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Authors: Sudmeier-Rieux, Karen, Jaboyedoff, Michel, Breguet, Alain, and Dubois, Jérôme

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The 2005 Pakistan Earthquake Revisited: Methods for Integrated Landslide Assessment

Karen Sudmeier-Rieux, Michel Jaboyedoff, Alain Breguet, and Jérôme Dubois*

** Corresponding author: karen.sudmeier-rieux@unil.ch*

University of Lausanne, Faculty of Geosciences and Environment, Institute of Geomatics and Risk Analysis, Amphipôle 330, CH-1015 Lausanne, Switzerland

Five years after the 2005 Pakistan earthquake that triggered multiple mass movements, landslides continue to pose a threat to the population of Azad Kashmir, especially during heavy monsoon rains. The thousands of landslides that were triggered by the 7.6 magnitude earthquake in 2005 were not just due to a natural phenomenon but largely induced by human activities, namely, road building, grazing, and deforestation. The damage caused by the landslides in the study area (381 km^2) is estimated at 3.6 times the annual public works budget of Azad Kashmir for 2005 of US$ 1 million. In addition to human suffering, this cost constitutes a significant economic setback to the region that could have been reduced through improved land use and risk management. This article describes interdisciplinary research conducted 18 months after the earthquake to provide a more systemic approach to understanding risks posed by landslides, including the physical, environmental, and human contexts. The goal of this research is twofold: to present empirical data on the social, geological, and environmental contexts in which widespread landslides occurred following the 2005 earthquake; and, second, to describe straightforward methods that can be used for integrated landslide risk assessments in data-poor environments. The article analyzes limitations of the methodologies and challenges for conducting interdisciplinary research that integrates both social and physical data. This research concludes that reducing landslide risk is ultimately a management issue, based in land use decisions and governance.

Keywords: *Integrated risk management; landslide mitigation; vegetation cover; post-earthquake Pakistan; community risk perceptions; interdisciplinary research; Pakistan.*

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Introduction: the 2005 Pakistan earthquake and landslides

On October 8, 2005, a 7.6 magnitude earthquake caused an estimated 73,000 casualties and left 3.5 million people without permanent shelter in northern Pakistan. Thousands of landslides triggered by the earthquake caused 1000 fatalities, destroyed homes and agricultural land, created artificial dams, and blocked roads for weeks after the earthquake (Owen et al 2008). The worst-affected areas were the North-West Frontier Province (now called Khyber Pakhtoon Khwa) and Azad Kashmir. The Neelum River Valley north of Muzaffarabad, the location of the earthquake epicenter, was blocked for 47 days after the only access road collapsed (Figure 1). An estimated 90% of landslides were small (<1000 m^2 in area) shallow rock and debris falls and mostly involved the top few meters of weathered bedrock, regolith, and soil (Owen et al 2008).

Recent studies of landslide activity in the region show that the number of new landslides since the earthquake increased but not to the extent originally predicted (Khattak et al 2010; Saba et al 2010). Most new landslide areas are found along roads and rivers. According to Khattak et al (2010), 80% of landslides showed little or no change, 9% had increased in size, and 11% showed a partial vegetation recovery on the slopes. During the heavy monsoon rains in August 2010, 170 houses in Muzaffarabad district were swept away by heavy rains, which also destroyed bridges, roads, and land, damaging 2000 houses, killing at least 46 persons, and displacing 25,000 persons (NewsHome.com 2010; Figure 1). Many roads under construction were the cause of most landslides, creating severe disturbance to traffic over several weeks. Thus, 5 years after the earthquake, landslides continue to remain a threat to the population during the monsoon season.

This article describes research that was conducted 18 months after the 2005 Pakistan earthquake and reflections on the earthquake 5 years later. The goal of this research was twofold: to present empirical data on the social, geological, and environmental contexts in which widespread landslides occurred following the 2005 earthquake; and, second, to describe straightforward methods that can be used for integrated landslide risk assessments in data-poor environments.

FIGURE 1 Neelum River and road near quarry north of Muzaffarabad. (Photo by Rauf Qureshi, 2010)

Integrated risk assessments

Over the last few decades, a paradigm shift has occurred from the top-down hazard-oriented approach to disasters to the view that effective risk reduction needs to be integrated with sustainable development approaches (Birkmann 2006). It is now commonly agreed that disasters are "a complex mix of natural hazards and human action" often deeply rooted in social, economic, and political processes that need to be understood for decision-makers and communities to address causes and if possible to prevent or minimize new disasters (Hewitt 1983; Wisner et al 1994). Community-based disaster risk management and integrated risk assessments are being increasingly promoted as more holistic and sustainable approaches to understanding and addressing risk (Kafle and Murshed 2006; Bollin and Hidajat 2006; Wisner 2006; Khan and Mustafa 2007).

However, more examples are needed to illustrate how to operationalize risk assessments, especially in data-poor environments (Cardona 2004). One method of preventing, predicting, and managing landslides is through integrated risk assessments for understanding the geological, environmental, and social contexts in which landslides occur (Crozier and Glade 2005; Leroi et al 2006) (Figure 2). Integrated risk assessments require bringing together data across disciplines. Methods for each context are not new, but the novelty lies in the interdisciplinary coordination. Proponents argue that even if upfront costs for integrated risk assessments may be time consuming and costly, this investment is necessary for prevention measures and reconstruction efforts to be effective and sustainable (Zimmermann and Issa 2009).

Study area: Neelum Valley, Azad Jammu and Kashmir (AJK), Pakistan

The study area—the lower Neelum River Valley with an area of 381 km^2 and a population density of 264 persons/

FIGURE 2 Conceptual framework for integrated landslide risk assessment. (Modified from Leroi et al 2005)

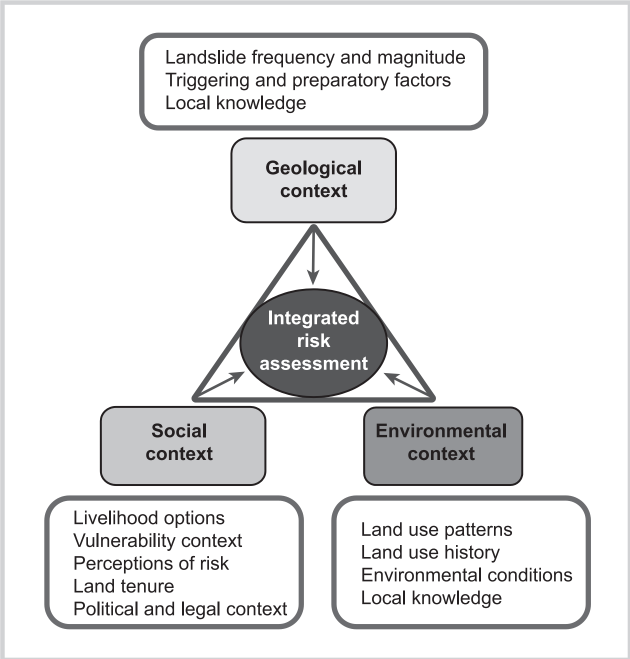

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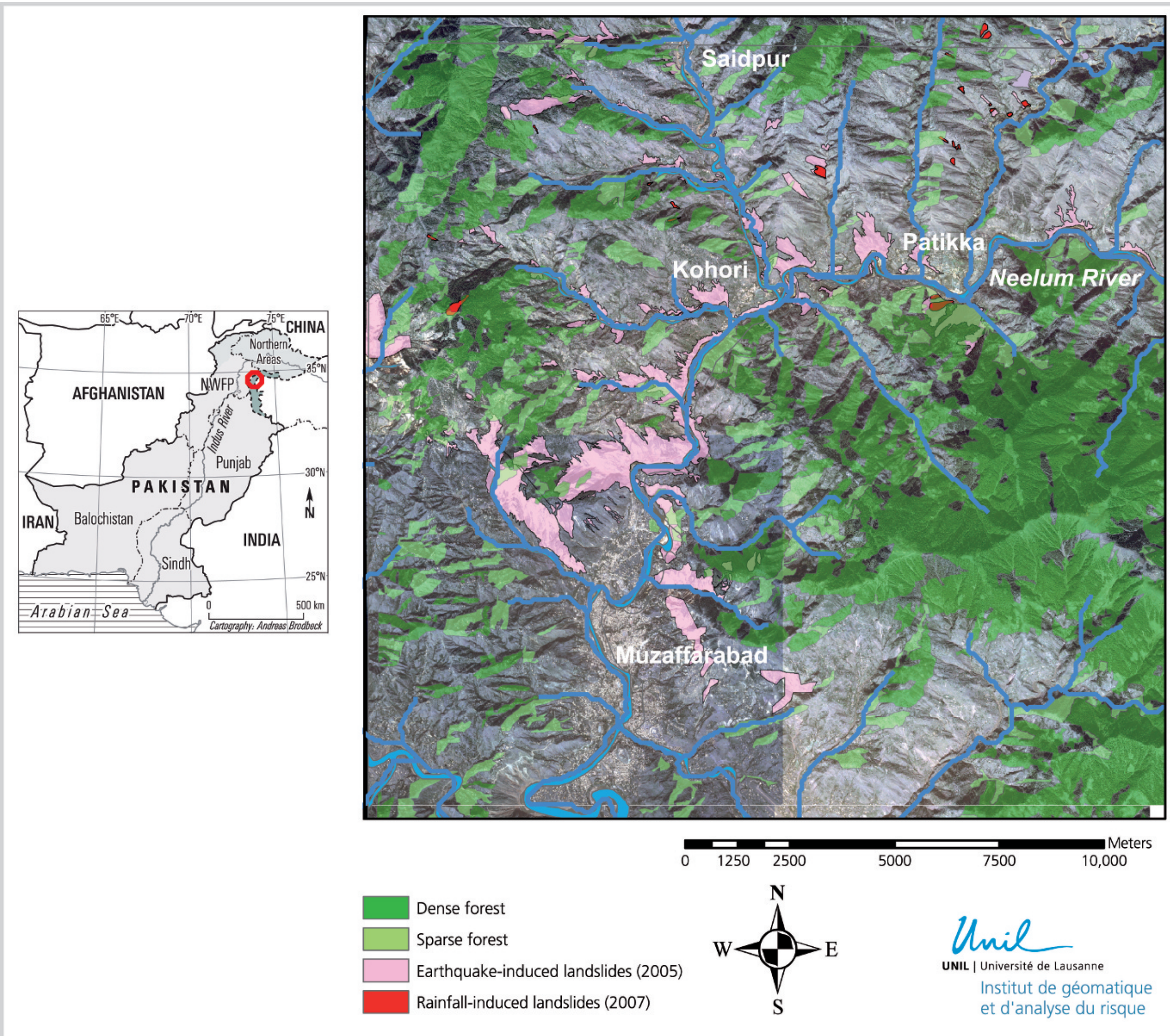
FIGURE 3 Map of earthquake- and rainfall-induced landslides, and forest cover in Neelum Valley, AJK, Pakistan. (Map by Jérôme Dubois and Alain Breguet, University of Lausanne, 2011)



km^2 (AJK Planning Dept 2005)—was chosen because of its 2 very distinct river banks and because this was the location of the earthquake epicenter (34.493°N, 73.629°E) (Owen et al 2008). The lower Neelum River Valley is a west–east-oriented steep V-shaped valley with an estimated slope range of 35–65°, an average width of 15 km, and an altitude range of 800–3000 m (Figure 3).

The study area is largely composed of Murree Formation, a mix of sandstone, siltstone, and shale, characterized by low cohesion and high susceptibility to landslides due to rainfall, and, second, by Abbottabad Formation, largely composed of dolomitic limestone. The average annual rainfall is 1527 mm and can be especially intense during the monsoon months, July and August, with as much as 100 mm during 1 single event (GSP 2007). The southwest-oriented right bank is mainly privately owned and has been converted into pasture fields and terrace agriculture, while the northeast left bank remains largely forested. The left bank has fewer villages and only a few roads, mainly along the river bed. This largely forested area is to a greater extent state owned, with few private and communal lands, or *shamilat*.

The 2 villages that were selected for a study of the social context are Saidpur and Kohori villages in Neelum River Valley, whose economy is predominately based on subsistence farming, fruit harvesting, animal husbandry,

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FIGURE 4 (A) Neogran hamlet, Saidpur village. A rainfall-induced landslide killed 1 child on her way to school in 2007. (B) Damaged house in Saidpur village after 2005 earthquake. Example of modern cinderblock house that was more prone to collapse compared with traditional houses. (Photos by Karen Sudmeier-Rieux, 2007)

remittance income, and various off-farm activities (Halvorson and Hamilton 2010; Schütte and Kreutzmann 2011). In Saidpur village (population 1500 before the earthquake), approximately 100 persons lost their lives during the 2005 earthquake (Figure 4A). Typical for this valley, the village is highly dependent on farming and livestock, combined with remittance incomes from commuters to Muzaffarabad and elsewhere. The main crops are maize, wheat, rice, walnuts, and fruits. The second village, Kohori (population 5000 before the earthquake), supplements its farming income considerably through shopkeeping. Kohori was more severely destroyed than Saidpur, most likely due to the higher frequency of cinderblock construction versus the traditional *katcha* houses, constructed from logs and mud in Saidpur (Figure 4B).

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TABLE 1 Comparative data of land use surrounding landslides as proportion of landslide area. Total number of landslides, $n = 100$; right bank, $n = 84$; left bank, $n = 16$.

Land use/cover[a)]	Landslides (%)	Right bank (%)	Left bank (%)
Grazing/deforested	54.8	59.6	29.7
Terraces	24.0	23.5	26.6
Housing	23.8	22.9	28.1
Forest	17.0	16.1	21.9
Water channel	14.0	15.5	6.3
Road	9.3	7.4	18.8
River	5.0	2.7	17.2
Reforested	1.5	1.8	0.0
Commercial	1.5	1.2	3.1
Footpath	1.0	0.9	1.6
Bridge	0.5	0.3	1.6
Landslides	0.5	0.6	0.0
Water supply	0.3	0.3	0.0

[a)]Multiple land uses possible.

Methods of investigation

The study was divided into 2 parts at different scales. One part was a geological and environmental study of 124 landslides over 381 km^2 in lower Neelum Valley; the second part was a case study of the social context in the 2 villages described above. The first step was to conduct more than 30 interviews with local and national authorities involved in disaster management and land use planning, civil society organizations, village leaders, and women's groups to scope available data and assess the level of interest and knowledge about landslide management.

Geological and environmental data were collected on 100 landslides triggered by the earthquake and 24 landslides triggered by rainfall over 18 months after the earthquake. Landslides were analyzed using a Quickbird satellite image taken on 22 October 2005 (0.6-m resolution) covering all major and many minor landslides within the study area. A quantitative landslide assessment (ie lithology, landslide type, slope gradient, GPS location, and damage assessment) was combined with a qualitative field survey of each landslide. Preexisting land use characteristics were observed on a 200-m strip of land surrounding each landslide (grazing, forested, terraces, gravel excavation, road, trails, housing, etc); vegetation type was noted as well as economic assessments of the damage (forestland, agricultural land, housing), ownership and casualties, and local knowledge of the area. Data from Neelum Valley's right bank were compared with data from its left bank (Table 1).

We focused our study of the social context on 2 villages in lower Neelum Valley, Saidpur and Kohori villages, using a case study approach. The case study was based on 27 semistructured household interviews using a questionnaire and 8 focus group discussions. The study team consisted of a geologist, 2 social scientists, a forester, and 1 male and 1 female translator. Households were sampled to reflect as diverse a range of households as possible, consisting of poor, middle-income, and wealthier families, as well as families living on different types of terrain, from high to low risk. Equal numbers of females and males were interviewed, and several focus groups were female only, interviewed separately by female interviewers. The household interviews included a question on concerns before and after the earthquake to understand how concerns for geophysical risks ranked alongside development-related risks, such as unemployment and housing. Respondents were given a list of options and asked to rank them by order of importance. Households were asked about the perceived causes of the landslides, mitigation, and coping strategies. Risk to buildings and roads in Saidpur was calculated by simplifying a methodology developed for calculating risk in the European Alps (Wilhelm 1997). Risk is determined based on estimates of exposure of houses and roads, the physical vulnerability of buildings, and the probability of landslide reoccurrence.

Results

Interviews with decision-makers and planners demonstrated the great interest in this study. Little or no

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TABLE 2 Ownership of land surrounding landslides as proportion of landslide area. Total number of landslides, $n = 100$; right bank, $n = 84$; left bank, $n = 16$.

Land ownership	Landslides (%)	Right bank (%)	Left bank (%)
Private	50.0	50.0	50.0
Private/*shamilat*	23.0	27.4	0.0
Private/government	17.0	14.3	31.3
Shamilat	0.0	0.0	0.0
Government	10.0	8.3	18.8

data were available, and a low priority was given to landslide mitigation explained by many other competing needs. Institutional divisions and coordination problems impeded information exchange, such as the difficulty of obtaining basic geological maps. Results from the geophysical and environmental study of landslides largely mirrored results from the social context survey: Low awareness about landslide causes and mitigation runs parallel to the large number of small and shallow landslides on privately managed lands caused mainly by overgrazing and road construction.

Geophysical and environmental context: lower Neelum Valley study

The number of landslides and surface area were significantly higher on the right bank ($n = 84$ and 13.45 km^2) than on the left bank ($n = 16$ and 3.57 km^2). There were 22 rainfall-induced landslides on the right bank (0.42 km^2) versus 2 landslides on the left bank (0.092 km^2), which occurred between November 2005 and June 2007. The majority of landslides occurring on the Murree Formation were small and shallow, whereas the landslides near Muzaffarabad occurring on the Abbottabad Formation were large and deep seated.

Table 1 illustrates comparative data for land use on an approximately 200-m strip of land in all 4 directions surrounding each landslide (earthquake triggered). On the right bank 56% of landslides were located in grazing or deforested areas, followed by terraces, inhabited areas, and forested areas. This finding is corroborated by subsequent studies of the area based on remote sensing techniques (Kamp et al 2008; Owen et al 2008; Kamp et al 2010; Khattak et al 2010; Peduzzi 2010).

There are clear ownership differences between the 2 banks, with a higher percentage of land under private/*shamilat* (state land under private management) on the right bank as compared with the left bank, where the forests are state owned and more restricted to public use (Table 2). The majority of slope failures on both banks occurred on southwest-oriented slopes, which tend to be slopes attractive to cultivation and grazing and mainly covered by grasses or shrubs (Table 3). The value of damage caused by the landslides in the study area (381 km^2) was estimated at US$ 3.6 million (including damage to the power supply) and can be compared with the annual public works budget of AJK for 2005 of US$ 1 million.

Geological and environmental context: Saidpur risk map

Because of time constraints and local interest, a combined land use and risk map was developed only for Saidpur (Figure 5) based on the integrative risk model: a geological survey, an environmental assessment of land use, and participatory mapping exercises conducted through focus groups. Land use and risk, more commonly shown separately, have been integrated to better illustrate the cause and effect between the two. Terraces supporting rainfed agriculture cover 33% of the village, followed by grazing (26%) and forest (20%) cover. Those areas most affected by landslides are in grazing zones, concurring with findings from the larger Neelum Valley study area. Figure 5 shows that an entire hamlet is situated within the zone classified in yellow as "highly susceptible" to landslides. One critical portion of the main access road has been classified as "high risk," along with the main bridge at "very high risk." Houses are largely being reconstructed per government earthquake reconstruction standards (light materials and poorly insulated), often on safer ground that was previously under cultivation.

Social context: Saidpur and Kohori case studies

The case study of the social context was focused on understanding the main concerns or perceptions of risk before the earthquake compared with after the

TABLE 3 Vegetation types in relation to landslides.

Land cover	Landslides $n = 100$ (%)[a)]
Grass	92.0
Shrub	86.0
Broadleaf	70.0
Chir pine (*Pinus roxburghii*)	38.0
Blue pine (*Pinus wallichiana*)	16.0
Deodar pine (*Cedrus deodar*)	0.0

[a)]Multiple answers possible.

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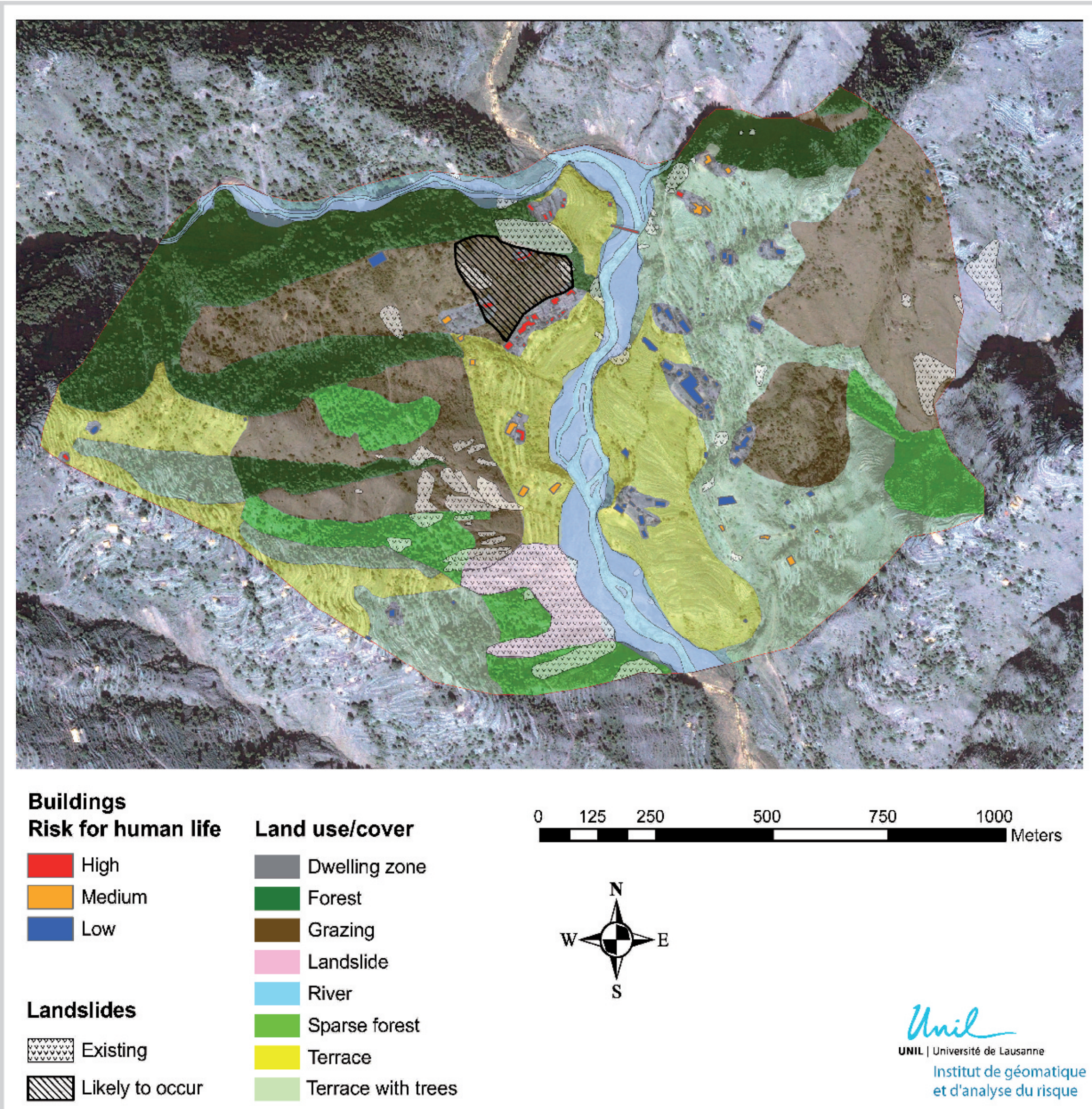
FIGURE 5 Saidpur Village land use and risk map, based on Quickbird image and field survey data. (Map by Jérôme Dubois and Alain Breguet, University of Lausanne, 2008)



earthquake, perceived causes and mitigation strategies for the landslides, and coping strategies (Table 2).

Concerns before and after the earthquake: Eighteen months after the earthquake, in both Kohori and Saidpur, concerns before the earthquake were not surprisingly focused on the fear of reoccurring earthquakes and landslides, followed by concerns about the road to Muzaffarabad, the loss of land for agriculture and earthquake-safe house construction, the high cost of building materials, and a perceived moral decline (Table 4). Before the earthquake, the main concerns reported had been employment, medical facilities, and access to fuelwood. With the exception of flash flooding, respondents had been consistently little concerned with hazards before the earthquake. A few landslides had occurred before the 2005 earthquake, but no specific mitigation measures had been taken. In both localities, women voiced a greater concern about landslide risk than men. Another concern that was raised during focus group discussions was the type of lightweight housing that was being promoted by the government. Respondents found this housing too cold in the winter and too hot in the summer, and most were planning to rebuild traditional *katcha* mud and wood houses for their comfort. Similar findings have been highlighted by other authors (Khan and Mustafa 2007).

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TABLE 4 Overview of Saidpur and Kohori people's concerns in relation to earthquake and landslide risks.

Time	Main concerns[a)]	$n = 27$ (%)
Before earthquake	Medical facilities	46.1
	Employment	34.6
	Fuelwood	26.9
	Crop pests	11.5
After earthquake	Earthquake danger	88.4
	Landslide danger	88.4
	Earthquake-safe house	84.6
	Road to Muzaffarabad	34.6
	Loss of land	26.9
	High cost of materials	19.2
	Loss of moral values	15.4
Causes of landslides	Rain	61.1
	Do not know	31.2
	God's will	6.2
	Deforestation	6.2
Mitigation	Gabion walls	50.0
	Plant trees	34.6
	Do not know	26.7
	Other: God's will, move elsewhere	7.6

[a)]Multiple answers possible.

Perceived causes of the landslides and mitigation solutions: A majority of respondents in both villages mentioned rainfall as the immediate cause of landslides, followed by "God's will" and deforestation. However, there was also recognition that community education about landslide stabilization and better care for the land would be beneficial to avoid further landslides. There was very little knowledge about landslides before the earthquake. The few landslides that had occurred before the earthquake were managed either by avoiding them or by building retaining walls, which most respondents felt were not adequate. Erosion had also been actively managed by retaining walls and plantation of trees along slope contours, a relatively successful combination according to respondents. There had been no other predisaster preparedness or mitigation measures for the earthquake or landslides.

Coping strategies and livelihood options: In both villages, the main coping strategies included moving houses to safer land, in effect reducing the amount of available land for cultivation and male migration for employment, leaving a high percentage of females in charge of households. Communities adapted to the situation after the earthquake by abandoning agricultural fields and constructed houses because they considered the previous sites too exposed to risk. These at-risk areas also corresponded to areas identified as most susceptible to future hazard events according to the geological survey. Families own small plots of land (1.5–2.0 ha) spread between rice paddies, terraces for rainfed agriculture, and pastureland. The land has been divided through inheritance and land purchases, mainly to reduce food insecurity. In Saidpur, access to firewood was mentioned as a main source of livelihood insecurity, and some women reported spending 6 hours every other day on firewood collection, whereas households in Kohori were able to purchase firewood and cooking gas. According to survey respondents, forest degradation has occurred over the years as gradual upward creep of forested area because of local deforestation, rather than commercial or illegal logging, which is prevalent elsewhere in the valley.

Over time, the population in both villages is likely to cultivate "risky" fields as relief assistance dwindles. Few families were relocating from the village, even if landslide risk is still perceived as high. Household income had declined: Men who migrated for work returned during this period to reconstruct their houses. Many stated that as a result they had lost their jobs, but many expected to migrate to find new employment as soon as reconstruction was completed. These findings are consistent with other studies conducted after the earthquake, which demonstrate that remittances constitute a significant portion of incomes and coping strategies for households in AJK—approximately 30% in the Muzaffarabad district (Suleri and Savage 2006; Halvorson and Hamilton 2010). Even if payments were disrupted during the aftermath of the earthquake, those families who had received remittances recovered more quickly than those who had not benefited from this source of income. Respondents in Saidpur who belonged to one of the formally established "cluster organizations" (or grassroots organizations supported by NGOs) noted that they were better prepared and organized to deal with the aftermath of the earthquake and landslides. According to one of our expert informants, such groups—organized into women's, men's, or mixed groups—have been established over the last 10–15 years to prioritize development needs.

Discussion

Eighteen months after the earthquake, the population was still in recovery mode and overwhelmed by numerous landslides, cracks, and gullies surrounding the villages. Over time, the main concerns will likely shift back from fear of reoccurring landslides and earthquakes toward livelihood issues. It is not surprising that rainfall and "divine causes" were mentioned as the most common factors causing landslides (Halvorson and Hamilton 2010).

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Yet rather than a complete fatalistic perception of landslides, we also observed calls for action and responsibility for the land. This is consistent with other studies on the link between Islam, environmental protection, human life, and disaster management (Paradise 2005; Ghafory-Ashtiany 2009). The potential for disaster risk reduction through local mosques is enormous and has not been adequately explored in terms of such opportunities as developing community-based early warning systems and awareness-raising (Dekens 2007).

Grazing and road construction were not mentioned as direct causal factors of landslides by respondents. Yet both have important implications for future mitigation of landslides. We observed extensively degraded forests, with little to no vegetative ground cover, and large numbers of goats grazing indiscriminately. Options are to implement and enforce improved community-managed forestry and livestock husbandry by encouraging greater community participation in land use management and stall-fed animal husbandry versus unrestricted grazing. Other practical solutions to landslide mitigation include working through forest and agricultural extension programs to plant deep-rooted species along contours that may also have utility for livelihoods and bioengineering measures, including proper drainage. For road construction, obvious measures include well-known but rarely applied bioengineering stabilization methods.

Conclusions

These results demonstrate that human activities, especially grazing and firewood pressures, followed by conversion of land to poorly managed grazing and road construction, significantly impacted the occurrence of shallow landslides in the field study area. This finding has been corroborated by subsequent studies based on remote sensing techniques (Kamp et al 2008; Owen et al 2008; Kamp et al 2010; Khattak et al 2010; Peduzzi 2010). Privately owned or managed lands were more prone to severe degradation due to grazing and forest pressures versus highly restricted state forest lands. In this context, land use and tenure issues are thus root causes of shallow landslides (Halvorson and Hamilton 2010) that need to be addressed as part of a more sustainable and integrated approach to landslide risk reduction.

The proposed methodologies provide straightforward and cost-effective means for obtaining information about community concerns and the social, geological, and environmental contexts leading to landslide risk in a data-poor environment. The main constraints included lack of baseline data for in-depth social vulnerability analysis and limited time in the field. One of the main benefits of this broader, interdisciplinary approach was to build on key stakeholders' information needs to ensure maximum utilization. Documenting a basic history of land use and disasters in the region helped to explain landslide patterns, risk perception, governance issues, and lack of preparedness for earthquake and landslides. By combining socioeconomic qualitative data on risk perception, main concerns, land tenure, and land use with geological data, we obtained a more systemic view of the underlying causes of landslides and mitigation options in the study area.

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