Mass movement events in the Himalaya: The impact of landslides on Ladakh, India.

Sian Hodgkins
Geology for Global Development

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Executive summary

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Landslides in Ladakh are caused by changes to slope stability which initiate debris flows and rock falls. A change in slope stability may be caused by a change to the slope angle, a change to the slope vegetation (cohesion) or a change in the saturation (pore pressure) of sediment on the hillslopes. The weathering of the hillslopes in the Ladakh mountain range has formed loose regolith and sediment which is susceptible to landsliding. Rivers and glacial streams have incised the valleys forming steep sided slopes. Debris flows, rock falls and mudflow landslides are then triggered either naturally, by heavy precipitation and earthquakes, or unnaturally, by vibrations from heavy vehicles such as army trucks or where humans have modified the hillslopes. Debris flows are formed from a mixture of rock, mud and water which carries trees, boulders and debris. Rock falls occur on steep slopes which have been undercut by streams or by the construction of roads. Loose rocks and boulders that have become detached from the slope fall rapidly through the air, which is particularly hazardous on the mountain passes in Ladakh. Landslides may also form natural dams as they block the course of rivers in Ladakh. Behind these dams lakes form which may flood the surrounding region when the dam breaches. Therefore, it is important that the stability of landslide dams in Ladakh is monitored so that hazardous flooding events can be prevented.

In Ladakh the Kelang Serai, Patseo and Chilam landslide deposits were triggered during periods of increased monsoon strength. These historic deposits are examples of large landslides that have occurred in the region. The Darcha landslide (also an historic landslide) was caused by the structure (bedding and faulting) of the geology, which created lines of weakness along which the slope failed.

In the last decade landslide events in Ladakh have been reported in the media and recorded by geological organisations such as the United States Geological Survey. These landsliding events have caused loss of life, injuries and road blockages. The most significant event to have occurred in recent history was the 2010 cloudburst event. This event was caused by a period of unusually intense precipitation on the hillslopes which triggered debris flows and mudflows. Over 200 people died in the event from multiple causes, including by drowning in the mudflows/floods or from head injuries caused by falling debris. The debris flows also destroyed homes, roads, bridges, the Leh hospital, drinking water canals, farmland and lines of communication. In 2005 approximately 1000 people died directly from landslides triggered in a region over 7500km^2, by the 'Kashmir earthquake' (Owen et al., 2008). Over half of the landslides studied following the Kashmir earthquake were linked to human activity. The construction of roads was the most common cause of landsliding as they steepen the slope angle. Other forms of human activity that can cause landslides include building on fragile slopes, deforestation, forest fires, terraces built for agriculture and the vibrations caused by construction or vehicles.

Climate change poses a great concern for future risk to landsliding in Ladakh. An increase in global temperatures may cause an increase in the frequency and magnitude of storm events over the Himalaya. An increase in intense precipitation in Ladakh will increase the probability of large landslides in the region. In addition, the expansion of towns and villages in Ladakh as the region develops may influence the chance of landsliding. Homes built on fragile hillslopes are at a greater risk of landsliding as they further destabilise the slope and increase the chance of slope failure.

1. Introduction: Landslides in mountain environments

The most common forms of landslides in mountain environments are rock falls, debris flows, ice avalanches and creep. The Ladakh landscape is highly sensitive and susceptible to mass movement events. Ladakh lies in northern India in the Himalayas, southwest of the Tibetan Plateau. The region is shadowed from the Indian summer monsoon by high elevation areas of the Himalaya to the south and the Karakoram mountain range to the north; both act as orographic barriers, creating an arid environment (Bookhagen et al., 2005). Consequently, the Leh valley only receives on average 41mm of precipitation between June and September, which is delivered by the southwest monsoon, and an average of 53mm of precipitation between October-May delivered by the incoming Westerlies (Sant et al., 2011). Therefore, climate is the main control on the frequency and magnitude of mass movement events in Ladakh.

The potential for landslide failure in Ladakh is determined by the first principles of landslide dynamics quantified by the factor of safety (F) equation.

$$F = \frac{\sum resisting\ forces}{\sum driving\ forces} \quad F = \frac{Shear\ Strength}{Shear\ Stress} \quad F = \frac{C' + (W cos\beta - \mu) tan\emptyset}{W sin\beta}$$

Where C' = cohesion, β = Slope angle, μ = pore pressure, tanø = friction angle. When F<1 this leads to slope failure and when F>1 the slope is stable. The critical slope angle (β) is modified naturally by stream undercutting and unnaturally by the construction of roads. The hill slopes of the Ladakh Range are sparsely vegetated by small shrubs and grasses due to the aridity of the area (Bhattacharyya, 1989). Therefore, weak root cohesion on the hill slopes decreases shear strength of the slope increasing the likelihood of failure. The pressure of ground water in the subsurface is known as the pore pressure and determines the relative soil moisture content. It varies as function of drainage area of a basin.

2. Pattern of landslides in Ladakh

2.3 Introduction

The geomorphology of the Leh valley basin is determined by the mechanics of erosion and deposition acting in a paraglacial environment. The Indus River flows through the Leh Valley, separating the Zanskar Range to the south and the Ladakh Range to the north. Glaciers have formed in cirques on the northern slopes of the Ladakh Range in the snow accumulation zone above ~5100 m (Jamieson et al., 2004). For the last 130,000 years retreat of the glaciers in the Leh Valley has dominated mass wasting events in the Ladakh region. At altitudes above ~4800m the slopes undergo large variations in temperature, which causes frost shattering of the rocks and produces unconsolidated sediment and debris (Jamieson et al., 2004). As both the Zanskar and Ladakh Ranges are situated in a climatically sensitive zone, the hill slopes consist of unconsolidated clasts created by the mechanical weathering of the Ladakh batholith and Zanskar metasediments (Sant et al., 2011). This material is the primary constituent of landslides in the Leh Valley and is transported downslope by meltwater from the glaciers, by the glaciers themselves or by the process of creep (Sant et al., 2011). Significant deglaciation of the valley from ~30Ka to present day has produced glacial streams forming fluvial terraces and floodplains in the Ladakh Range (Pant et al., 2005). These fluvial processes have incised the Leh Valley and formed the River Indus which, coupled with rapid tectonic uplift, has produced steep sided "V" shaped valleys and gullies. A combination of steep slope angles and poor root cohesion on these un-vegetated hillslopes means that the Ladakh valley is highly susceptible to landsliding in the form of rock falls, debris flows and mud flows. The causes of large landslides (>$10^6 m^3$) in Ladakh are outlined in table 1. Debris flows are particularly hazardous in Ladakh as they travel at high velocities carrying soil, rock, mud, regolith and vegetation.

Natural		Unnatural
Geological	Morphological	
Rock mass discontinuities: - Bedding - Fault - Unconformity	Steepening of slope by: - Fluvial incision - Glacial incision - Undercutting	Tourism: - Excavating slopes for buildings. - Construction of paths for trekking.
Rock mass strength	Precipitation: - Rainfall - Snowfall	Construction: - Building on slopes - Roads
Joints	Snowmelt	Vibrations from lorries
Permeability	Freeze Thaw weathering	Slope modification
	Decreased root cohesion	Forest Fires
	Soil thickness	Agriculture: terracing
	Vegetation type	Deforestation

Table 1 – Causes of landslides in Ladakh.

2. 2 Historic landslide events

Historically large landslides in the Ladakh region have been triggered by periods of intense precipitation or seismic shaking. Dortch et al., (2008) investigated the occurrence of large landslides (high magnitude–low frequency) in the Himalaya as they have a higher perseveration potential than small landslides (low magnitude–high frequency). The study analysed and dated four large landslides in Lahul and Ladakh that occurred during the Holocene, around 2000 years after deglaciation. They were compared to twelve landslides that had been previously dated, to establish the causes that make the slopes susceptible to land sliding and the triggers that initiate slope failure. Details of the four landslides studied are summarised in Table 2. The Kelang Serai, Patseo and Chilam landslides were likely to have been caused by an increased in pore water pressure over a period of increased monsoon strength (Bookhagen et al., 2005). However, they suggest that the Kelang Serai landslide was caused by undercutting of the slope or by changes in the shear strength of the slope (Mitchell et al., 2005). All these landslides occurred after deglaciation and therefore, as well as intense rainfall, they may also have been triggered by seismic shaking. Dortch et al., (2008) determined that the Darcha landslide was likely to have been initiated by "gravitationally induced buckling" of the steeply dipping rock mass discontinuities. This is because it does not coincide with a recorded period of intense monsoon strength.

Landslide Deposit	**Darcha**	**Patseo**	**Kelang Serai**	**Chilam**
Age (ka)	7.7±1.0	7.9 ± 0.8	6.6±0.4	8.5 ± 0.5
Surface area (m^2)	$0.2 x10^6 m^2$	$1.7 x10^6 m^2$	$5.2 x10^6 m^2$	$3.2 x10^6 m^2$
Debris volume (m^3)	10,000,000	127,500,000	520,000,000	240,000,000
Trigger	Gravitationally-induced buckling	Increased pore water pressure	Increased pore water pressure	Increased pore water pressure

Table 2 –Examples of four historic landslides in the Ladakh region.

2.3 Recent landslide events

In the last decade there have been a number of recorded landslide events in Ladakh. There is no official record of every event and so the list compiled in Table 3 is from media reports and the USGS landslides hazard programme (Web USGS). However, the recorded cases are likely to be events where people have been injured, killed or where there have been disruptions to major roads.

Year	**Location**	**Description**	**Injured**	**Dead**	**Source**
August, 2013	Road at Chang La on the way to Pangong Tso	Rockfall caused roadblock.	0	0	Web I
May,2013	National Highway	Landslide caused roadblock.	0	0	Web II
July, 2012	Durbuk–Pass, Ladakh	Landslide	400 tourists	0	Web III and IV
August, 2010	Leh	Cloudburst Event	~ 400	~179-500	Web V
December, 2007	15th December Landslide	Landslide - No reported trigger	6	2 (military)	Web VI
October, 2005	Kashmir	Earthquake on Pakistan/Indian border. Triggered landslides and mudslides.	6,266 (Jammu and Kashmir)	~865 – 1350 (India)	Web VII and VIII

Table 3 – Examples of recent landslides in Ladakh.

3. Secondary hazards triggered by landslides.

In mountain regions landslides can cause further natural hazards such as flooding. Landsliding in Himachal Pradesh and Jammu and Kashmir has blocked river valleys, creating naturally dammed lakes. The following section looks at a historic paleolake outburst event in Leh and the 1871 great Indus flood in Pakistan.

3. 1 Landslide dams and lake outburst events

Debris from landsliding in the Himalaya can construct natural dams when sediment, from adjacent valley sides blocks river flow forming new lake basins (Anderson and Anderson, 2010). Release of the reservoir behind these landslide dams can cause catastrophic flooding. Two lake damming rock fall events that cross the Manali-Leh road to the north of Kyelong town, Himachal Pradesh have been recorded by Weidinger (2006) and are summarised in Table 4. The Pateo landslide dammed the Bhaga river and drained the lake within a short period of time, creating deep gullies within the deposit. These gullies have the potential to cause future landslides (by fluvial undercutting), which would dam the river and pose a hazard to the villages downriver (Weidinger, 2006). The Serai Kenlung landslide dammed the Yunan Chu river. The proximal part of the landslide and the series of eroded terraces suggest there were "several outbreaks of the lake" (Weidinger, 2006). Both landslides demonstrate the importance of calculating landslide dam stability in the region. This would help determine the potential for landslide dam failure and prevent the secondary flooding hazard associated with lake outburst events.

Parameters	**Pateo**	**Serai Kenlung**
Location	Bhaga Valley, Himachal Pradesh, India *(At Pateo, confluence of N-S Bhaga River valley with an eastern tributary)*	Yünan Chu Valley, Zanskar, India *(5.5km NNE of Bara Lacha pass, confluence of N-S Yunan Chu valley with an eastern tributary)*
Altitude	3850-3925m	4810m
Lithology	Limestone, dolomite	Conglomerate, quartzite, shists, dolomites
Material size	Boulders/rock fragments ≤0.5m	Boulders/rock fragments ≤10m
Volume of lake(s)	Lake 1 – 300 mill. m^3 Lake 2 – 62.5 mill. m^3	125 mill. m^3
Stability of dam	Deep gully erosion through the deposit	Stable due to cementation with sediments.
Life span of lake	Both disappeared within short periods	≤ 3000 – 5000yr

Table 4 – summary of lake damming rock fall events from Weidinger (2006)

In January 1871, an earthquake-induced landslide dammed the Indus River in Northern Pakistan forming a temporary lake (Schneider et al., 2013). When the dam breached in June 1871, ~ 3 - 5 billion m^3 of water was released over 24hours, killing ~500 soldiers in the Sikh army encamped on the floodplain at Attock (Shroder, 1988). In the Spituk-Leh valley Sangode, et al., (2011) recorded a paleolake outburst that occurred due to a breach in a natural dam. The authors of the study agree with Owen et al., (2006) that the dam was formed from glacial moraine deposits although, Phartiyal et al., (2005) suggested the river was dammed by debris flows. Sangode et al. (2011) suggest that "seismic activity, climate oscillations and the critical hydrostatic conditions resulting from geomorphic inequilillibria" could have caused changes to the hydrostatic pressure in the reservoir resulting in the subsequent breach of the dam. These examples of lake outburst events in the Himalaya demonstrate the susceptibility of the Indus River to landslide damming.

4. Damage caused by landslides in Ladakh

Landslides in Ladakh have not only killed and injured people but they have also cause damage to the infrastructure which connects remote villages and army bases in the region.

4.1 People

The most well documented case on loss of life due to landsliding in Ladakh is from the 2010 cloudburst event. Cause of death was most commonly drowning in floodwaters, being buried alive in the mudflows, head injuries from falling debris, haemorrhage from open wounds and exacerbation of underlying medical conditions (Rashid et al., 2012). The landslides in 2010 have also caused many "bruises, abrasions and laceration" injuries.

4. 2 Homes

In Ladakh, homes are often built traditionally using sun-dried mud bricks, with roofs made from Willow branches, Poplar beams and clayey mud (Image i, Rashid et al., 2012). The homes are specifically adapted for the arid climate and therefore intense rainfall causes significant and immediate damage (Image ii). Over 1000 homes were washed away in a short space of time by flooding and debris flows during the 2005 cloudburst event due to this structure. Homes in Ladakh need to be built to withstand landslide events in the future.

Images - (i) - Traditional Ladakh homes (Sian Hodgkins, 2013); ii) Damaged home during 2010 Cloudburst event ; iii) Damaged telecommunications (Web IX)

4.3 Water

Freshwater is provided in Leh through a network of hand built canals that drain melt water from the glaciers and irrigate 10,190 hectares of land (Daultry and Gregan, 2011). The 2010 cloudburst event damaged drinking water supplies as the headworks of the Zamindari Khuls Canals were destroyed and the irrigation khuls in Leh damaged (Leh management plan). Sediment loading and accumulation from landslides may dam these canals and prevent fresh drinking water from reaching areas of the town.

4.4 Communication

Lines of communication were lost during the 2010 cloudburst event as the Bharat Sanchar Nigam

Limited (BSNL) Telecom was washed away as well as the local radio station (Image iii, Leh disaster management plan). During a natural disaster the loss of a mobile network can significantly hinder the relief efforts.

4.5 Roads

Landslides in Ladakh cause road blockages on the high altitude mountain passes throughout the year. In the winter months the region is completely cut off by snowfall on these mountain roads and therefore landslides can prolong road blockages making them a problem throughout the year. During the 2010 cloud burst event 26 roadways (688.80 km) were damaged in Leh district, which accounted for 40% of all roadways. Of this 662.34 km of roads were under floodwaters and sludge. Of the bridges 29 in the region were damaged and 10 of these were completely washed away (Leh management plan).

4.6 Hospitals

The Sonam Norboo Memorial hospital (SNM) in Leh was also damaged during the 2010 cloudburst event with the heating system destroyed as well as the operating theatre, surgical warms, medical wards, labour room, OPD and the C.T scan (Leh disaster management plan).

4.7 Agriculture

Ladakh is supported by nomadic subsidence farming creating a terraced landscape (Daultrey and Gergan, 2011). In the 2010 landslides, farmland was covered under mudslides destroying valuable crops and damaging the irrigation network.

5. Landslide triggers: Natural and anthropogenic factors exacerbating risk

Landslides in mountain regions are triggered by both natural and anthropogenic disturbances that initiate slope failure. The most common natural landslide triggers in Ladakh are (i) an increase in the intensity of rainfall and (ii) seismic shaking caused by earthquakes (Dortch, et al., 2008). The following case studies describe two different events in the last decade that have triggered land sliding in Ladakh.

5. 1 Natural triggers – Intense rainfall

The strength of the Indian monsoon determines the intensity of precipitation events in the Himalaya. Changes in the intensity of the southwest monsoon, during years of strengthened atmospheric circulation correspond to an increase in the number of large landslides (>0.5 km^3) in the Late Pleistocene and Holocene periods (Bookhagen et al., 2005 and Dortch et al., 2008).

The Ladakh Cloudburst event, 2010

The most devastating landsliding event to occur in Ladakh in recent history was triggered by an abnormal period of intense rainfall known as a cloudburst event. On the 6th August 2010 the Ladakh Range experienced two hours of concentrated precipitation which reached a peak intensity of ~75mm of rainfall over a thirty minute period (Hobley *et al*., 2013). The event was caused by 500mb winds and a series of mesoscale convection systems which developed to the East of Leh and caused a localised cloud burst (Indian MET Department, 2010). A report by the American Meteorological Survey describes the weather conditions prior to the cloudburst event in detail and includes satellite images of the storm (Rasmussen and Houze, 2012). The Indian Air Force recorded 250mm of rainfall over one hour at Leh airport. Ladakh normally receives ~15 mm of rain in August and the highest ever single rainfall event recorded was 51.3mm over twenty four hours on 22nd August, 1933 (Daultrey and Gergan, 2011, Indian MET Department, 2010). The intense rainfall caused loose sediment on the hillslopes to reach critical saturation levels initiating slope failure. Subsequently, mudflows and debris flows accumulated boulders, trees and building debris as they travelled towards the Indus river. A debris flow from Choglamsar reached 2km in width and travelled 10km, whilst the debris flow in Leh travelled 3km from source through the town (Daultrey and Gergan, 2011). The death toll for the disaster varies within the literature and media with the majority of reports stating 200 people died; 179 reported dead by Rashid et al (2012) and ~600 reported dead in a paper by Hobley *et al*., (2013). The discrepancy in this figure could be due to the remoteness of the villages in Ladakh and lack of communication during the disaster. The Leh disaster management plan states that over 200 lives were lost in Leh, Choglamsar, Saboo and Phyang (Leh disaster management plan, 2011). Following the floods the BBC reported the day after the disaster that officials has estimated “80% of Ladakh's infrastructure [was] partially damaged or totally destroyed” by flooding and mudflows and there was more than 150 million USD worth of damages to buildings and infrastructure (WEB BBC, Parkash, 2012). As well as impacting the local community, tourists who were in the region for the short summer trekking season were also caught in the debris flows. Hundreds of tourists were stranded on the Skiu-Markha trekking route and in the Wanla and Rumste regions (Leh disaster management plan, 2011). One group of trekkers caught in the Markah Valley sheltered in a hill top village without any communication until they were rescued on the 8th August (Web X).

5.2 Natural triggers – Seismic shaking

Earthquakes are another natural trigger of landslides in Ladakh and cause mass movement events in the form of debris falls and rock avalanches (Barnard et al., 2001). The 2005 earthquake in Kashmir, Pakistan was felt up to 1,000 km away including in Delhi and caused the death of at least 1350 people in Jammu and Kashmir and injured ~6,266 people in the state (Web encyclopaedia). The 1999 Garhwal, India earthquake occurred east of Ladakh and triggered localised landsliding. Both case studies demonstrate the susceptibility of Ladakh to earthquake induced landslides. Keefer (1994) and Owen et al., (2008) have suggested that a threshold (~7.5 moment magnitude) exists on the magnitude of earthquake needed in the Himalaya to initiate "widespread landsliding" and large landslides. There is evidence to suggest that 7.5 M earthquakes in the Himalaya may have occurred in the past during strengthened monsoon periods, having a cumulative effect on the triggering of landslides in Ladakh.

The Kashmir earthquake, 2005

In neighbouring Pakistan, Owen et al., (2008) studied landslides triggered by the 2005 earthquake. The 7.7 M_s magnitude earthquake triggered thousands of landslides which directly caused ~1000 deaths. Out of the 1293 landslides analysed in the study, 90.1% were rock falls or debris falls and at 53% of the sites human activity had contributed to slope failure. The debris analysed was very fragmented suggesting that the landslides travelled at speeds around ~10 m/s. Of the sites where failure was linked to human activity, the construction of roads on slopes >50° was the most common cause of the landslides. Following the earthquake, in 2006 the monsoon season triggered further debris flows and flooding caused by fissures produced in 2005. The authors suggest that because the Kashmir earthquake mobilised a greater volume of material, than the Garhwal earthquake, this is further evidence that a critical magnitude threshold exists for large landslide events in the region (Owen et al., 2008).

The Garhwal earthquake, 1999

In 1991 (M_s 7.1) and 1999 (Ms 6.6) earthquakes hit the Himalayas in Garhwal, India. Barnard et al., (2001) studied 56 landslides triggered by the 1999 earthquake and 282 other landslide deposits caused by both natural and human factors. Like the Kashmir landslides the mass movement events following the Garhwal earthquake were in the form of debris and rock falls. Debris flows were associated with non-earthquake induced landslides. However, the study concluded that human activity had contributed to or directly initiated two thirds of the landslides investigated which suggests the increased likelihood of human induced landslides in Ladakh.

5. 3 Anthropogenic triggers

Human activity in Ladakh has modified the hillslopes and resulted in the triggering of landslides. Anthropogenic disturbances from construction, deforestation, lorry vibrations, road and path construction, forest fires, agriculture and terraces contribute to slope failure (Barnard et al., 2001). The construction of roads decreases slope angle and slope cohesion by cut and fill and removal of toe slopes (Barnard et al., 2001). This involves excavating notches into the weathered bedrock on one side [of the road] and using the excavated material as fill to support the opposite side of the road (Owen et al., 2008). Following the Kashmir earthquake in 2005, slopes with an angle >50° failed, causing landslides across the roads (Owen et al., 2008). It was noted by Owen et al., (2008) that failure also occurred along the road margins due to poorly compacted fill when the roads were first constructed. Undercutting of the slopes in Ladakh also occurs during the construction of footpaths and terraces that increase the angle of the hillslopes.

6. Landslide hazards in the future

Landslides pose an imminent and very real threat to the people of Ladakh. The 2010 cloudburst event demonstrated the devastation that debris flows and mudflows can cause in a very short space of time. Climate change will have the greatest influence on the frequency and magnitude of future landslide events. Increasing global temperatures will affect the “capacity of air to hold moisture”, leading to an increase in the occurrence of storm events with high levels of precipitation and greater wind speeds (Stoffel and Huggel, 2012, Sat and Litt, 2013). The tectonically active nature of the Himalayas contributes to the creation and movement of sediment. This generation of sediment means that sediment supply does not act as a limiting factor landslide frequency in the region. Therefore, the landscape can be described as being in a state of dynamic equilibrium as it is self-regulating and self-adjusting, through the mechanisms of negative feedback. Ahnert (1994) suggests that the presence of inherited landforms (e.g. moraine and U-shaped valleys) that formed during the last period of glaciation in Ladakh, indicate that the landscape has not yet reached a steady state (where this is no net change of mass in the landscape, independent of time). Oscillations in climate prevent the landscape from reaching this steady state equilibrium. In the Late Cenozoic, increased storm events were linked to an increase in mass movement events and an increase in sediment accumulation (Molnar, 2004). Molnar, (2004) suggests that global climate instability is more effective at removing sediment than climate stability. In Ladakh, future debris flows “have the potential to become larger...but not necessarily more frequent” (Stoffel and Huggel, 2012). This is because, in general, increasing global temperatures will increase the probability of large (>$10^6 m^3$) landslides in mountain environments as permafrost becomes less stable (Huggel, 2009).

The fragility of the Ladakh region is not only going to be influenced by climate change, but also by the expansion of settlements and an increase in tourism. The construction of homes and hotels on the fragile slopes exposes the population of Ladakh to the risk of landsliding (Sati and Litt, 2013). An increase in construction in the region destabilises slopes, and the associated vibrations can act as a trigger. Oberoi and Thakur, (2005) used GIS modelling to generate landslide hazard maps of the Manali-Leh road which could be used in the future to help planners predict road blocks from landslides. Similar studies in the region would be invaluable in preparing for future natural hazard events. However, the uncertainty over the future effects of climate change on landsliding in the region “does not constitute a case for inaction” in Ladakh (Sati and Litt, 2013). Hazard zonation mapping and risk planning will be essential in protecting the population of Ladakh from future debris flows and rockfall events.

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