore, it is to consider that the distinction of the interviewed expert between 'expert' and 'private person' is hard (Bogner et al. 2002) why also the stated perspectives are a mixture between institutional and private knowledge. This further weakens the dichotomy.

7.2.3 Place of residence and work

An explanatory approach for the interviewees' risk perception is a spatial factor. The respondents' places of residence and place of work have shown to essentially influence their risk perception (see Figure 22). If an interviewee lives and works in a rural or in an urban area considerably influences the statements regarding water related risks. This circumstance consolidates the division between the perception of the local residents who live in rural areas above Huaraz in close proximity of the mountains and the experts who live in urban areas of Huaraz or other cities. The majority of the experts live in Huaraz and few in Lima and Cusco while the local residents live in the villages of Yarush, Llupa, Coyllur and in the municipality of Nueva Florida. The latter has a special role since it is situated in the transition zone from rural to urban area. For the local residents, the place of residence almost fully coincides with their place of work. Except for the residents of Nueva Florida, who have their fields in another place, the small-scale farmers have their fields within the reach of their village. Therefore, their life predominantly takes place in the range of their village. The experts' offices, which are located in urban areas, also do coincide with their place of residence. But in comparison, the activity area of some experts' jobs goes beyond urban areas up to the headwaters of catchments and also to catchments outside the Quillcay catchment in other parts of the Cordillera Blanca.

The villages as places of residence and work, influence one's risk perception in the following way. First, the direct impacts of heavy rain are perceived as dominating because they damage rural infrastructure such as roads for example. Second, GLOFs are not so much of a concern for the local residents since their houses are out or reach of a potential flow path. Third, any change in water resources is noticed immediately as the villages are not connected to the water supply system of the city but directly obtain water from rivers and springs. Thus, no distribution system can balance their water supply and water scarcity is rapidly perceived. Last, bad water quality is perceived by those who live in Coyllur since this village is situated in the Quillcayhuanca catchment and obtains naturally contaminated water from the Auqui river.

Living and working in urban areas affect risk perception as follows. The experts do not feel the direct effects of torrential rain to the same extent since they live in cities where infrastructure like roads are generally made of more stable material. However, they are more familiar with cascading impacts of rain since their work also brings them outside of the Quillcay catchment to

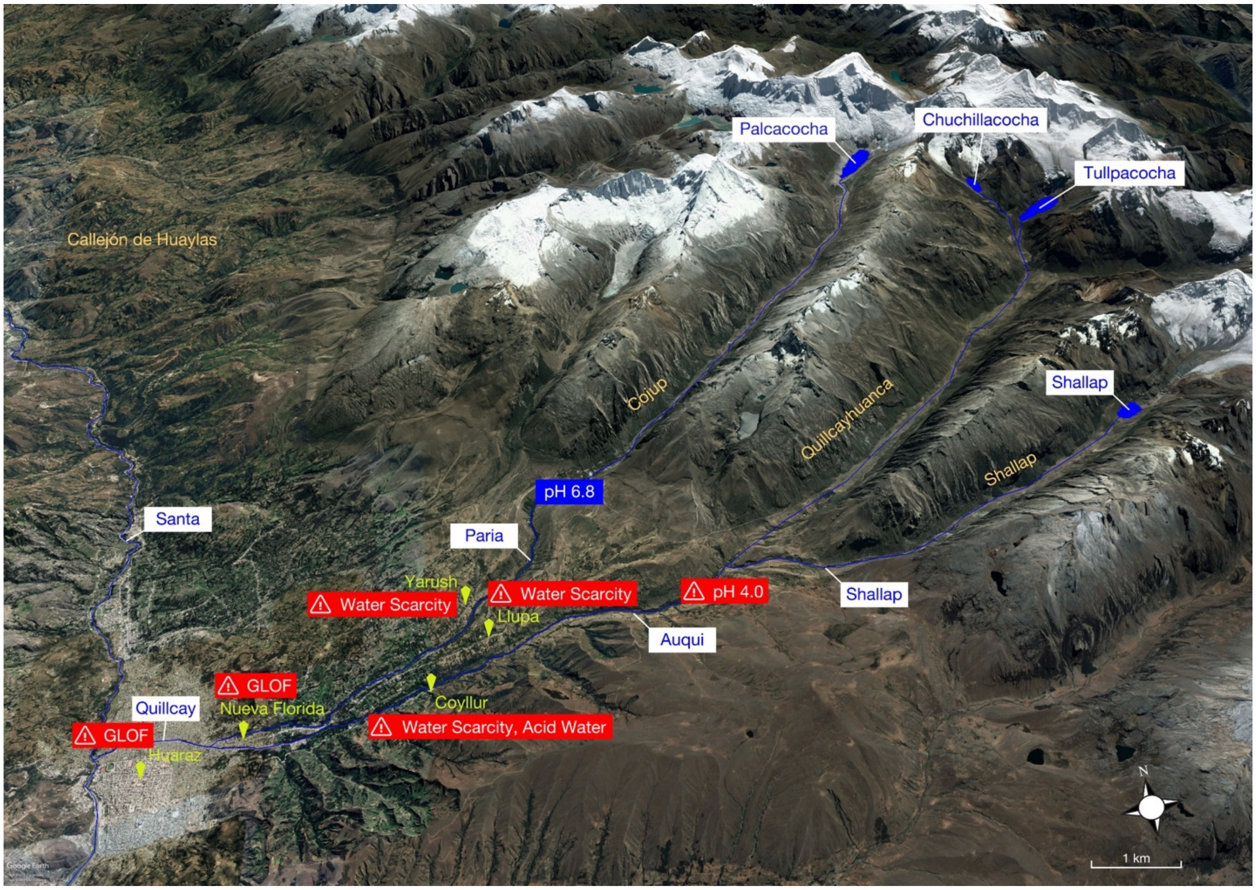

Figure 22 The Quillcay catchment with high and low flow water risks. GLOF, water scarcity and water quality are indicated according to their spatial distribution. Source: Google Earth 2018, edited by the author

other parts of the Cordillera Blanca, where more of those events occur. As a potential GLOF event would mainly hit the centre of Huaraz and some of the experts' houses and offices, it worries them much. Individual urban residents, like the experts, do not feel a change in water quantity and quality as quickly since they obtain water from the municipal water supply. It extracts its water from the Paria river and is able to balance water supply to some extent.

Thus, the physical place of residence and work determines to a great extent how water related risks are perceived. So the environment of rural villages creates a focus on perceptions of direct impacts of heavy rain, water scarcity and quality while an urban surrounding emphasises the perception of cascading impacts of rain and GLOFs. This mirrors the actual threat of water scarcity in the rural areas and GLOF risk in the centre of Huaraz.

7.2.4 Subsistence activity

In addition to the places of residence and work, interviewees' work itself has an effect on the risk perception. Through the formation and experience of the corresponding work, respondents amplify their perception of specific risks. This situation further consolidates the division between the local residents' and the experts' risk perception since the local residents mainly work in farming and the experts work in water and risk management. Therefore, the respondents' subsistence activities further influences the perception of rainy season risks, GLOFs, water scarcity, water quality and the assessment of the most important risk.

Farming activity impacts risk perceptions in the following way. The local residents, who are all famers, perceive the direct impacts of torrential rain strongly since it harms their fields. Moreover, few local residents have been at the Palcacocha lake and neither have they studied nor worked in this field to assess the actual threat of a GLOF event professionally. As a result, the Palcacocha lake and hence the source of a GLOF is far away from their daily lives and probably also from their mind. Expert 18's (Wayintsik) statement visualises the situation aptly by saying "a GLOF is something remote, which may not even pass"[34]. The low probability of occurrence of a GLOF event may also hamper a pursuant risk assessment for the local residents since it is harder to imagine impacts of an event that rarely occurs. Due to their farming activity, which highly depends on water, the local residents notice changes in water supply on a daily basis and thus water scarcity is perceived quickly. The water quality is decisive in farming and so are changes noticed rapidly.

Work in water and risk management influences risk perception as follows. The experts are more familiar with cascading impacts of heavy rain since they work in this field. Their studies and work experience help them to assess the GLOF risk more accurate. For example, they can assess the probability based on scientific documents and reports. Furthermore, some experts have already been at the Palcacocha lake and were able to see and assess the situation at first hand. The experts' jobs do not depend on water but they might have heard of water scarcity and poor water quality through their work in water and risk management.

As shown, farming activity mainly extends the perception of direct impacts of heavy rain, water scarcity and quality. On the other hand, jobs in water and risk management broaden the perception of cascading impacts of rain and GLOFs, and partly also water scarcity and quality. Combined with the places of residence and work, a difference between the local residents and the experts can be observed. For the local residents, the two aspects evoke similar perception patterns. For the experts, the risk perception gained through their place of residence and work could be

[34] "un aluvión es algo remoto, que tal vez ni pase"

extended by their jobs. Thus, a greater awareness of water scarcity and quality could be expected. However, this is not always the case.

Considerations on spatial and social factors

When arguing with someone's place of residence and work, the local residents cannot be blamed for their lack of knowledge about GLOFs as either their place of residence nor their subsistence activity has anything to do with it. In comparison, even though experts are not yet affected themselves in their place of residence by water scarcity and bad water quality, they could be better informed about the problems existing in villages due to their work in water and risk management. Especially those working with water management could have known the problem since their work should address these topics. In addition, they could have heard of the problem from hydropower companies which notice the reduction in water amount and quality as well. Strangely enough, the experts, who state that water scarcity is not a problem in the Quillcay catchment or not a problem at all, are part of the National Institute of Civil Defence, the National Institute of Glacier and Mountain Ecosystem Research and even the National Water Authority. These are the institutions in whose field of work the observation and even the management of changing water resources should be included.

Byg and Salick (2009) also found that the perception of climate change impacts varies with location. Local residents' perceptions were significantly related to the village people lived in. Additionally, they also identified that the subsistence activity of local residents influences their perception of climate change impacts. Jurt (2009) also stated that perceptions vary between villages on a very local scale.

To summarise, the answer is provided to the research question *"How can differences or similarities between local residents' and experts' perceptions be explained?"*. The differences between the local residents' and the experts' perceptions can be explained by considering dimensions beyond the mere characterisation of the physical risk. Economic, social and cultural aspects can explain why the local residents and the experts perceive low and high flow water risks differently. For that purpose, the interviewees' places of residence and work was analysed. It shows that it makes a great difference in perception whether an interviewee lives in a rural village or in the urban centre of Huaraz. The rural environment influenced the interviewees to perceive water scarcity as the more important risk. On the other hand, the urban surrounding leads to a stronger emphasis on GLOFs.

7.2.5 Most important risk

The risk that the interviewees assessed as the most important may also be explained by their places of residence and work and subsistence activities. The local residents mention water scarcity the most by far because it is the water related risk that dominates their daily lives. The experts similarly often mention water scarcity and GLOFs as the most important risk. This mirrors, on the one hand, their place of residence and work, where they perceive the threat of GLOFs, and on the other hand their additional experience in water related risks due to their work in water and risk management.

The question after the most important risk aimed at detecting which high or low flow risk, namely GLOF or water scarcity, was more important for the respondents. Nevertheless, the interviewees mentioned water quality, which does not fit into the categories of water scarcity or GLOFs since it is neither a low nor high flow risk and it does not depend on a season either. The terminology might have influenced that outcome since both groups did not understand low and high flow risks. This is why water related risks in general were addressed during the interviews and the division according to seasons was adopted with time. Moreover, it might also be the severity of the bad water quality that lets respondents overlook any categorisation and just mention it as they think about water. Findings on the role of water support that explanation since local residents from Coyllur promptly mentioned bad water quality when talking about water in general.

The answer to the research question *"Which low or high flow water risk do local residents and experts perceive as the most important one?"* is compiled as follows. On the one hand, it consists of the interviewees' statements about what they considered to be the most important risk and on the other hand of the analysis about the interviewees' statements over the entire interviews. The vast majority of the local residents stated that they consider water scarcity as the most important low or high flow water risk. Further, few times GLOFs, water quality, heavy rain and earthquakes were mentioned as the most important risk with decreasing frequency. Equally frequent as GLOFs, it was stated that GLOFs and water scarcity are equally important. The statements correspond to the observations made during the interviews in which the local residents tell more and in more detail about water scarcity and its causing conditions and consequences than about any other risk. Therefore, it is assumed that water scarcity is the most important risk for the local residents. The majority of the experts also state that the most important risk is water scarcity. Thereafter, GLOFs, GLOFs and water scarcity, water quality, earthquake, heavy rain and conflicts are mentioned. However, the experts' statements throughout the interviews and the context of the institutions work revealed that GLOFs are equally if not more important than water scarcity.

This allows the conclusion that GLOFs are the most important risk for the experts. Overall, it can be concluded that the local residents perceive water scarcity and the experts GLOFs as the most important risk.

7.2.6 First mentioned risk

The first mentioned risk shows contradictory results in comparison to the most important risk (see Figure 19 and Figure 20). This represents the general tendency of the interviewees' risk perception. The most important risk exposes a similar importance of water scarcity and GLOFs for the experts and a much higher importance of water scarcity for the local residents. A contrary

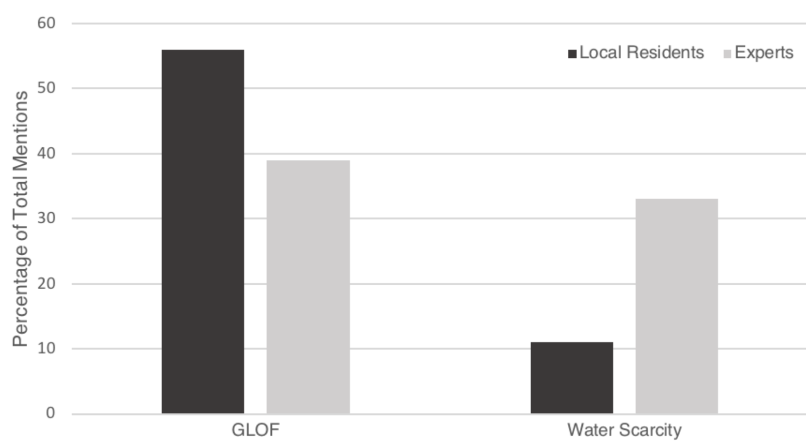

Figure 23 Extract of the first mentioned risk (compare to Chapter 6.2.1).

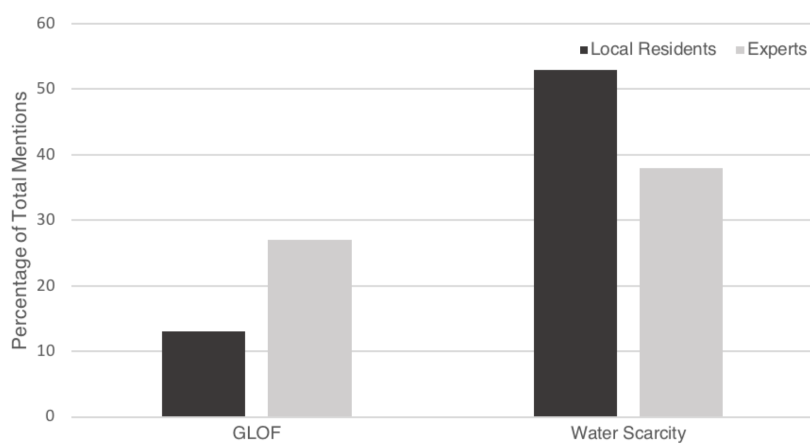

Figure 24 Extract of the most important risk (compare to Chapter 6.2.5).

pattern is shown in the initial phase of the interview in which the role of water and the water related risks were assessed. There, the interviewees preferentially mention GLOF while water scarcity has a minor importance. Moreover, the experts display a more balanced situation as their mentions do not differ strongly. In this context, several local residents did not address water scarcity by themselves when talking about the role of water or water related risks. They only started to explain the problem once the interviewer raised it. The attempt to explain these circumstances provides insight into the notion of hazard and risk, as well as the interaction effect between the interviewee and the interviewer.

7.2.7 Risk terminology

The comparison between the first mentioned and the most important risk indicates that the used terms and the course of the interview had probably influenced the interviewees replies. This is especially valid for the replies of the local residents. Hence, at the start of the interview they responded differently than later on. The reason for the outcome of the first mentioned risk might lie in the introduction of the interview. At the beginning, the interviewees were informed that the following interview will address water related hazards in the Quillcay catchment[35]. Then, during the interview with many local residents, water scarcity had to be addressed by the interviewer. For these reasons, at the moment when being asked about which risk worries them most, they were aware of the whole range of risks which could be mentioned. So, probably the usage of the term *hazard* and the increasing range of risks introduced during the interview might have influenced the change of the local residents' answers along the course of the interview.

Apparently, the interviewees and in particular the local residents mention the term *hazard* to high flow or sudden onset risks like GLOF or debris flow. They happen suddenly and involve a large amount of water. Instead, low flow or slow onset risks such as water scarcity do not seem to be related to the term *hazard* for them. They refer to it as a type of problem. They used the term *problem* or '*the water problem*'[36]. For the experts, this effect is not so strong since the difference between the mentions of the first and the most important risks showed to be less distinct. Probably they are more familiar with the terms hazard and risk due to their vocabulary in their job. Nevertheless, they also used the term problem when referring to water scarcity. Eventually, the flow and the onset type also affect the perception of the risk's severity and the need for action.

Richardson and Reynolds (2000, p. 31) state to this "some glaciological phenomena can have significant impacts upon society over a short time scale (minutes-days), such as ice/snow avalanches and glacial floods. Other related hazards can be equally serious but less obvious when considered on a much longer time scale (months-years-decades), such as glacier volume

[35] 'peligros con agua'
[36] 'el problema del agua'

fluctuations leading to water resource problems". But the present study suggests that unless somebody has personal experience with a risk, for example local residents with water scarcity, high flow and sudden onset risks are perceived as more severe and where the need for action is seen to be more urgent.

It can be concluded that mainly for the local residents, low flow and high flow and slow or sudden onset risks are not perceived as belonging together. As an implication, the usefulness of the direct comparison of both types of risks is debatable. The comparison of low and high flow water risks, or slow or sudden onset risks seems to be rather difficult for the interviewees since the risks' dimensions of time and space differ strongly.

7.2.8 Interaction effect

Another approach to an explanation for the difference between the first and the most important risk is the interaction effect between interviewer and interviewee. Bogner et al. (2002) allude to the reaction of interviewees on the interviewer. Interviewees may respond according to their imagination about what the interviewer might expect to hear. In this case, the interviewees were told that the interviewer comes from an university background researching in water related risks. Hence, they might have wanted to reply what they thought the interviewer expected to hear. From their point of view this might have been the high flow risks which is why they mentioned them right away and neglected low flow risks even though they were shown to be more important to them. Findings of Walker-Crawford et al. (2018) also point to an interaction effect. Although they received similar results about the perceptions of local residents in the Quillcay catchment, the course of the interviews proceeded differently. Opposed to the present results, water scarcity was mentioned immediately in their interviews while GLOF risk had often to be raised by the interviewer. This might be related to the different researchers and their different thematic approach in interviews. Walker-Crawford et al. proceeded from water resource use and not from water related risks.

Moreover, the experts may have wanted to convey a specific strategic agenda (Meuser and Nagel 2009) that probably also influenced their statements. But unlike the local residents, the interaction effect might have increased the experts' mentions of low flow risks. For example expert 14 (INAIGEM) emphasised the severity of water scarcity and bad water quality for the local residents and put great importance on the close interaction with them when working on this topic. But research at the study site and statements of the other expert of the same institution (expert 13, INAIGEM) showed that the priorities of the institution's activities were rather on the investigation and management of high flow risks like the potential outburst of the Palcacocha lake. The document study of Walker-Crawford et al. (2018) supports this assumption as the focus of institutions' adaptation strategies lies almost solely on high flow risks and neglects low flow risks to a great extent.

7.3 Implications of the findings

The divergence of the perceptions of water related risk between the two sample groups suggests a situation that is not satisfactory for all stakeholders. The technical experts are responsible for the implementation of adaptation measures. Since they do not fully recognise the local residents' problem of water scarcity, they fail to provide the necessary measures to adapt to the problem. Instead, they rather focus on the implementation of GLOF measures. On the other hand, the technical experts are frustrated because they struggle to explain the relevance of GLOF risk to the local residents.

Important in this context is the consideration of the expert's knowledge and its implication for practice. As Bogner and Menz (2009) state, an expert is able to put his or her interpretative knowledge into practice and thus has power on decisions. In the present case of water and risks management, the experts' interpretative knowledge decisively influences the implementation and execution of adaptation measures. In this regard, the overemphasising of the experts' compared to the local residents' knowledge has particular importance. The hegemony of the experts' knowledge results in the implementation of measures which do not correspond to the circumstances reported by the local residents or shown by measured data.

The considerations of this chapter lead to the response of the research question *"To what extent do differences in perceptions between local residents and experts entail consequences?"*. For the local residents, the differences in perceptions entail consequences to a greater extent than for the experts. Since the experts are able to influence risk assessment and consequent adaptation strategies, their perception is influential in decisions on the implementation of adaptation measures. As a result, the local residents lack adaptation in the risk that they perceive as the most important one.

7.4 Risk perception according to theories

This section puts the findings of the present study into context with risk perception theories presented at the outset. This contextualisation aims at better understanding the differences of the interviewees' risk perceptions. The technical-scientific approach which signifies that the perception of risks is 'inherently subjective' (Gebrehiwot and van der Veen 2014) is shown not to be valid for the present research results. To some extent, the findings can be explained by the constructivist and cultural theory approaches which imply a social and cultural contextualisation of risk perception. To understand which risk is the most important for which sample group, will be illustrated with the risk networks (Jurt 2009) as follows.

7.4.1 Risk networks

The concept of risk networks (Jurt 2009) implies a more encompassing risk perception which should not solely see natural hazards as a product of natural processes but embedded in the context of social, cultural, economic, and political risks. New is the focus on the interconnection of these risks, i.e. the risk networks. So it is important how the perception of one risk influences the perception of other risks and vice versa. As a result, a risk perception analysis should not just consider the causes and consequences of a single risk but its embeddedness in further risks. The encompassing view of natural hazards is insofar interesting as it helps to explain why on a scale of the Quillcay catchment people face similar patterns of natural hazards but do not necessarily perceive them similarly.

The concept of risk networks allows to explain the different perceptions of risk between the local residents and the experts. It shows that for the local residents water scarcity is perceived as a high risk because it is interconnected with the economic risk of not being able to produce their main source of income: crops. The barrenness stands in further connection with the social risks of potential conflicts and migration. On the other hand, for the experts, there would be the risk of shortage in drinking water. Since the fewest are aware of this connected risk, water scarcity is not perceived as a high risk. When it comes to GLOFs, there does not exist a connected risk for the local residents. This might explain why they are not very worried about the GLOF itself. Whereas for the experts, there are many connected social and economic risks such as the loss of their houses and lives. This influences their perception of GLOFs. As showed, the interconnections of the risks illustrate why a risk is more or less relevant for an interviewee.

7.5 Contribution to the scientific debate

This study contributes to several areas as shown as follows. The approach itself and the investigated contents try to fill several gaps. The approach adopted complies with the call on more transdisciplinary work by including different disciplines as well as local knowledge. It is a qualitative social science study incorporating inputs from climate change and glaciology studies in high mountain area. This allows to assess and view results from different perspectives and gain insights into local perceptions that are crucially important to implement promising adaptation strategies. The qualitative semi-structured interviews enable insights from within communities. These are important to understand local perceptions and responses to climate change impacts. The study's content is insofar contributing as it tries to fulfil the demand for more research on human impacts of climate change and at the same time addresses the less explored low flow risks. But there is not a sole focus on low flow risks. They are looked at in combination with high flow risks in form of an integrated assessment. Furthermore, the perception of glacial high and especially low flow risk is investigated which so far has rarely been done. Lastly, the interview findings also add to the knowledge about local patterns of climate change and its impacts. These might encourage new hypotheses and research questions.

7.6 Limitations to the study

This section discusses some limitations to this study by reflecting on the representativity, the methods, the language and the positionality.

Representativity

First and foremost, it is to say that the study is not representative. The sampling number of 31 interviewees does not allow to draw fundamental conclusions on the whole society. Nevertheless, the written and graphically represented results are valid as an insight into the spectrum of perceptions of the local residents and experts in Huaraz and can probably be extended to the scope of the Cordillera Blanca. However, the findings are not generally applicable even within this scope as for example male interviewees dominate the sampling and female interviewees are underrepresented. A gender balance was initially intended but the access to women was hard for the local residents and most of the experts are male resulting in more men that were interviewed.

Methods

The snowball sampling might have delivered biased results because the approach to access new interviewees is based on recommendations from previous interviewees. In this study, it seemed to result in a range of interviewees with similar opinions. This becomes visible when comparing the present results to findings from Walker-Crawford et al. (2018) that show slightly different tendencies within the same research area (Cojup and Quillcayhuanca microcatchment). One of the reasons for the differing outcomes might be the different sampling.

Language

The language was also a limitation since the interviewees and the interviewer did not speak the same first language. This might have led to misunderstandings from the start. Then, the language may have led to further interpretation steps during the interviews and during other work steps of the study like the translation of citations. For this reason, the original citations are stated in the footnote to avoid misinterpretations. Generally, conducting the interviews in Spanish worked very well with the experts and also with most local residents even though their first language is

Quechua. Only in the interview with informant 7, a female farmer from Llupa, the Spanish language imposed a greater barrier in communication. It seemed that she did not feel very comfortable communicating in Spanish. This affected the course of the interview.

Positionality

During research, a researcher takes a certain position and thus influences the outcome of the research. "(…) as a means of avoiding the false neutrality and universality of … academic knowledge" it is important to identify and situate the researches' position within the research (Rose 1997, p. 306). Especially for researchers working outside their own cultural context, this consideration is important since they bring their own ideas of cultural normativity. In particular, when researchers from Western countries work in other parts of the world, they tend look down (Rose 1997). To avoid this, this issue was best possibly reflected. The influence of the researchers' position becomes especially biasing when conducting interviews because then, the research objects react to the researcher. The interviewer felt she was perceived in two different ways: as a female and as a foreign researcher from Europe. The two roles interacted resulting in one or the other role being in the foreground. During the interviews with the mostly male experts, the female role seemed to be dominating especially in the beginning. However, as the interview went on, the role of the foreign scientist often took over. With the local residents, the foreign researcher was the predominant role while the female role was secondary. This might be an explanation why it was difficult to approach local women. The outcome of the interviews might have been different if the researcher was not female and not European.

7.7 Outlook

This section indicates the omissions of the present study and the recommendations for further research as well as for practice.

Omissions

Due to the limited temporal and financial frame, the study had to focus on the relevant topics. At the same time, it had to omit further interesting topics. This concerned the data acquisition and in particular the data analysis. One omitted topic is the perception of adaptation strategies that the interviewees consider to take regarding the investigated high and low flow water risks. A further topic is the perception of climate change in general, going beyond the perception of water related risks.

Recommendations for further research and practice

Considering the limitations to this study, a different and larger sample, a different sampling method and an inclusion of Quechua are suggested. The use of Quechua would facilitate the access to local women, which are underrepresented in this work. The sample could be adapted to gain deeper insight either in the local resident or the expert sample group. A larger sample could include urban residents of Huaraz that were not included in this study. These approaches may allow to gain a more differentiated view on the topic and therefore better understand the situation in the Quillcay catchment. Further, it may increase the representativity of the research and conclusions with a higher claim to validity could be drawn. Moreover, similar research could be conducted at another study site to broaden the perspective on the topic.

Since this study is only a minor contribution to the stated research gaps, a further pursuit of those is valuable (see Chapter 1.1). In particular, the focus on local insights and the consideration of social, cultural, economic and political dimensions when investigating risk perception is recommended. This helps to better understand all stakeholders leading to an improvement of future adaptation strategies. In this process, a transdisciplinary approach is indispensable.

Drawing on the results of this study, it is highly recommended that the experts should consider the local residents' perceptions.

8 Conclusion

The study analysed the perception of high and low flow water risks of two sample groups of *local residents* and *experts* in the Quillcay catchment, Cordillera Blanca (Peru). The analysis of qualitative semi-structured interviews showed that the notion of water evokes manifold connotations for the interviewees, from water being beneficial to detrimental. High flow risks such as GLOFs were assigned to the rainy season and low flow risks like water scarcity to the dry season. However, differences were observed between the perceptions of the two groups. The local residents perceived water scarcity as the most important risk by far and ascribed minor importance to GLOFs. On the other hand, the experts perceived water scarcity to be only slightly more important than GLOFs. One striking observation was that some experts did not even consider water scarcity to be a problem in the Quillcay catchment. Thus, a discrepancy exists between the perception of water scarcity by the affected local residents and the experts. This is also reflected in the main topics of the interviews. The local residents predominantly reported on water scarcity, whereas experts had a stronger focus on GLOF risk. Moreover, the qualitative analysis showed that poor water quality is an important aspect, since it is perceived to be a more severe problem than GLOFs and water scarcity by some interviewees. Differences in risk perceptions were also found within the two groups, which suggested that perceptions are strongly heterogeneous. Furthermore, ambiguities existed among the experts regarding the definition of risk. In a few cases, experts even lacked a proper definition.

The perceptions of the impacts of climate change by both the local residents and the experts were largely in line with scientific data. Rising temperature, retreating glaciers, declining discharge were some of the perceived changes. However, their perception of declining precipitation and the assignment of GLOFs to the rainy season did not correspond to measured data.

The different perception patterns between and within the two sample groups could largely be explained by the local residents' and the experts' places of residence and by their subsistence activities. Living in a rural village was shown to increase the perception of low flow risks such as water scarcity, while living in an urban surrounding such as Huaraz increased the focus on high flow risks like GLOFs. In addition, farming activity amplified the interviewees' awareness of water scarcity, whereas working in risk management heightened their perception of GLOFs.

The difficulty arising from this situation is that the perception of each group affects practice to a different degree. The experts' perceptions influence decisions on the implementation of adaptation measures, whereas the local residents' perceptions do not have such an effect. Therefore, the experts' emphasis on GLOFs entails a focus on GLOF measures. This leads to a lack of support for adaptation measures against the risk that the local residents perceive as most important, water scarcity.

Therefore, it is recommended that local residents should be included for further comprehensive investigations of risk perceptions. Social, cultural, economic and political dimensions should be considered to a greater extent in the future to broaden the understanding of risk perceptions. A more complete consideration of these aspects can hopefully enhance the effectiveness of future adaptation measures, and simultaneously prevent conflicts. The destruction of the early warning system at lake no. 513 showed vividly that an encompassing assessment of local residents' risk perception is necessary for successful adaptation strategies.

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10 Appendix

10.1 Interview guideline experts

Guía de entrevista: entrevista experta con representantes de instituciones que se ocupan con agua y con riesgo

Interés	Preguntas abiertas	Posibles preguntas de profundidad
Introducción		
	• Soy Angela de la Uni Zürich, trabajo con Christian • Proceso: yo voy a hacer preguntas y usted responde • Le parece bien si grabo? • Tema, ámbito de trabajo: • (Si le parece bien voy a indicar la institución y su puesto, prefiere salir sin o con nombre?) • Importante: como respuesta no hay correcto o falso • Siempre pregunte cuando algo no está claro • Al finalizar la investigación les voy a compartir mi trabajo y un resumen en español	• Tema: me interesan los peligros hídricos de la región y como ustedes los manejan. Es importante conocer los diferentes puntos de vista para mejorar el desarrollo de medidas adecuadas • [Cuales peligros hay, cuales son los mas importantes] • Ámbito: las montañas altas, la Cordillera Blanca con un enfoque en la subquenca Quillcay (estudio de caso)
Risk framing of hydrological hazards		
Framing of low and high flow water processes	• Si hablamos de agua, que es lo primero que le viene a la mente?	• Que peligro con agua le viene a la mente? • En la época de lluvias? • En la época seca?

		• Algo ha cambiado en los últimos años en relación a esto peligros? • Porqué ha cambiado?
¿En qué medida estos peligros de agua representan un riesgo?	• Cual de estos eventos afecta a la población?	• En la época seca/ de lluvias? • A quien mas afecta? *Gente rural/urbana* • Porque?
	• Se puede decir cual de estos eventos es el mas peligroso/dañino?	• Cual es el peligro que le preocupa mas? • Porque? • En que peligro ustedes trabajan mas?
Concepto de riesgo	• Y hablamos de peligro y de riesgo, como institucionalmente definan estos términos? *(técnicamente)*	• Y para su institución, que exactamente es ... y ... ? *peligro, vulnerabilidad* • Como evalúan este tipo de peligro/riesgo?
Adaptation		
Adaptation strategies for low and high flow water risks	• Cómo enfrentan los peligros de agua? A nivel técnico, social, político?	• ¿Tienen una manera definida de enfrentar estos peligros? • ¿Hay algo en esta área que se debería cambiar según usted?
Different perceptions of risk		
Difference to local people	• Como piensa que los residentes locales perciben estos peligros?	• Los de la zona urbana? • Los de la zona rural?
Consecuencias	• Y eso es un problema que ellos piensan diferente?	• Debería cambiar algo?
Razones	• Como cree que esta percepción diferente se formó?	• Y porqué?
Confianza	• Porque no confían?	• La gente local a las autoridades?

		• Las autoridades a los científicos (extranjeros)?
	Cuando no menciona la escasez	• Usted, que opina sobre la afirmación que las sequias preocupan la gente mas que los aluviones?
Conclusión		
	• finalizar	• Tiene usted alguna pregunta para mi? • Algún comentario adicional?
	• Información personal	• De donde es usted? Edad? Cargo? • Datos de contacto?

10.2 Interview guideline local residents

Guía de entrevista: entrevista episódica con residentes locales

Interés	**Preguntas abiertas**	**Posibles preguntas de profundidad**
Introducción		
	• Soy Angela • Proceso: yo voy a hacer preguntas y usted responde • De momento esta difícil de tomar notas, entonces le parece bien si grabo? • Tema, ámbito de trabajo • Importante: como respuesta no hay correcto o falso • Siempre pregunte cuando algo no está claro • Al finalizar la investigación les voy a compartir mi trabajo y un resumen en español	• Tema: me interesan los peligros hídricos de la región y como ustedes los manejan. Es importante conocer los diferentes puntos de vista para mejorar el desarrollo de medidas adecuadas • [Cuales peligros hay, cuales son los mas importantes] • Ámbito: las montañas altas, la Cordillera Blanca con un enfoque en la subquenca Quillcay (estudio de caso)
Risk framing of hydrological hazards		
	• ¿A que dedica Usted su vida? Diferentes trabajos? Familia? Donde vive exactamente? • Tiene propiedad en Nueva Florida?	
Perception of low and high flow water processes	• Si hablamos de agua, que es lo primero que le viene a la mente? • Que peligro con agua le viene a la mente? • En la época de lluvias?	• Tiene experiencias con demasiada agua o con escasez de agua? • Cuando? En que contexto? • Como es cuando no hay suficiente agua?

	• En la época seca? • Algo ha cambiado en los últimos años en relación a esto peligros? • Porqué ha cambiado?	• Porque no hay suficiente agua? • Es frecuente? • Ha cambiado en los últimos anos? • Como es cuando hay demasiado agua, es decir inundación o huayco? • Porque vienen inundaciones y huaycos? • Hacen danos? Son un peligro? Tiene miedo? Han cambiado? Porque?
	• Que rol tiene el agua en su vida? Es importante? Porque?	
Perception of low and high flow water processes as a risk To what extent do residents perceive low and high flow water processes as a risk?	• ¿El agua la percibe como un beneficio o también como un peligro? • Para quien? • Ha cambiado algo? Porque?	• ¿Para quién representan un peligro/riesgo? • ¿Qué peligro preocupan ustedes más?
	• Que es el mayor problema, escasez de agua o inundación/huayco?	
Las causas	• Es la naturaleza y/o el hombre que esta causando el problema? Como, porque?	• ¿Porque usted cree que a veces hay agua y porque a veces no?
Different perceptions of risk		
Difference to institutions	Como piensa que las autoridades ven estos peligros?	• Como los manejan?

Consecuencias	Y eso es un problema que ellos piensan diferente?	• Debería cambiar algo?
Razones	Como cree que esta percepción diferente se formó?	• Y porqué?
Confianza	Porque no confían?	• La gente local a las autoridades? • Las autoridades a los científicos (extranjeros)?
Conclusión		
	finalizar	• Tiene usted alguna pregunta para mi? • Algún comentario adicional?
	Información personal	• Edad? • Datos de contacto?

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Personal Declaration

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

Zürich, 1st October 2018

Place, Date

Signature