Disaster scenario simulation of the 2010 cloudburst in Leh, Ladakh, India

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ABSTRACT

In August 2010, Leh district in the Ladakh region of north-western India experienced a disaster when a cloudburst generated debris flows, killed hundreds of people, destroyed houses, and damaged the hospital, communication infrastructure, the bus station, and vital roads. A simulation of the Leh cloudburst disaster analysed the disaster itself, disaster risk reduction plans in the region, gaps in existing response mechanisms and reducing hazard impacts in the future. The participant group comprised academic researchers and industry experts in natural hazards, social vulnerability, engineering, historical and social sciences, education, journalism, disaster management and disaster risk reduction. Many of the participants had extensive local

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knowledge of Ladakh or comparable neighbouring Himalayan regions. Following the disaster, Leh Autonomous Hill Development Council (LAHDC), produced a District Disaster Management Plan (DDMP), which addressed many of the gaps identified in the simulation. Most importantly, the document outlined a civil protection mechanism to respond to future hazardous events. This was utilised to assess future disaster response in the simulation scenario. From analysis of the scenario simulation, the role of the army was found to be key in minimizing the impact of the 2010 disaster, although in the future, the army may coordinate with the civil protection body as set out in the DDMP. Participants identified the lack of a local formalized civil protection plan as a major vulnerability, and the most vulnerable populations as the migrant communities. The group also discussed evidence of resilience among the population such as the role of monasteries and spirituality in psychological recovery and the impact of the initial local response. From broader discussion of the simulation scenario, it was possible to identify aspects of resilience for further study in a wider research project, such as identifying hazardous slopes ~~in~~ from satellite mapping, informing the fieldwork program, designing social questionnaires to understand risk perception and formulating questions to guide focus-group discussions on community resilience.

1. Introduction

Leh district (Fig.1), in the historical Ladakh region (Jammu and Kashmir state, India), was selected as the focus of a research project designed to investigate resilience to environmental hazards in border conflict zones [1]. It is subject to multiple natural hazards such as cloud bursts, landslides, glacial lake outburst floods, fluvial flooding and extreme temperatures. The region is the grounds of several wars over territory disputes between India and Pakistan in 1947, 1965, 1971 and 1999 and between India and China in 1962. Ladakh borders Pakistan-administered Kashmir at the heavily militarised 'Line of Control', and Chinese-administered Aksai Chin at the 'Line of Actual Control'. This complex political situation makes Ladakh an important case study for the research project.

Fig. 1. Approximate location of Leh district within India and surrounding broad scale geography. Leh City is situated in Leh valley between the Ladakh and Zanskar mountain ranges near the Indus river. Map data: Google, 2018.

Disaster scenario simulations offer an opportunity to draw on multidisciplinary expertise and a pool of experience in order to analyse a historical disaster and provide a basis for further work to devise strategies for disaster management planning and efforts to increase resilience. Early in the project timeline, in February 2017, a disaster scenario simulation of the 2010 cloudburst event was placed before a multidisciplinary research team with the aim of providing a framework for sharing expertise and local knowledge about Leh. The objectives of the exercise were to (a) explore causality of impacts and damage, (b) to identify key resources and gaps in data and disaster response mechanisms, and (c) to understand vulnerability and resilience in the region and their contribution to risk. The 2010 Leh cloudburst is a well-documented event that offers a realistic scenario for a future disaster. Hence, using present-day information on the local population and its vulnerability to disaster, the scenario simulation could aid with planning a future disaster response.

1.1 Cloudburst disaster

Cloudbursts are common in the Himalayas when monsoon clouds bring extreme rates of rainfall. On 6 August 2010 (from 0000 hours IST onwards) in the Leh district during a cloudburst, rainfall intensities of 356 mm of rain in two hours were reported, although rainfall was variable along the valley [2]. It triggered numerous debris flows and significantly widened the lower reaches of the main tributary valleys.

After 24 hours, the cloudburst triggered debris flows on the sediment-laden mountain slopes in Leh City and surrounding villages of Leh District. Some 255 people were killed and hundreds were injured in Leh and nearby villages [3,4], houses were swept away and vital infrastructure was severely damaged. In the immediate aftermath emergency actions included search-and-rescue operations and temporary housing set up by the Indian army and the local community [2]. Fig.2 shows an area of Leh that was rebuilt after the destruction of the debris flows that resulted from the cloudburst event.

Fig.2. A street in Leh east of the old city. This small ravine was the origin of a debris flow that swept through the streets. Recent building and materials are clearly visible in the bottom right quadrant of the image (photo: Sonja Mueller, 2017).

2. Background of Leh

Like many regions in the Himalaya, Leh and the historic Ladakh region are remote, are subject to numerous environmental hazards, and represent complex examples of resilience, capacity and vulnerability. The social, economic and political circumstances of the population in the city and surrounding area are changing rapidly as communication and transportation networks continue to develop following the opening up of Ladakh in 1974 and the growth of tourism [5]. The city of Leh (Fig. 3) is the main urban area and seat of government of Leh district within Jammu and Kashmir state, India. The district population is 133487 spread across 21,424 households in 111 villages [6]. The city of Leh has an agricultural area (Fig. 4), a dense urban area (Fig. 5), and steep hillsides containing important historical and religious landmarks (Fig. 6).

As Leh historically has been an important trading centre for centuries, the population of Ladakh is diverse. Scheduled tribes, which are historically disadvantaged population groups, make up 72% of the population [6]. Leh has three main religious groups, a Buddhist majority (66.40%), Hindus (17.14%) and Muslims (14.2%) [7]. The city hosts large migrant populations consisting of nomads, economic migrants and refugees [8]. In addition to residents, tens of thousands of foreign and domestic tourists visit the region every year [5]. Leh is the economic hub of Ladakh. As can be seen in Figure 2C, the bazaar and commercial streets are lined with small shops that sell everyday items and with businesses related to tourism. The city is connected to the rest of Ladakh and India by two major highways, respectively to Srinagar and Manali, which are open on a seasonal basis. There are radio and television communications, mobile phone networks and an airport. According to the last census, approximately 10% of the population has no access to communications or transportation [6].

Fig. 3. Looking northeast across the valley at Leh from Stok. From this view, Leh is clearly situated on a fan, similar to many settlements across Ladakh. (photograph: Thomas Bowhay, 2017)

Fig. 4. An example of typical agricultural plots in Leh and Ladakh. This home vegetable garden in Leh is irrigated by glacial melt water distributed through a complex network of channels across the settlement. (photograph: Thomas Bowhay, 2017)

Fig. 5. The bazaar in Leh, a centre of social activity. This photograph also shows typical building styles and the density of urban areas. The foreground shows modern buildings, while the furthest back buildings are part of Leh’s old city. (photograph: Thomas Bowhay, 2017)

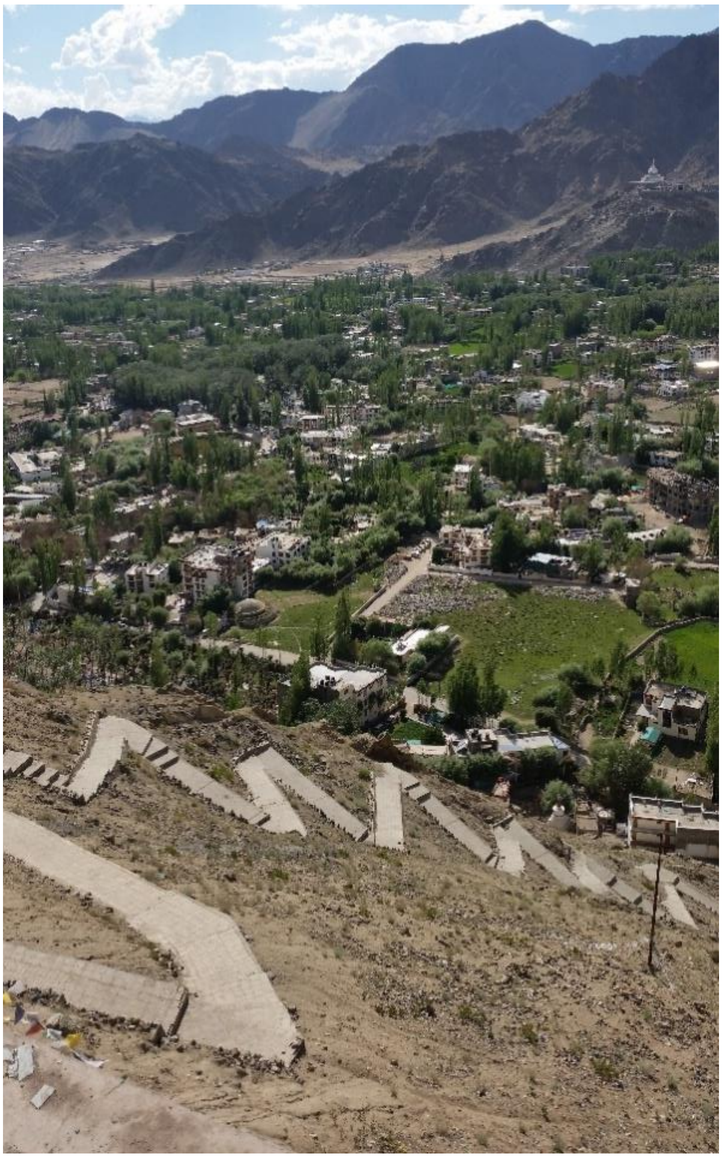

Fig. 6. This image was taken looking northwards from a walkway on the hill up to the Imperial Palace and the monastery Tsempo Gompa. The photograph highlights the steep, sediment laden slopes surrounding Leh. (photograph: Sonja Mueller, 2017)

The climate of Ladakh is a cold and dry high desert resulting from its position in the continental interior and in the rain shadow of the Himalayas (Fig. 1). Temperatures range from 33°C to -40°C and the daily winds can reach 60 km/hr. There is a single growing season from May to October, and water is a precious resource [4]. The dry climate allows buildings to be constructed of substances classified as temporary materials in the national census, such as unfired mud bricks, wood and earth. In Leh District, 67% of all households occupy temporary structures, and for urban households, the figure is higher at 86% [6].

3. Scenario methodology

Modern scenario methodology grew out of the need to plan for uncertain futures [9]. Scenarios in various forms are used across a wide range of disciplines to manage uncertainty, give economic forecasts, plan military operations, determine business strategies, and manage disasters. The essential purpose of scenario simulations is to see “aspects of the future in the past” [9]. Alexander (op cit.) discusses the development and variations of scenario methodology in greater detail, so the present summary will be brief.

Scenarios can be a valuable tool to assist decision makers and researchers in understanding the complexities and numerous possibilities of an event. By approaching a past or hypothetical event from different angles, scenarios aim to answer one or both questions of ‘what happened?’ and ‘what if..,?’ [10]. A postdictive reconstruction of events, also called backcasting, reconstructs a disaster to understand what happened and may also help understand how a similar event may be prevented in the future. Desk studies of emergency management involve simplified hypothetical scenarios that identify physical and organizational mechanisms, gaps, and lessons, and then direct these insights to policy and planning [6,8].

Scenario methodologies applied to natural hazards involve a hazard acting on a set of exposed vulnerabilities. The hazard is commonly framed as a reference event based on either a typical real event or a worst case, depending on the aim of the exercise. The exposed vulnerabilities include the population and subgroups, vital infrastructure, preparedness and available resources [6,7].

3.1 Hazards in Ladakh

Ladakh has a dramatic and fragile physical landscape with high rates of weathering and active tectonics that produce a range of hazardous events which could be modelled in a scenario simulation. Diurnal and seasonal temperature variations have resulted in the formation of a thick, loose sediment cover on the granitic terrain of the Ladakh batholith. Fig. ***7*** highlights the relief that surrounds Leh and neighbouring villages.

Fig. 7. Satellite image of Leh and the surrounding area, including the Ladakh range at the north of the image, and the Indus valley in the southwest. Leh is positioned in a small valley in the Ladakh range with few transport links, which leaves it vulnerable to the impacts of

natural hazards. The high relief in the image shows that slope-related hazards are significant in Leh and at nearby settlements. The Indus River, its small tributaries, steep relief, and a history of cloudbursts suggest that flash flooding and fluvial flooding could threaten many settlements. The few roads that connect Leh to nearby villages highlight the difficulties of the terrain, the remoteness of the region, and the critical importance of land transport routes. [11] (Map data: Google, 2018)

Small earthquakes occur frequently in the region and the likelihood of a very large, devastating earthquake is supported by geological evidence, even though no such earthquake appears in historical records [10]. Flooding takes many forms, such as fluvial flooding in the valley floors, flash floods in the mountain streams, cloudbursts, glacial lake outburst floods and landslide dam-breach floods [10, 11]. Mass movements are common, with debris flows, landslides, slumps, avalanches and rockfalls often blocking roads during periods of precipitation and extreme drought [13]. Leh and Kargil districts of Ladakh in India share contested borders with Pakistan and China. As a result, the region has a large military presence and conflict is an ever present hazard. The possibility that multiple hazards may occur together as coincidence, secondary hazards, or as a cascading disaster must be carefully considered in scenario planning

3.2 The scenario

Leh city and the surrounding villages are primarily located on slopes of unconsolidated sediments within an arid high mountain landscape in the rain shadow of mountain ranges [10, 13]. On 5th and 6th August 2010, intense rain fell throughout the night, and debris flows began at around 09:00 on the 6th, flowing through Leh city centre as shown in Fig. 8 [1, 14]. Debris flows in Leh damaged Sonam Norboo Memorial Hospital, the radio station, the main bus station, roads and electricity distribution infrastructure [1, 14]. Numerous houses were swept away by debris flows [3].

Fig. 8. Approximate location of debris flows in Leh city (after Ghosh and Parkash, 2013 [14]).

Approximately 60 surrounding villages were also affected [15]. The army base, city airport, and monastery were not damaged and remained functional [15]. The army was immediately willing and able to mobilize search-and-rescue operations, aided by spontaneous volunteers from the civilian community [2]. Tourists also participated in initial rescue operations, but most of them were evacuated.

The research team discussed the impact of this cloudburst and compared it with trends identified in the research literature, their own professional expertise and their personal experience. Generally, cloudbursts occur regularly in the Ladakh region and in the future may happen more frequently due to climate change [15]. Given that the population includes domestic and foreign migrant workers, refugees, nomadic populations and tourists [4], the trend towards a more mobile and diverse society have increased the vulnerability and exposure of the growing population in Leh to these hazardous events [2, 16, 17]. Longer-term impacts on the population include psychological distress and fear, economic impacts from reduced tourism and reconstruction, and the need to prepare for future extreme events. The location of the disaster near contested borders could limit access to affected communities or have political consequences deriving from the involvement of the Indian Army. In order to summarize relevant structures and resources in the context of Leh and Ladakh that contribute to the vulnerability and capacity of the community to respond to a natural hazard, participants were shown the illustration reproduced in Figure 6.

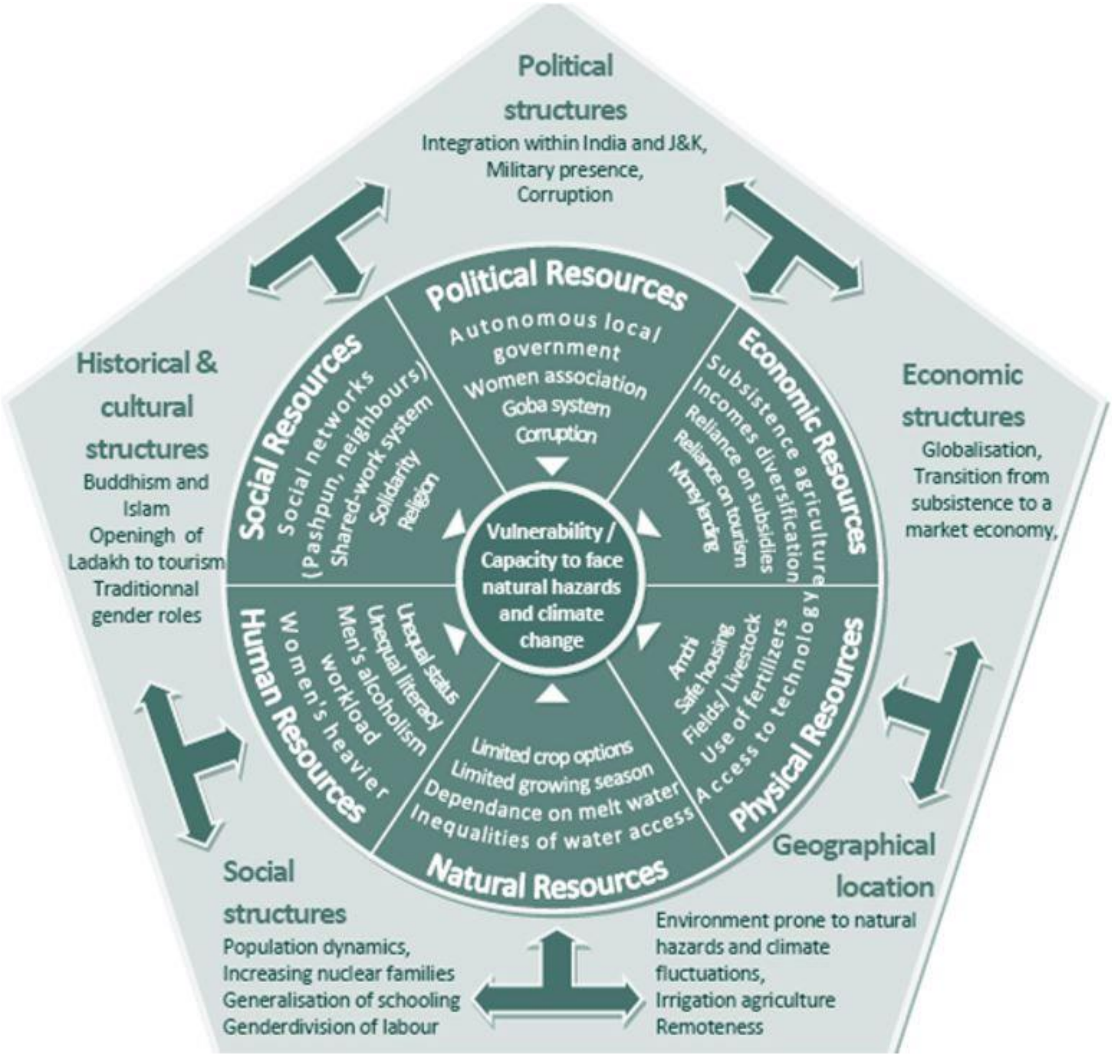

Fig. 9. The structures and resources that shape community vulnerability and resilience in Leh. This diagram was shown to discussion groups as a summary of boundary condition information to set the scene for the disaster simulation scenario. Used with permission: Le Masson, 2013 *[8]*.

4. Methodology

This disaster simulation scenario is both a desktop exercise in emergency management and an exploratory reconstruction of a past event. The scenario building process loosely follows Alexander's [16] adaptation of Schoemaker's methodology [17]. Execution of this chosen scenario requires scenario methodology, backcasting and investigation of possible futures in order to identify stakeholders and mechanisms that operate before, during and after the disaster.

It may also be necessary to look up to 30 years into the future. Figure 7 illustrates a general flow of discussion for a disaster scenario, with the main components, such as a reference event and initial conditions, evolving along a timeline and leading to evaluation of the progress of the scenario.

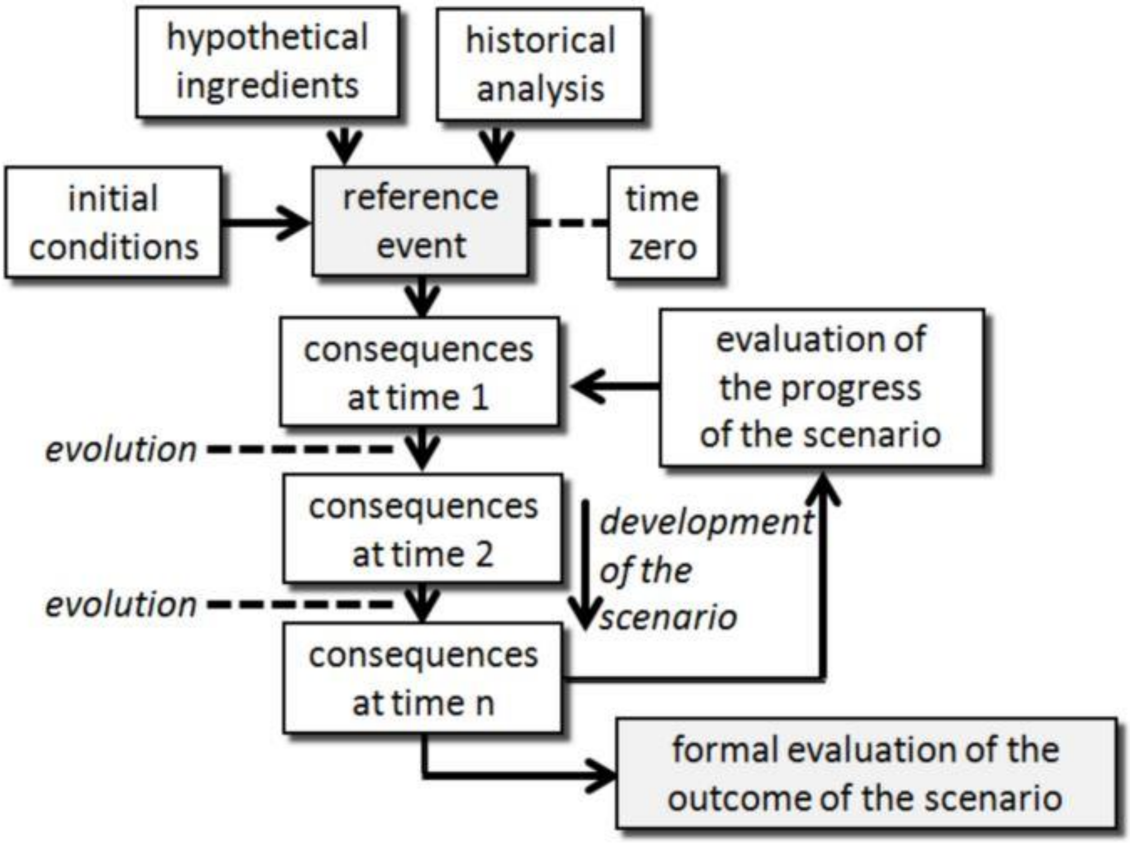

Fig. 10. Schematic flowchart of a generalized progression of a scenario with key components and processes. Used with permission: after Alexander, 2006 [9].

The ultimate objective is to share information within the research team and inform the scoping project. Hence, in this instance, the scope of scenario methodology was broadened to match the project by including resilience and secondary hazards. Also, several of Alexander's steps are posed as open questions for participants to discuss, as the aim is to explore the issues from the viewpoints of different disciplines. Broad questions and an informal methodology are appropriate in this instance, as a very limited number of scenario builders could not encompass all the possible dimensions that were covered by the participants.

Scenario participants were members of the research team, who were primarily academics and partners in the private sector. Their diverse expertise covered a spectrum of fields related to disaster risk reduction, hazards, history, vulnerability, physical sciences, education, journalism and disaster risk reduction. Many members had lived or worked extensively in Ladakh, Jammu and Kashmir State, or in the broader Himalayan region.

The 2010 cloudburst event in Leh was selected as the reference event for the disaster scenario simulation because it was recent, relatively well documented, and benefitted from the ready availability of supporting data and expertise within the group. Moreover, similar events have occurred nearby. Hence, the 2010 event was considered to be particularly significant and diagnostic of future events in Ladakh. Supporting documents to guide discussion questions, and specific documents, such as the 2011 District Disaster Management Plan for Leh, were distributed to participants so that they could familiarise themselves with the details of the event.

On the day of the meeting to formulate the scenario, the methodology and purpose of scenario simulations was presented to the participants. In order to set up the scenario and convey details about the specific hazard event and vulnerabilities in Leh, boundary conditions were introduced through presentations and visual aids (see Fig. 9, above). Table 1 summarizes some of the important conditions and details for the simulation, such as the approximate timing of the first debris flows, the map of inundation of the old city of Leh (Fig. 8), social groups in the Ladakh community, and lists of damaged and undamaged infrastructure. Additional discussion points included plausible secondary disasters, cascading disasters, the impact of climate change, and looking 30 years in the future.

Table 1. Summary of boundary conditions presented to the study group in order to outline the scenario.

The Scenario:

Key groups in Emergency Response

	Civilians	Non-governmental organizations (NGOs)
	Local government	Casualties
	State government	Homeless
	Indian army	

Timeline

	The Event	1 month later
	Next 1-2 days	1 year later
	1 week later	Beyond 1 year

Physical Boundary Conditions:

Debris flow hazard [3,4]

	Flows occurred early in the morning	255 dead
	Map is Figure 3	Hundreds injured

Damaged infrastructure [2]

	Sonam Norboo Hospital	Roads near old city
	Old Bus station	Highways connecting Leh with region
	BSNL telephone exchange	Approximately 1000 residences collapsed
	Radio station	

Undamaged Infrastructure

	Kushok Bakula Rimpochee Airport	Much of Leh
	Indian army base	Portions of villages

Social Boundary Conditions:

Religions

	Buddhism	Muslim
	Hindu	

Ethnic groups

	Indian domestic migrants	Nomads

	Tibetan refugees	Scheduled Tribes
Other vulnerable groups		
	Women	Children
	Elderly	Disabled
	Sick	Social groups without decision-making power

Looking Forward:		
Secondary and cascading disasters		
	Earthquake	Flood
	Landslide	Waterborne disease
	Winter cold	
Future Impacts [4,18]		
	Climate change	Increasing migration
	Increasing globalization	Border conflict
	Pollution (water and air)	Increasing population

To allow more opportunity for personal interaction, participants were divided into two smaller groups with facilitators. Scenario simulation discussions lasted approximately one hour, with periodic reminders of the objectives. After a short break, each group summarized its findings and participants criticised the simulation, the discussion and outcomes. The final output of the simulation involved presentations on boundary conditions, summaries generated by groups, and voice recordings. These were compiled into a report that was disseminated to the research team. The account below is a summary of this document.

5. Results and discussion

The results of unstructured discussions have been grouped thematically around the three objectives: potential secondary and cascading hazards, fortunate circumstances, and looking 30 years ahead at Leh and in other parts of Ladakh .

5.1 Cause of impacts and damage

The main causes of impacts and damage identified in the scenario included development in hazardous areas, lack of awareness of hazards among local government and the community, absence of a formal civil protection body, and absence of a formal local disaster management plan. A fortunate circumstance that limited the impact of the disaster was the lack of damage to the local Indian Army base, which allowed immediate search-and-rescue operations to take place, and civilian casualties to be treated in the Army's hospital. Without the Army's assistance, spontaneous civilian efforts would not have been able to respond fully to the impact of the disaster.

A prominent point made by both analysis groups was the lack of urban planning in Leh. After easing of access restrictions in 1974, decades of expansion have resulted in urban sprawl without limitations or guidance about building in hazardous areas. Migrants and modern infrastructure have expanded development into less desirable areas around Leh and nearby villages, turning stream beds, sediment laden hillsides, and rocky cliffs into residential areas and sites for vital infrastructure.

Discussions also highlighted the lack of a formal and organized civil protection body in 2010. Since the 2010 cloudburst, Leh has produced a detailed District Disaster Management Plan, although it has yet to be tested by a major disaster [4]. There was some disagreement among participants about the current status of a formal organization to respond to disasters and the speed at which emergency actions could be executed in future crises. This point led to the insight that lack of awareness about disaster response creates a self-fulfilling perception of poor preparation, even when detailed plans are in place. Such insight highlights the importance of community engagement and disaster awareness-building in all areas of society. Also important is the co-production of resilience planning by experts, policy makers and the community. Participants discussed many ways of mitigating impacts through preventative measures. These included designing and enforcing building codes and hazardous zones, fine resolution hazard mapping, creating and practicing disaster management plans for public buildings and the wider community, and building awareness through education and community engagement programs.

Discussion of factors that limited the impact of the disaster focused on two points. The first was that the physical destruction caused by the debris flows was limited and large parts of the city and towns were not catastrophically affected. Despite some difficulty in the city, water, food, shelter, electricity, and every day needs could be accessed. The second point was the quick Army response, which was widely agreed to depend heavily on the lack of damage to their own infrastructure and strategic positions. If any Army infrastructure were damaged, military priorities could divert resources from search-and-rescue operations and emergency management. In recent disasters, such as the Kashmir earthquake of 2005, the Indian Army showed their capacity to respond, as they were the first responders and transported the injured to hospitals in Srinagar, despite heavy losses of their own personnel [19–21]. To complement the Indian army’s response in future disasters, the Ladakh District Management Plan has formalised civil protection for municipal structures, self-organizing civilians and locally based non-governmental organizations.

5.2 Key resources and gaps

Participants in the scenario-building exercise identified the Indian Army, monks at the nearby monasteries and spontaneously organised community members as key players in the disaster response. Equally, the absence of a formal civil protection organisation was considered significant. However, this gap is addressed in the current District Disaster Management Plan, although its effectiveness is yet to be tested.

Discussions of population needs and priorities after the disaster highlighted the fact that water will be a key resource. Numerous streams flow through Leh and there are many groundwater wells, whose quality could be compromised in a disaster [2]. Electricity could temporarily be provided from tourist hotels and guesthouses by the high number of generators in the city and surrounding area.

Several pathways for immediate aid to Leh were identified in the simulation, particularly the possibility of relaxing controls on contested borders. The long distance from Leh to any national borders led the groups to agree that aid from across the border by road was unlikely to be significant. As national borders limit access to family and social support networks, this could be considered as a gap in resources. In the past, Pakistan has allowed aid to be transported across contested borders during large disasters such as the 2005 earthquake, but for a smaller-scale disaster like a cloudburst such a concession would be unlikely.

Domestically, support and aid for relief and recovery were commonly given in the form of government cash grants [1, 3]. The Indian Red Cross began relief operations with an immediate response, along with the many international non-governmental organizations and local project partners already established in Leh [4]. The tourism economy slowed initially and affected many livelihoods, but rebounded a few years later. Most structures were rebuilt on their damaged and cleared sites. Participants recall this pattern from previous disasters, which suggests a common practice across the region, with possible reasons founded in tradition, lack of funds or available land to move, and desire to locate businesses along roadways.[15].

Identification of information and data as key resources for disaster mitigation highlight the challenge of obtaining high quality datasets in order to study and model the variety of hazards in Ladakh. The difficulties identified include insufficient time-series data sets, military restrictions on high resolution images and collecting demographic data for mobile telephones, and the highly variable and diverse population, with many migrants, refugees, and tourists. Ideally, available data would feed models that estimate and quantify future hazard, such as climate variability analyses, hydrological modelling, frequency analysis of cloudbursts, debris flow modelling, and estimation of distances from watercourses. These estimates and forecasts could then inform decision makers and their disaster mitigation policies.

Following up on these challenges, discussion turned to creative options for proxies and indirect measurements. Possible sources of climate information included monastery records, cemeteries, records from Moravian Church missions and fieldwork activities such as coring and examining sediments or boulder size distribution. Participants recognised the value of contacting a local meteorologist to gain expert knowledge on the details of cloudburst formation in the region. Overall, both analysis groups agreed that to assist in addressing disaster mitigation, large amounts of data would need to be collected in order to generate useful hazard models for the region, to provide forecasts, and to inform decision makers.

5.3 Understanding vulnerability and resilience

Discussions of vulnerability, capacity and resilience covered a multidimensional spectrum of indicators and trends with respect to factors that ranged from ethnicity to land ownership and religion. Participants broadly agreed that the migrant community in Leh was the population most affected by the disaster and hence the most vulnerable group. In their new location, migrants or previously displaced populations may have little knowledge of hazards, and may be constrained by ownership restrictions as well as the availability and expense of land. Also, without a social network to support them during a disaster, they are likely to be in greater need of immediate forms of assistance, such as food, shelter, cash and emergency kits. A diverse community under stress could exacerbate pre-existing tensions and social conflicts among the many ethnic and religious communities by targeting aid to their own group, excluding migrants, and this could lead to an unequal distribution of aid and resentment of non-indigenous people. Alternatively, a disaster might result in the community coming together.

Monasteries and religious institutions have multiple influences on communities, focussing on identity, spirituality and psychological recovery after a disaster. Monasteries and mosques may also temporarily host large numbers of displaced people. They may provide shelter and hot food, as they do for pilgrims and during festivals. Monasteries are very old, resilient communities and are often located on high ground out of the way of floods and debris flows. They provide spiritual and psychological support to the wider community [16]. Religious networks were also identified as sources of social capital that contributes to community resilience. As it is a pillar of society, religion could be an important resource, as well as a source of vulnerability if religiously significant buildings are damaged or inequalities along religious divides are brought out during relief and recovery efforts. Awareness of the potential for religion to be a powerful resource or a point of contention in disaster management is an important consideration in research and planning.

Discussions suggested several other dimensions of vulnerability. 'Wild-card' events that were identified include festivals and pilgrimages to Leh, which could increase the migrant population by tens of thousands [4]. Such an increase in the vulnerable population exposed to a hazard would escalate the scale of emergency response and probably overwhelm the city's resources.

5.4 Potential secondary hazards and cascading disasters

Secondary hazards and cascades merit incorporation into planning activities. Participants identified earthquakes, mass movements like large landslides, floods from blocked rivers, outbreak and control of diseases like cholera and dysentery as plausible secondary hazards and cascading hazards.

6. Looking forward

Participants in the scenario-building exercise considered the future of disaster management in the Ladakh region. The disaster response plan released in 2011 has yet to be tested by a major event and needs to be reviewed periodically. Broadly, participants agreed that changes in climate and migration patterns are key drivers of future actions and planning needs. Migrant and tourist populations in and around Leh are expected to continue to increase and the residential population will probably decrease as young residents go to university and migrate away from Ladakh region. An overall increase in population will place a stress upon scarce natural resources, and the new additions to the population have been identified as the most vulnerable groups in disaster.

Currently, the main concerns of the local population are pollution and climate change [4,18]. In a usually arid region, the former is expected to increase rainfall. Structures built using traditional techniques may suffer great damage in the future. Monasteries and religious buildings are of concern as many are already experiencing damage and are central cultural institutions that support communities [4]. Outreach and awareness-building in communities regarding hazards and mitigation will be a significant need in order to reduce the impact of disasters in the future.

Leh is a remote and isolated city, and cloudbursts in nearby places show that severed transportation links will delay the emergency response. Such isolation highlights the importance of building capacity at the municipal level, with well trained and adequately equipped local response teams. Additionally, building resilience by managing critical infrastructure and public buildings will be vital in future disaster responses. Infrastructure can be improved and designed for greater resilience. Critical infrastructure, including, hospitals, schools, and public buildings, should be assessed for its resilience and resistance to hazards.

7. Informing the research project and public policy

The disaster scenario simulation informed multiple components of the research project and its fieldwork programme. Examples of the way in which the simulation has directed research involve both formal questions and informal conversation about specific recent and historical events. They also involve the residents' outlook on the future, the interaction of religion with disasters, and specific fears about the next disaster. A desk-based study using satellite data to predict hazards on slopes could be checked with ground truth in several locations against the impacts of the 2010 cloudburst [17]. The discussions also guided questionnaires that were used in social surveys of residents in order to understand their perceptions of risk and memories of environmental hazard events. Discussion also guided semi-structured interviews of leading figures in disaster management policy development and local government.

In order to project what a future disaster might look like in Leh, the simulation relied heavily on the 2012 District Disaster Management Plan. The Leh District Government and the Leh Autonomous Hill Development Council (LAHDC) acknowledge the presence of a high-risk environment in Ladakh and are well aware of the complexity of the task and expertise required to design an effective disaster response and management plan [4]. At the time of this project, the disaster management plan was being revised and updated by the LAHDC and local officials were invited to participate in the conference "Increasing Resilience to Environmental Hazards in Border Conflict Zones" hosted by the research team. Preliminary project results were presented to stimulate discussion amongst stakeholders, including local government officials, prominent citizens, community members, journalists and academics. The conference was a successful opportunity to share information among the community, institutions and research team and discuss possibilities for moving forward toward a more resilient community in the Leh district.

7.1 Uncertainty

Discussions about the scenario highlight several important uncertainties. The District Disaster Management Plan which details a civil protection body to work alongside the Indian Army is yet to be tested in a disaster on a similar scale to that of the 2010 cloudburst. The unknown frequency and magnitude of many hazards in the Ladakh region pose difficulties for planning, mitigation and response to both typical and extreme events. The nature of the population of Leh at the time of a disaster would greatly affect the required scale of emergency response, for example in the tourist high season and during festivals. The scenario method allowed some exploration of these uncertainties, and further study could reduce the level of uncertainty or provide multiple possible futures by means of disaster scenarios.

8. Reflections and conclusions

The disaster scenario simulation was successful in that it achieved all the objectives posed when analysing the cloudburst scenario. Participant feedback was positive and affirmed an improved understanding of the 2010 disaster from a multidisciplinary perspective. A large group of expert participants shared knowledge and refined research questions through the identification of gaps in data and resources, by improving understanding of the current situation and recent history, by registering on-the-ground impressions, and through knowledge of resilience, strengths, weaknesses, vulnerabilities and luck in the field context. The interesting insights thus gained have potential for increasing resilience and were identified for further study in the research project and among the wider academic community. Monasteries and religious institutions, in particular, have a multi-faceted influence on communities, centring on identity, spirituality and psychological recovery after a disaster. The role of the Army was fundamental to minimising the impact of the 2010 disaster, and in the future will pribably be coordinated with the new civil protection structures. The civil protection component designed in the District Disaster Management Plan is yet to be tested in a similar emergency. Both analysis groups broadly agreed that migrant communities were the most vulnerable populations in Leh and the Ladakh region and should be a key focus of research to reduce vulnerability and build capacity and resilience.

The simulation also achieved its purpose in refining the project, as insights from the simulation effectively informed the field research programme. Every member of the research team gained a multidisciplinary understanding of resilience in Ladakh that will help inform future work. Additionally, the wider academic community will find an example of a disaster simulation scenario and insight on Ladakh through the lens of increasing resilience in border conflict zones. Discussion and reflections generated in this scenario will assist the research team and the wider academic community in forming a more complete and multidisciplinary understanding of the mechanisms underlying resilience in Leh and the Ladakh region, as well as the gaps in understanding and data that could form the basis of future work and research.

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