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Interconnected geoscience applied to disaster and risk: case study from SECMOL, Ladakh, N. India

Michael Petterson
School of Science, Auckland University of Technology, Auckland, New Zealand
Lanka Nanayakkara
King Edward Parade, Auckland, New Zealand, and
Norgay Konchok, Rebecca Norman, Sonam Wangchuk and
Malin Linderoth
SECMOL, Leh, India

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Abstract

Purpose – The purpose of this paper is to apply the concept of "Interconnected Geoscience" to a disaster and risk reduction (DRR) case study at SECMOL College, near Leh, Ladakh, N. India. Interconnected geoscience is a model that advocates holistic approaches to geoscience for development. This paper reports research/practical work with Ladakhi students/staff, undertaking community-oriented DRR exercises in hazard awareness, DRR themed village/college mapping, vulnerability assessments and DRR management scenario development. The geoscientific hazard analysis work is published within a separate sister paper, with results feeding into this work. This work addresses aspects of, and contributes to, the DRR research (science)-policy-interface conversation.

Design/methodology/approach – Interconnected geoscience methodologies for DRR here are: the application of geoscience for hazard causality, spatial distribution, frequency and impact assessment, for earthquakes, floods and landslides, within the SECMOL area; the generation of community-developed DRR products and services of use to a range of end-users; the development of a contextual geoscience approach, informed by social-developmental-issues; and the active participation of SECMOL students/teachers and consequent integration of local world-views and wisdom within DRR research. Initial DRR awareness levels of students were assessed with respect to earthquakes/floods/landslides/droughts. Following hazard teaching sessions, students engaged in a range of DRR exercises, and produced DRR themed maps, data, tables and documented conversations of relevance to DRR management.

Findings – Students levels of hazard awareness were variable, generally low for low-frequency hazards (e.g. earthquakes) and higher for hazards such as floods/landslides which either are within recent memory, or have higher frequencies. The 2010 Ladakhi flood disaster has elevated aspects of flood-hazard knowledge. Landslides and drought hazards were moderately well understood. Spatial awareness was identified as a strength. The application of an interconnected geoscience approach immersed within a student+staff college community, proved to be effective, and can rapidly assess/build upon awareness levels and develop analytical tools for the further understanding of DRR management. This approach can assist Ladakhi regional DRR management in increasing the use of regional capability/resources, and reducing the need for external inputs.

Practical implications – A series of recommendations for the DRR geoscience/research-policy-practice area include: adopting an "interconnected geoscience" approach to DRR research, involving scientific inputs to DRR; using and developing local capability and resources for Ladakhi DRR policy and practice; using/further-developing DRR exercises presented in this paper, to integrate science with communities, and further-empower communities; taking account of the findings that hazard awareness is variable, and weak, for potentially catastrophic hazards, such as earthquakes, when designing policy and practice for raising DRR community awareness; ensuring that local values/world views/wisdom inform all DRR research, and encouraging external "experts" to carefully consider these aspects within Ladakh-based DRR work; and further-developing DRR networks across Ladakh that include pockets of expertise such as SECMOL.

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Originality/value – The term "interconnected geoscience" is highly novel, further developing thinking within the research/science-policy-practice interface. This is the first time an exercise such as this has been undertaken in the Ladakh Himalaya.

Keywords India, DRR, Community-based disaster preparedness, DRR policy and practice, Geoscience, Interconnected geoscience, Ladakh, SECMOL College

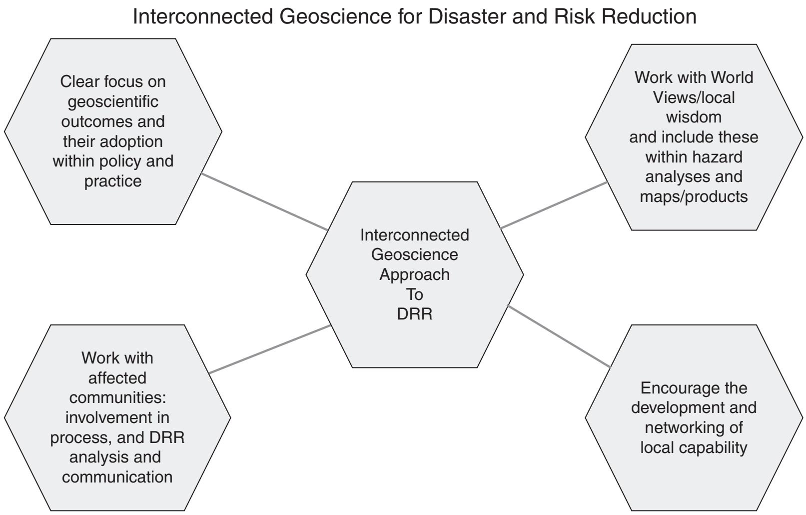
Paper type Research paper

Background and literature review

This paper forms part of a two-paper exploration of how interconnected geoscience can be applied, in the context of disaster and risk, at a college setting (SECMOL, near Leh), in the Ladakh region of the NW Himalayas, India. Interconnected geoscience is a conceptual model of geoscience application to international development. A definition of interconnected geoscience is:

> […] a philosophy that combines geoscience expertise with an equivalent expertise/consciousness in the understanding of developmental situations, conditions, and context, including the integration of diverse world views/wisdom and values', placing development-goals at the heart of the interconnected-approach. (Petterson, 2019, Figure 1)

In the case of disaster and risk reduction (DRR), the interconnected geoscience methodology herein advocates: the application of appropriate geoscience for hazard analysis; the generation of accessible (to many audiences) products and services (e.g. maps, models and advisory policy documents); the contextualisation of geoscience to DRR (e.g. social/community/developmental/values/world-views); and community inclusion. The Interconnected Geoscience approach builds upon previous work. Stewart (2016) promotes a "sustainable geoscience" methodology whereby geoscientists integrate their expertise with communication, education, social science



Notes: Science alone can struggle to integrate with policy and practice in DRR. Contextualised science, consciously developed to accommodate issues such as local cultural values, world-views, developmental context, communities and end-users leads to scientific services and products with a greater probability of uptake in DRR policy and practice

Source: Adapted after Petterson (2019)

Figure 1. An interconnected geoscience approach to DRR

and policy/planning/practice. Gill and Bullough (2017) emphasise the ethical dimension to geoscience engagement, with geoscientists encouraged to develop professional and social responsibilities. Di Capua *et al.* (2017) produced a statement of "Geoethics" documenting ethical guidelines that include knowledge sharing, adopting a spirit of cooperation and reciprocity, and respecting community sustainable development issues. Weischselgartner and Kasperson (2010) examined a range of project outcomes within DRR, particularly around the science/research/policy/practice interface. They concluded that barriers can exist, particularly between academic researchers within a competitive research environment and the generation of products/services of immediate DRR practitioner use. They advocate less "silo" oriented, and more inclusive approaches with a wider set of stakeholders/communities/end-users. A range of practical methodological frameworks for the adoption of multi-disciplinary approaches to DRR are discussed within UNISDR (2006). Dransch *et al.* (2010) discuss the communication of DRR issues presented on maps/GIS models, a common geohazard product and the challenges of communicating complex data/concepts for a wide range of audiences. What may be obvious to the expert is not immediately apparent to others. Close working between end-users and DRR geoscientists, assists with the development of more user-ready products/services. Cronin *et al.* (2004) adopted elements of "Interconnected Geoscience" for DRR in Savo, Solomon Islands. This work involved c. one-third of the resident population of this volcanic island, including the less empowered demography (e.g. women/children). Island geohazards had scientifically been assessed, and hazard-analyses were communicated directly with potentially affected island residents. A series of work programmes enabled communities to interact, engage and participate, in turn feeding new dimensions into the DRR work. The combined DRR geoscience-community work has become the foundation of DRR management in Solomon Islands for Savo. When Cyclone PAM struck Vanuatu, in 2013, at a financial cost of two-thirds of the national economy, an integrated/multidisciplinary response occurred, involving geoscientists, disaster management offices, diplomatic missions, aid agencies, armed services, etc., (Pacific Community, 2015). Gill and Bullough (2017) suggest that international frameworks such as the Sendai framework for DRR, and the United Nations 2030 Sustainable Development agenda are strong encouragers for interconnected geoscience (UNISDR, 2019, United Nations 2015). This paper adopts a range of principles from the Sendai and Sustainable 2030 agenda that address education, safe communities, understanding DRR, informing DRR governance, improving DRR resilience and enhancing DRR preparedness.

For the Ladakh region, particularly within the SECMOL locality, this paper is informed by new and previously published research. Petterson *et al.* (2019) present a multiple hazard assessment of the SECMOL college area from original research, and incorporating the work of hazard geoscientists (such as Bilham *et al.*, 2001; Bilham, 2019; Bhan *et al.*, 2015; Bollinger *et al.*, 2014; District Disaster Management Plan, Leh, 2011; Hobley *et al.*, 2012; Hodgkins, 2013; Mukhopadhyay and Dasgupta, 2015; Petterson, 2018; Rasmussen and Houze, 2012). Petterson *et al.* (2019) report work that forms a sister paper to this one, examining three main hazard types (seismic, flood and landslide). Some key results are reproduced here (Table I). In brief, the SECMOL region is vulnerable to low-frequency (10s–100s of years) medium-high magnitude (magnitude 6– > 8) shallow earthquakes, large-very large floods, similar to the Leh 2010 major floods (e.g. Bhan *et al.*, 2015) at 10–50 year frequencies, and landslides (small magnitude, high frequency, monthly – 5 yearly) with significant landslide risk from a ridge situated north of the SECMOL campus. Suggested risk mitigation strategies (Table I) focus on building strengthening, alternate water supply considerations, campus evacuation plans and engineering solutions to the ridge north of SECMOL.

Students' Educational and Cultural Movement of Ladakh (SECMOL, 2019, https://secmol.org/) is an independent residential College that targets young people, mostly aged 16–20, who mainly originate from remote and less affluent villages (Figure 2 and Plate 1, SECMOL, 2019). The SECMOL curriculum is independent, and College-defined. It focuses on

Table I. Summary of main SECMOL geohazard types

Hazard type	Causation and risk summary	Impacts/mitigation options
Earthquakes	Most earthquakes linked to regional geological structures (e.g. Nanga Parbat, Karakoram Fault and Indus/Shyok Sutures). Some seismicity away from these structures. Largest historical E/Q c. magnitude 6. Shallow earthquakes common. Second highest seismic hazard zone within India. Relative seismic "quietness" could reflect accumulating stored energy, generating future large E/Q Potential for magnitude 7–8+ earthquake. Frequency of largest earthquakes: 50–500 years	Plan for a large-magnitude, local, shallow earthquake Largest earthquakes potentially catastrophic Buildings to be earthquake-proofed where possible Use of existing local affordable and appropriate building technologies advocated Water supply could be compromised: Indus River can provide a temporary supply
Floods	Immediate eastern SECMOL catchment is a small river but connects to the much larger Upper Taroo Catchment A Leh-August 2010 style extreme weather event would produce large floods, lasting many hours Low frequency medium-high magnitude hazards (Decadal-50 years)	In 2010, the SECMOL River levels approached the eastern SECMOL campus gates. This event was c. 13–20 mm/h intensity at SECMOL. A 142 mm/h event (as close to Leh in 2010) could produce a? 7-fold greater flood. Buildings, compost toilet waste, ans water supplies would be compromised. Possible casualties Main management strategy: evacuation. This requires vigilance re weather forecasting and local weather warnings Extreme precipitation is historically rare, but weather patterns are changing
Landslides/ Debris Flows	Triggered by extreme weather and proximal, shallow (1–20 km deep) earthquakes with magnitudes > c. 6 Low-medium frequency local hazard of moderate impact, but could include building damage and casualties	Highest risk hazards are ridges immediately north of SECMOL. Steep slopes can fail, generating slides/flows Management action could include: reducing the slope angle; moving large boulders to lower ground and thus forming a restraining wall; change building usage Small slides/particle flows occur within the lower part of the SECMOL River Valley and the Indus cliffs, south of SECMOL. Risks here are low: maintain a watching brief

Source: Adapted from Petterson *et al.* (2019)

aspects of sustainable development, rural development, rural technologies, English language and life-skills. Students are given a high degree of organisational responsibility, and manage numerous aspects of College life, under the supervision of staff (SECMOL, 2019). SECMOL is situated some 35 km west of Leh (Figure 2) in the region of Ladakh, Jammu & Kashmir State, N. India. Ladakh is a sparsely populated, high-montane desert. Most villages are situated between 3,000 and 4,000 m above sea level. Surrounding mountains rise to elevations of 5,500–7,500 m above sea level. The climate is dry, and extreme in terms of temperatures which can fall as low as −25 to −65°C in the winter. There are numerous, widespread and small to medium-sized villages in Ladakh. Many people live traditional rural lifestyles. There is a growing urban population in the townships of Leh, Choglamsar and Kargil and larger rural village hubs. Ladakh is a border region, with a large military presence. Roads are generally of a high quality. The region can become completely cut off by snowfall during the winter months. Hazards that can affect Ladakh include earthquakes, floods, landslides, droughts and extreme cold.

A focus of this research is on young people and DRR. Young people are viewed from a range of perspectives with respect to DRR. On the one hand, they are designated as "vulnerable", reflecting a lack of social power within most communities, and possessing a

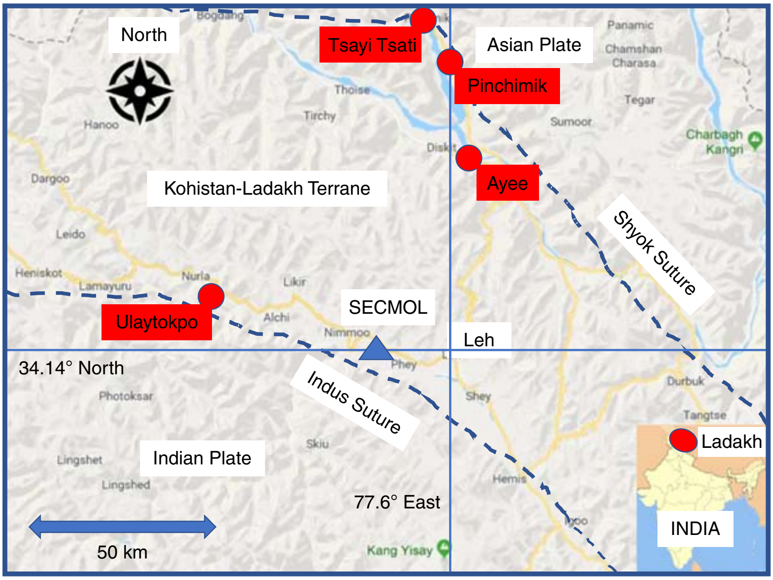


Figure 2.
Location of SECMOL College close to Leh, Ladakh Region, North India

Notes: The diagram indicates the positions of the Indian and Asian Plates, together with the Kohistan-Ladakh Terrane. The Sutures, or boundaries between the plates are areas of higher seismicity. The locations of villages used for social-hazard mapping exercises, (Figures 3 and 4), are indicated

Plate 1.
Images of part of the SECMOL buildings and surrounding environment

Note: SECMOL is situated close to the River Indus, within a high-mountain terrane environment lack of local knowledge/hazard awareness. From another stand-point, young people are viewed as "change agents", or people who, once trained, can become active within their communities, influencing better practice (Abramson *et al.*, 2010; Fothergill, 2017; Johnston *et al.*, 2011; Manesh, 2017). Research presented in this paper results from a series of community exercises with groups of young people and staff at SECMOL. Results from this work are used to inform the geoscience-policy-practice platform.

Methodology

This methodology for this work is, in part, inspired by workers such as (Cronin *et al.*, 2004; District Disaster Management Plan, Leh, 2011; Dransch *et al.*, 2010; Greiving, 2006; Le Masson, 2015; Hearne and Shilston, 2017; Kaur *et al.*, 2018; Papathoma-KÖhle *et al.*, 2016; Shah *et al.*, 2018; UNISDR, 2006). Le Masson (2015) examines a range of social dynamics that impact upon DRR in Ladakh, including the increase in nuclear families, the reduction in polyandry, changing demographics, historical/cultural influences, the presence of Buddhism/Islam, colonial history, and remote geographies. This background forms part of the developmental and regional context for interconnected geoscience approaches (Petterson, 2019). Le Masson (2015) argues that current Ladakhi DRR practice relies too much on scientific and technological approaches typical of the "dominant approach to DRR" (Gaillard, 2010). A more balanced approach is advocated, that examines and responds to the root causes of population vulnerability, drawing on local (rather than external) capacity. The Leh District disaster management plan, whilst extensive in descriptive terms for the 2010 Leh flooding disaster, is light on future policy and planning. This work can inform a more future-planning oriented approach. Le Masson (2015) notes that people have re populated high-risk-flood areas of Leh, and notes the limited DRR capacity within Ladakh. This work indicates possibilities for accessing existing Ladakhi capability for DRR. Dransch *et al.* (2010), Kaur *et al.* (2018) and Greiving (2006) present advice/methodologies for integrating hazard, risk and vulnerability data into map format, and suggesting methods for calculating vulnerability and risk. This paper has used, in part, some methods described by these authors, particularly working with students in assessing the vulnerabilities of demographic subsets within communities, and infrastructure. Petterson *et al.* (2019) geohazard assessment results are interweaved into this work. Ideas and methods reported by Papathoma-KÖhle *et al.* (2016), Dransch *et al.* (2010) (e.g. Table I), UNISDR (2006) and Cronin *et al.* (2004) have been extensively used in this paper, working with staff and students to articulate individual ideas concerning risk, hazard and vulnerability, using their own maps and world views. The highly-illustrative and pictorial, and field-based-experiential approach of Hearne and Shilston (2017) has been adopted, working with SECMOL communities in the field environment, sharing mutual experiences of hazards and vulnerable elements within and around the SECMOL campus. The work of Shah *et al.* (2018) is critical, as it includes detailed work with communities across Kashmir and Ladakh, assessing levels of awareness re DRR. Findings were mixed. Communities had an increased awareness of floods following the 2010 Leh floods, but a variable appreciation of other hazards (e.g. earthquakes and landslides). Even the prescient knowledge of floods did not prevent people returning to, and re-settling within, areas of high flood risk. This paper assessed, and worked with an aspiration of increasing awareness of a range of hazard types.

A cohort of 40 SECMOL students were involved in a range of planned DRR activities, designed to: assess existing levels of initial DRR awareness; increase hazard and risk awareness (hazard defined as a phenomenon that can cause harm, and risk as the probability that the hazard will cause harm and the possible magnitude of harm produced); assess vulnerable elements; explore ideas for mitigating risk/increasing resilience (resilience being defined as the ability of a community to both prepare for and mitigate disasters and recover from disasters); and working within the SECMOL environs, to further develop DRR awareness and exercises. Bespoke learning experiences explored the concepts of hazard and risk, alongside examples of the causes, magnitude and impacts of geo-meteorological hazards. Smaller groups of students (14 students) undertook a range of more intensive student-focused exercises centred upon hazard awareness (cause, magnitude and potential impact), village and College mapping (spatial mapping of constituent components of the college or village), vulnerable element analysis and hazard and risk mitigation/resilience analysis (Table II). Exercise 1 assessed pre-existing awareness levels of earthquakes, floods, landslides and droughts. Awareness was assessed through group discussions and

Exercise	Purpose, key results
Identification of Hazard	Purpose: to ensure all participants had a workable knowledge of the definition of hazard and risk and the development of an ability to apply knowledge Participant awareness of hazard and risk was low-moderate, depending on hazard type. Students were most aware of floods and landslides, Although conscious of earthquakes, these hazards, and the risks associated with earthquake hazards were relatively unknown. Other identified hazards included droughts, fire, and health related hazards (e.g. poor sanitation, domestic waste)
Village and College Social Mapping	Purpose: to focus students on village/college for DRR work in terms of constituent elements and demographics Participant spatial awareness was good. Maps were constructed with a good level of detail and logic. Knowledge of home village was high. College spatial knowledge was competent: this increased with residence time at SECMOL. Village-mapping indicated a close consciousness of mountains, the main water supply, and rivers. Alternative water supply knowledge was more limited. A significant proportion of vulnerable demographics are present in villages (e.g. children, carers, older people). "Private Business" was viewed as "important": many villages have a limited cash economy
Village/College Vulnerable Element Analysis and weighting exercise	Purpose: for students to consider vulnerability and vulnerable elements "Vulnerable elements" was defined, and a list of main elements mutually agreed. Students quickly/knowledgeably created lists/maps. Weighting of element assessments variable. Students struggled to allocate weighting priorities. High ratings attached to some elements […] e.g. school bus
Hazard and Risk Mitigation/Resilience Improvement Analysis	Purpose: to analyse methods for risk reduction at village/College levels Social mapping and vulnerable element analysis formed the baseline. Students considered how risk could be reduced. Student solutions were people-focused, e.g. how existing College/Village management systems could be adapted for DRR reduction, and how vulnerable demographic elements could be properly considered (e.g. children). Physical elements were then considered. In most cases, more than one water supply could be identified. Farmland was viewed as "less important"/difficult to protect (farmers may view this differently). Village amenities (e.g. community hall/Monastery) were viewed as culturally important with uses for evacuation/safe accommodation during disaster
Potential DRR learnings from other SECMOL systems	Students highly aware of the value of managing College waste streams (toilet and all other waste streams). The dining hall earthquake proof design and mud-bricks technologies are viewed as "appropriate Ladakhi solutions" with adaptations to aspects of DRR

Table II.
Summary of exercises undertaken with SECMOL students

student-only activities (e.g. students were asked to provide three key facts for the causes/impacts/magnitudes of earthquakes). Following DRR formal lessons, students then undertook village and/or College mapping exercises. The data were analysed for vulnerability assessment of identified elements. Exercises concluded with group discussions on risk mitigation and resilience-building options. Methodologies followed approaches published in articles such as Cronin *et al.* (2004), IHRAI (2015), Johnston *et al.* (2014), Pınar (2017), UNISDR (2006), Papathoma-KÖhle *et al.* (2016) and Dransch *et al.* (2010).

Values of between 0 (limited/no awareness) and 5 (exceptionally high awareness) were determined according to knowledge displayed during preliminary exercises. Using earthquakes as an example: a Level 1 equates to a simple knowledge that earthquakes exist, but a lack of awareness of causality; Level 2 equates to a knowledge that earthquakes are linked to plate tectonics; Level 3 equates to a knowledge that geological structures (faults) focus earthquakes; Level 4 equates to a knowledge of earthquake parameters (e.g. epicentre, focus, magnitude and energy); Level 5 equates to an understanding of how 1–4 affects impacts. Similar knowledge-level estimates were applied to floods, landslides and droughts, normalised to students awareness of domestic waste management (see below).

Exercise results were recorded as analytical debate notes, specific data, maps and tables (Tables II–VI and Figure 3 and Plate 2). Levels of awareness are compared/normalised to student knowledge of domestic waste management, a high-priority issue at SECMOL. Unlike most of society, where consumers are largely separated from waste disposal/recycling, SECMOL deals with every aspect of waste management, from the receipt of waste, to re-use, recycling and disposal. SECMOL operates strong sustainable development principles and is unconnected to electricity, water or waste grids. The College develops its own solutions for energy/toilets/sewage/domestic waste. Students are well-prepared for the holistic waste management cycle, and good/poor practice. Students are actively involved in all forms of waste management (waste reduction/segregation-sorting/re-use/re-sale/disposal. (e.g. Figure 5). This existential high awareness level for waste serves is an excellent comparator for DRR awareness levels.

Staff/students undertook a number of DRR fieldwork experiences. Field groups witnessed a range of geohazard/hydrological related phenomena, engaging in field activities that included: landslide deposit identification/description; flood deposit observation/measurement; floodplain/river valley morphological observation and analysis; slope angle measurement; vulnerable element mapping; and group discussions re hazard impacts for earthquakes, floods and landslides, as a cumulative multi-hazard and as individual hazard-types.

Results

Examples of results from the various exercises are shown in Figures 3 and Plate 2, summarised in Figure 4, and presented in Tables II–VI. Hazard awareness was low to variable. Knowledge baselines were low-very low for earthquakes, and higher for local aspects of floods/landslides/droughts (similar to Shah *et al.*, 2018). Student awareness levels were variable, reflecting differing individual educational-geographical contexts. Earthquake awareness was largely gained from the internet/TV media, and limited previous school education. Earthquake knowledge was abstract and viewed as unimportant. There was no community knowledge of historical earthquake events within the local environment. Earthquake global distribution and causality were vaguely understood. An ability to apply theoretical knowledge for local use was lacking prior to subsequent teachings. Flood awareness was significantly higher than earthquakes. Although Ladakh is a desert environment, the 2010 major flood event (Petterson *et al.*, 2019; Bhan *et al.*, 2015) was within the student memory, some of whom were affected by the disaster. The students had also gained knowledge from their community elders. Awareness of flood hazard-causes, apart from heavy rainfall, was limited. There was a lack of knowledge of how rainfall events are localised, and water catchment dynamics, except for village irrigation applications. Landslide awareness levels were intermediate between

Table III. Population, household, vulnerable element scores, demographic and gender data for examined Ladakhi Villages

Village name	Number of households	Population	Vulnerable elements Value matrix, 1–5, 5 highest		Village demography % by age range		Male Female
Pinchimik, Nubra District	85	500	Water supply	4	1–11	15%	60% female
			Farmland	3	11–25 (youth)	30%	
			Houses	3	Working	30%	
			Monastery	4	Carers	10%	
			Clinic	4	Older	10%	
			Private Business	2	Disability	5%	
Ayee, Nubra District	35	150	Water Supply	5	n/a		n/a
			Farmland	4			
			Houses	4			
			Monastery	4			
			Community Hall	3			
			Clinic	5			
			Private Business	5			
TsayiTsati, Nubra District	35	370	Water Supply	5	1–11	15%	52% female
			Farmland	5	11–25 (youth)	20%	
			Houses	5	Working	30%	
			Monastery	5	Carers	10%	
			Community Hall	3	Older People	24%	
			Clinic	5	Disability	1%	
			Private Business	5			
Ulaytokpo, Lamayuru (Indus Valley) District	25	50	Water Supply	5	1–11	16%	60% female
			Farmland	4	11–25	37%	
			Houses	4	Working	31%	
			Monastery	3	Carers	8%	
			Community Hall	3	Older	8%	
			Clinic	5	Disability	0	
			Private Business	5			

Note: Data derived from community discussions and analysis

flood/earthquake awareness. Landslides are common on Ladakhi roads, and within high-montane village settings. Students who were well road-travelled or came from high-montane villages possessed the highest landslide awareness. TV/internet media commonly discuss landslides. A wider knowledge of landslide causality, ranges of magnitudes/impacts and spatial distribution was lacking. Droughts were well understood. Ladakhi communities exist within dry-extremely dry environments. There is a high knowledge of water transport engineering and irrigation. A knowledge of droughts compared closely to domestic waste awareness, with earthquake awareness being situated at the other (lower) end of the awareness spectrum (Figure 4).

Table IV. Qualitative community assessment of SECMOL College discrete elements, with related commentary on community values for each identified element

Vulnerable element	Commentary
Road Bridge	Participants significantly concerned: road bridge viewed as essential to communication with “home”. See comments for school bus
SECMOL College BUS	Although a mobile and relatively replaceable element, the College bus appeared as of the highest concern to participants
College Buildings	Viewed as of high significance for shelter purposes and posing a life hazard if the buildings collapsed: further strengthen/change usage for some hazards
Animals	SECMOL keeps a small dairy herd. Participants demonstrated a strong emotional attachment to the cows, and wanted these protected
Food Supply	Food is stored within a pest free cool room (summer) and warmer room (coldest season). This was given a high value, particularly for the immediate post-disaster phase
Solar Energy Generators	These were given a low-medium significance level. Participants felt they “could cope” without power. Many Ladakhi villages operate on low energy requirements
Water Supply	The water supply was given a low-moderate level of significance. It was acknowledged that the well may be at high risk for some hazards. River Indus was viewed as a reliable alternative water supply
Farm, sports fields, and other elements	These “other elements” viewed with a relatively low priority. There was a recognition that open spaces are useful as helicopter landing sights (the large military presence in Ladakh makes helicopter rescue a realistic possibility). However, it was argued, that helicopters could possibly land in other spaces close to the college

Table V. Student suggested methods for improving resilience to hazard-risk at village level

General Awareness	Levels of awareness for disaster and risk at village levels viewed as quite low, although variable. Areas that experience landslides and floods are more aware (on local scales). Earthquake hazard awareness thought to be “very low”
Social Mapping at Village Level	Students felt that their villages would benefit from a “professional mapping exercise” of vulnerable elements and community-inclusive management/ mitigation/resilience discussions
Links to Regional Disaster Management	Some students are aware that Ladakh has regional/ sub-regional disaster and risk management offices/officers. They deemed it important to link expertise to individuals within the village who could become disaster and risk wardens. Similarly, a linking of village level governance with wider governance was viewed as important
Monasteries and Monks/ Nuns	Monasteries were viewed with a particular importance re disaster and risk. Monks (and nuns) are viewed with a high respect, with close two-way links between monks/nuns and community. Monasteries may also be a place of refuge, as they are mostly well built/located on higher ground

Table VI. Student suggested methods for improving resilience to hazard- risk at SECMOL

General Awareness	It was deemed important that an overall raising of awareness of a full range of hazards was required for college staff and students
Disaster and Risk Officers	Students have numerous managerial and organisational roles within the College. Designation of some students for hazard and risk specialisms, with appropriate training was considered to be appropriate
Earthquake Proofing	When the issue of earthquake proofing of buildings was raised students thought this to be a good way forward but recognised affordability challenges, particularly as they saw the risks as relatively low
Evacuation Procedures and Practice	Students thought that this is an area that could be further developed, particularly for flood risks. Sports fields were viewed as “safe areas” for hazards such as earthquakes

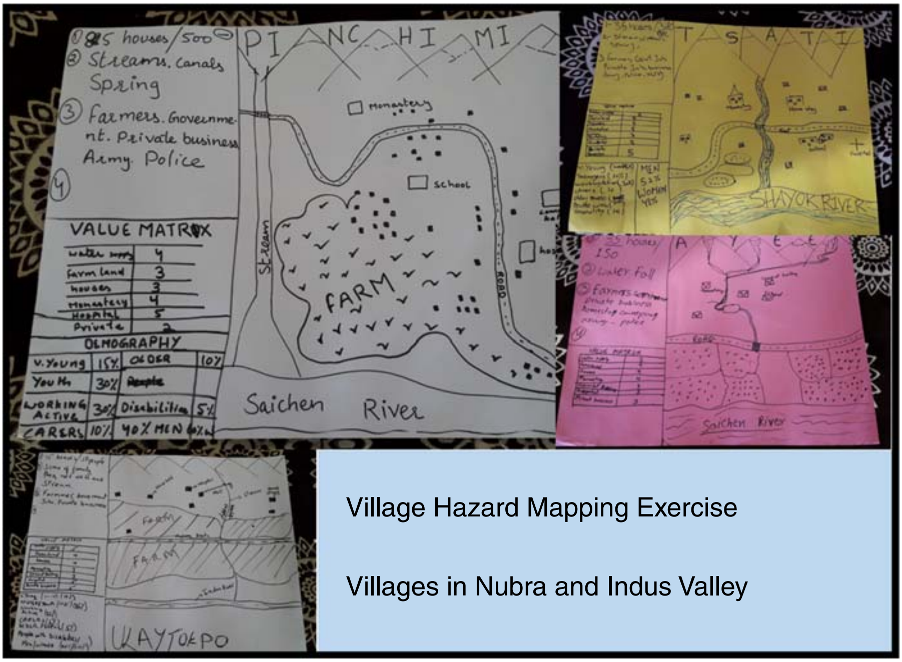
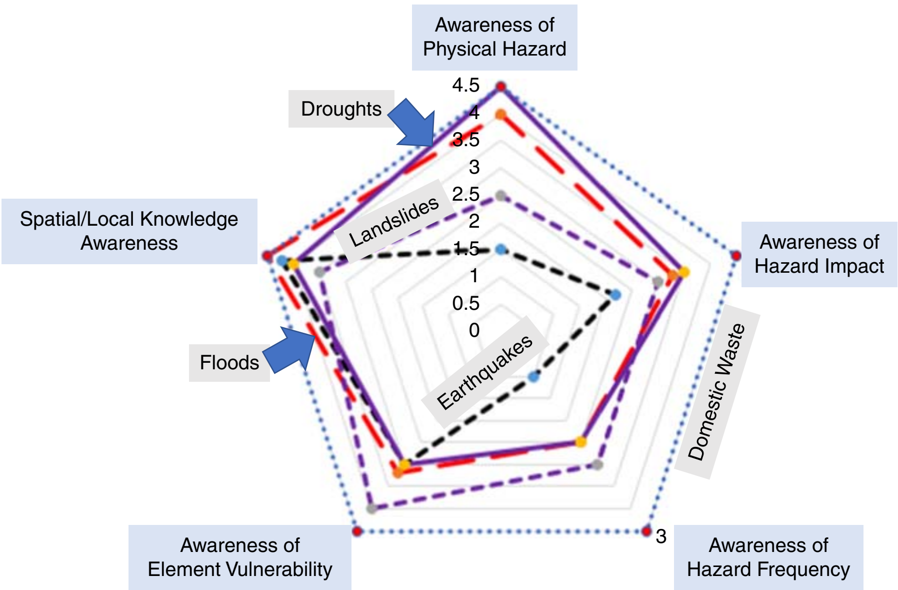


Figure 3. Examples of student village mapping exercise outputs

Note: Village locations indicated in Figure 2

Plate 2. Examples of student mapping exercises for SECMOL College

Following hazard and DRR teaching sessions (e.g. dealing with subjects such as hazard causality, spatial distribution, frequency, magnitude, impacts, vulnerability and resilience) the students engaged in a series of exercises designed to capture their hazard and DRR thinking and analysis (Plate 1 and Figure 3 and Tables II–IV). Results from these exercises indicate that: spatial awareness and local village/college environmental is high. The main elements of villages/College were readily represented on maps resulting from group and individual work. Group-work revealed high levels of consensus amongst the students relating to what should/should not be recorded on maps. Unsurprisingly, a close consciousness of mountains was



Notes: Five awareness aspects are shown as terminal points of a pentagon: physical hazard, hazard impact, hazard frequency, vulnerable elements and spatial knowledge. Levels of awareness are compared to student awareness of domestic waste management (SECMOL encourages a high student involvement in domestic waste management). Spatial/Local knowledge awareness scores highly for all hazard types. Earthquakes display the lowest levels of awareness, particularly for aspects of the physical hazard itself. Floods and droughts score the highest values with landslides in between earthquake and drought/flood awareness levels

Figure 4. Radar Hazard awareness diagram

strongly expressed (this was invariably the first feature that was drawn). The second highest level of consciousness, particularly for villages, related to water supply. Houses, buildings, roads and agricultural components, scored highly in awareness levels. Other components, such as monasteries, the College bus, private-businesses (e.g. guest houses) and College animals (a small dairy herd) appeared quickly on student maps. Students attached high levels of importance to these components, confirmed by subsequent value estimations. Allocation of numerical values between 0 and 5 (5 being highest value) for community values of map components elements, proved to be a more difficult exercise. Students were encouraged to discuss methods and reasoning relating to valuation. Some students struggled to give values less than 4/5 for many map components. Table III lists examples of valuations for four Ladakhi villages. Whilst the students struggled to allocate low valuations, a general picture emerged. Clinics and water supplies scored highly (as did food stores in subsequent discussions), whilst agricultural land scored at the lower end of the scales. Monasteries and the College bus scored highly, reflecting personal/ community/cultural values. A bus is a replaceable, mobile entity, but represents a connection between the college and the outside world. Monasteries and monks/ nuns are held in high esteem and viewed as important for DRR management.

Students progressed to demographic elements (Table III) testing perceptions of village population sub-groups. Student awareness was relatively high for village population numbers and households, and broad divisions between agricultural workers/younger non-working people. Ladakhi villages tend to be small, and the students are an integral part of cohesive village social units. Student perceptions were less adept at defining "vulnerable people" with respect to hazard and risk. For example, young children were not initially viewed as particularly vulnerable, because they spent time with mothers in the field, or with grand-parents. Deeper analysis identified types of people who could be more adversely affected by hazards. Older people, people with disabilities, and (eventually) younger people were viewed as being at higher levels of risk, compared to fully-abled adults. The "more vulnerable people" elements of villages constitute between 30 and 40 per cent of total populations. Villages have a higher ratio of women for much of the time.

With respect to DRR mitigation/management, students considered that villagers, in general, had low levels of DRR awareness with the exception of villages that had recently experienced landslides or floods. It was suggested that this could be addressed through village-community level awareness raising sessions provided by outside "experts". Sessions involving the whole-community were considered vital, with separate meetings addressing groups such as females viewed as valuable. A detailed hazard/social map of villages was considered important with respect to DRR planning and management. The appointment of a village hazard and risk officer, who could connect with Leh (and other) District DRR governance was regarded as "vital" to maintaining/mainstreaming hazard and risk management. SECMOL, as a College community, was considered to be at a higher level of awareness with respect to DRR, with room for improvement. As SECMOL actively encourages students to participate within College management it was suggested that a student (working with a nominated staff member) could become a "hazard and risk officer", with a remit of raising awareness, and promoting management best-practice. The SECMOL approach to domestic waste management was highly-valued as an appropriate generic management model.

SECMOL results analysis

The methodology and approach adopted for this work is generic, and applicable to a range of communities (e.g. school, village, company and government department). The methods are particularly conducive to a school/college environment, as there is a precedent discipline and culture for this genre of pedagogy and research, but an able researcher/facilitator can adapt the methods for other audiences. The exercises provide valuable insights regarding: student DRR awareness and perception including: the articulation/definition of their village/college contexts through simple map exercises; an ability to integrate spatial and theoretical data; and a potential to integrate community knowledge for hazard/risk resilience building purposes. The exercises reveal knowledge/awareness gaps, and areas of misconception. This analysis combined with a multi-hazard assessment of the SECMOL region (Petterson *et al.*, 2019) provide material for developing evidence-informed DRR management strategies.

SECMOL students displayed the lowest awareness of infrequent (but potentially very high magnitude) hazards, and the highest awareness of higher-frequency hazards. If the exercises were conducted prior to 2010, it is predicted that peoples' awareness of floods would have been lower/low, perhaps similar to that of earthquakes. Major floods are a historically infrequent occurrence within Ladakh with frequencies of 10–50 years (Petterson *et al.*, 2019; Bhan *et al.*, 2015). From an inter-generational community-knowledge standpoint, they are, therefore, infrequent. Low-medium magnitude/impact landslides are relatively frequent (monthly to 5 yearly) and have gained significant levels of community awareness. Larger, more impactful landslides, triggered by large-magnitude earthquakes/extreme weather events are less well understood. These variable awareness results confirm the work of Shah *et al.* (2018), and highlight areas requiring focus for DRR policy development and practice. This work reveals that successful Ladakhi community adaptation/management strategies exist for severe cold and drought conditions. Lessons learned from this experience can be studied and applied to other DRR themes. Table V records ideas from students that link their new heightened awareness of hazards and hazard management with their intrinsic knowledge of village environments and communities.

SECMOL students have a relatively good level of spatial awareness. This reflects their upbringing, within small and isolated rural village communities that require an intrinsic understanding of the immediate environment for survival/maximisation of local resources. There may be a nomadic element to some lifestyles requiring sound spatial knowledge over wider regions. This awareness is a foundation for multiple hazard analyses and risk assessments for villages/towns/colleges. If spatial and DRR knowledge levels are further developed, there are opportunities for developing Ladakhi-based, DRR-relevant and capability.

This work suggests that selected younger people can be trained for a range of DRR management. This can be used within their village and school/college environments. Ladakhi younger people have a strong knowledge of village/town social power structures, relative hierarchies and changing cultural dynamics for their societies (Dinnerstein, 2013). Younger people tend to occupy lower levels of the power hierarchy within societies in general, and can be excluded from important discourse. Their abilities may be underrated. This can expose young people, particularly at the later teenage/younger adult stage, to higher levels of vulnerability to disaster and risk. These exercises have demonstrated that, with targeted training, younger people can become part of a hazard and risk management plan, and through this, improve resilience within their village, as well as reducing their own levels of vulnerability (Fothergill, 2017; Manesh, 2017). DRR-trained younger people can become a part-solution for the further development of Ladakhi local capability, addressing a gap as noted in Le Masson (2015). Table VI demonstrates aspects of this discussion recording ideas for improving resilience to hazard and risk at SECMOL College.

Good practice at SECMOL that can be adapted for hazard and risk management

SECMOL students are encouraged to take on a range of organisational/administrative roles within the College (e.g. sanitation, cleaning and timetabling). Students gain experience of people management/organisation. SECMOL teaches a practical mountain-rural development and technology curriculum. The College mantra is "learning through doing". As an example, students manufacture high-insulation bricks made from local earth materials. The bricks maximise solar heat retention, resulting in internal building temperatures of c. +5°C when external temperatures are c. −15 to −25°C. This learning culture raises student awareness of practical environmental management. Another practical sustainable development management strategy is waste management (Figure 5). Students participate in all aspects of the waste lifecycle, from creation to disposal. If waste is disposed within a landfill, this is viewed as a disappointment. Practical measures are adopted for the reduction, re-use and recycling of waste. For example, students assist in the design of waste-sorting-systems and waste-stream-management (Figure 5) and waste materials are re-sold for money (e.g. electronic materials), re-used (e.g. in adding insulation to earthen bricks) and composted. The SECMOL pedagogical philosophy (independent learner, life-skills acquisition and practical hand-on learning), combined with the adoption of sophisticated management approaches, encourages the development of generic and transferrable skills. These can be adapted for Ladakhi DRR policy and practice, enhancing local capacity (e.g. Le Masson, 2015).

SECMOL has recognised the presence of earthquake risk with some of its later buildings. A good example is the dining hall, completed in 2017. This building has incorporated a number of design features to increase earthquake resilience (Figure 6). Thick wooden beams form the building superstructure. Numerous triangle structures have been in-built to maximise structural strength. Rivets and steel plates add strength to wooden beams. Wooden beams are embedded within panels of steel-reinforced cement panels. Windows are arched. Building foundations contain graded cobbles/pebbles/and, designed to dissipate seismic energy. The building was constructed to strict financial constraints, for

Figure 5.
Photograph of bins used to collect a range of domestic waste streams

Note: Students are actively involved in the design of waste streams and its subsequent lifecycle management

Figure 6.
Examples of design features for the earthquake-proofed dining hall at SECMOL

Notes: Arrows indicate arched windows, triangle structures, strengthened wooden beams with metal rivets and plates, and steel reinforced concrete wall panels

affordability, adopting an "appropriate affordable technology", approach rather than using the "highest-level-most-expensive-technology". This building is useful to wider Ladakh as an example of good practice for earthquake resilience.

Interconnected geoscience: the science-policy-practice platform

Challenges exist connecting science, policy and practice. Research/science can feed directly into policy/practice if has been designed with end-users in mind, and if it is of immediate relevance to policy/practice. An example of research into policy/practice is the identification of people with disabilities being at significantly greater vulnerability to disasters. The

Pacific Community (SPC) and the Pacific Islands Forum Secretariat worked collaboratively to produce a Pacific Framework for the "Rights of Persons with Disability" that included recommendations for awareness with respect to DRR. SPC further mainstreamed the disability issue within its DRR practical programme (e.g. PIFS, 2016). Research can also be so theoretical, or inappropriate, or expressed in inaccessible specialist language, that integrating results into policy and practice within realistic timeframes can prove difficult/impossible (Petterson, 2019; Choi *et al.*, 2005; DfID, 2014; Joynson and Leyser, 2015; Mazor *et al.*, 2018; Viergever, 2013; Weischelgartner and Kasperson, 2010). Other workers advocate more multidisciplinary/holistic approaches, designed to take account of social, economic and development contexts, in collaboration with end-users and policy-makers (Petterson, 2019; Weischelgartner and Kasperson, 2010; Stewart and Gill, 2017; Steffen *et al.*, 2018; Petterson and Tawake, 2018; Petterson *et al.*, 2008; Pacific Community, 2015; IPCC, 2014; Gill and Bullough, 2017; Di Capua *et al.*, 2017; Cronin *et al.*, 2004).

This paper, alongside Petterson *et al.* (2019), contributes to the science into policy and practice conversation. This work takes note of Shah *et al.* (2018) and Le Masson (2015) who comment upon Ladakhi DRR challenges including: limited in-situ DRR capacity; a variable hazard awareness; the return of people back into high flood-risk zones, post-disaster; the over-emphasis on science/technology dimensions and under-emphasis on the social/historic/cultural dimensions; an inability to move recommendations into planning policy; and; an inability to address poverty-linked root causes of development that inhibit DRR good practice, and Dransch *et al.* (2010) who discuss the challenges of scientific communications via maps and related products/services. A theoretical approach of geoscience for DRR termed "interconnected geoscience" is adopted here (Petterson, 2019, Figure 1), and is suggested as an approach that can improve the science-policy-practice interface (see also Gill and Bullough, 2017; Stewart and Gill, 2017). For this paper the geoscience was undertaken in close collaboration with the community it intended to serve, and end-users. This methodology allows bespoke analyses and communication products to be designed that are influenced by the user community. The work takes note of SECMOL community ethos, including a high consciousness in sustainable development, and a focus on practical education and theory that informs mountain development. The "external expert" became part of the SECMOL community, delivering services the community requested. The "external expert" was influenced by SECMOL world-views and local wisdom. This approach helps the science/research to make recommendation for due consideration by Ladakhi DRR policy makers and practitioners. Recommendations (below) are suggested for consideration, and presented in Table VII.

The first recommendation is for external DRR related scientists, geoscientists and technical experts, working in Ladakh, to adopt an "interconnected approach", to research, as outlined in this paper and Petterson (2019).

The second recommendation concerns in-situ Ladakhi DRR capacity, and the suggestion of Le Masson (2015) to rely more on enhanced local capability. This paper has demonstrated that local Ladakhi capability exists, or can become existent, with targeted training. SECMOL students can be incorporated within DRR activities, initially at local levels and more widely with further experience and training. A subset of younger people in schools/colleges could become community DRR activists and a catalyst for change. A DRR capability development scheme could pilot projects developing DRR talent for a number of villages/Colleges and similar. If successful the scheme could be scaled up. The purpose is to further enhance Ladakhi DRR capability.

A third recommendation concerns communication of DRR related ideas and outputs. This work has produced a range of student-populated DRR products: produced by the community, for the community, with the external "expert" as a facilitator and guide. The process the students and staff experienced comprising peer-peer/group thematic

Table VII.
Recommendations from this work for the Ladakhi DRR science-policy-practice framework

DRR Issue	Science	Policy	Practice
DRR science into policy and practice vs science for its own sake	Adopt an "interconnected" approach. Cognisance of context, world views, local values, developmental issues and so forth essential. Work with these in research design, practice, and outputs	Geoscience hazard focus here: earthquakes, floods, landslides. Geoscientists can work with policy needs in mind, e.g. how to make infrequent hazards such as earthquakes important to communities and planners	DRR practitioners to influence the geoscientist, encouraging services and outputs developed with practitioners in mind. E.g. production of landslide hazard maps accessible/influenced to/by village communities
DRR Capability within Ladakh	Geoscientists can work with communities, as demonstrated here for SECMOL, using accessible practical approaches, immersing "lay people" within concepts such as hazard, resilience, etc.	Geoscientists collaborating with DRR practitioners, together, within a community setting, are more likely to produce relevant policy-friendly options. E.g. affordable earthquake-proofing of buildings using local knowledge	Practitioners can work with geoscientists in rolling out science-oriented DRR community exercises, with the aim of increasing DRR awareness and harnessing local capability for DRR
World Views/ Local Wisdom	Geoscientists may have to train themselves or take advice on utilising local wisdom into hazard analysis	Policy makers to take on-board advice from science/practice and community to give high planning/mitigation values and/or intervention actions to areas of high community value and advise scientists that their work takes these issues into account	Practitioners to work with communities and geoscientists in assessing which indigenous cultural/spiritual values and beliefs are essential for DRR. E.g. high community values for Monasteries, local clinics
DRR Capability networks	This case study demonstrates that strong Ladakhi capability exists outside of Leh. Many similar capability centres exist in schools, colleges, villages, etc., throughout Ladakh. These can be networked to increase Ladakhi DRR capability	DRR policy can learn from existing non-DRR policy in other subject areas, with applications to DRR, using Ladakhi capability DRR. E.g. spatial planning policy in urban and rural environments	SECMOL has demonstrated appropriate local-culture-informed capability in areas of relevance to DRR practice, such as earthquake-proofing buildings, developing high-insulation building materials and waste management. SECMOL lessons can be more widely applied
DRR Communication	A range of geoscience based DRR outputs have been generated here working with the community from a science baseline that allowed all to take part	Products and outputs co-designed by community, scientist and practitioner can seamlessly inform policy. E.g. demographic vulnerability to disasters within villages data can inform policy re DRR and persons with specific vulnerabilities	Community outputs such as village and college maps with key data re infrastructure, buildings (and building use), social and demographic data and related vulnerability maps and tables of direct use to DRR practitioners
DRR Management	DRR management and mitigation options by existing good management practice in domestic waste	DRR policy can learn from non-DRR management practices, with applications to DRR, using Ladakhi capability	Parallel good practice management systems in non-DRR areas can be tailored for DRR using Ladakhi expertise

discussions has been an effective educational process, and can be further-refined. The maps/tables produced are "stepping stones" to the introduction of more complex geohazard and DRR analyses. This approach can be used by regional DRR practitioners with results informing policy.

A fourth recommendation is to give appropriate value to local wisdom/world-views for the full science-policy-practice spectrum. For example, an outsider to Ladakh may under/over-value specific assets with respect to vulnerability. SECMOL students give a high value to the College bus and its symbolic meaning (access to the world beyond SECMOL). Values such as these should be factored into DRR research, practice and policy to ensure communities will respond positively to DRR policies, and DRR-informed planning processes.

A fifth recommendation focuses on aspects of awareness in Ladakh, linked to DRR. This work agrees with Shah *et al.* (2018) that infrequent hazards (but potentially highly-impactful) require special attention to raise awareness levels. Awareness of people vulnerability (to DRR) requires careful consideration. This study at least, suggests that younger people are not necessarily aware that certain social subgroups are more vulnerable than others, and DRR policy and practice can include these issues.

A sixth recommendation is for central DRR agencies to further reach out and link up with pockets of expertise that exist in Ladakh, beyond Leh. These can be harnessed, with appropriate management, to serve regional DRR management. SECMOL is an example of a rural college with high levels of expertise in mountain development. SECMOL students are examples of a capability that could become DRR-focused. Village populations have communal memories of disasters: these could be studied/collated, further informing DRR policy. Collections of expertise occur across Ladakh (e.g. Kargil, University of Kashmir campus and the military). There is potential to further integrate Ladakhi-based capability for DRR.

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Corresponding author
Michael Petterson can be contacted at: michael.petterson@aut.ac.nz