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ORIGINAL PAPER

Causes and extent of environmental impacts of landslide hazard in the Himalayan region: a case study of Murree, Pakistan

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Abstract Pakistan is located at the cross-roads of plate boundaries, experiencing multiple hazards of earthquake, flood, drought, water-logging, salinization and recurrent landslides. This paper examines the causes and environmental impacts of frequently occurring landslide hazards in the Murree area of Pakistan's Himalayan region. These are wide ranging in nature and in terms of the damage that result. The area under research was divided into eight blocks and randomly data collected. It was observed that landslides mostly occur along the road network and disturbed slopes. Immature geology, a wide variation in climate and degradation of the natural resource-base were found to be some of the causal factors responsible for the landslide hazards. During the past three decades, rapid expansion of urban zones contributed to the changing vulnerability of the area. The analysis revealed that a large majority of the households (75%) in the area have been directly or indirectly affected by landslide hazards. Damages to already scarce agricultural land, infrastructure and other properties are each year a regular and escalating phenomenon. Landslide size, frequency and consequent costs of damage have increased considerably.

Keywords Landslide · Causes · Impacts · Damage

1 Introduction

This paper analyses the causes and extent of environmental impacts of landslide hazard in the Murree area, Pakistan. It is one of the worst slide-affected areas of Pakistan. It is located on a lateral spur of the sub-Himalayan Mountains (Abbasi et al. 2002) with an

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elevation ranging from 1,300 to 2,300 m above sea level (Khan 2000). Geographically, the study area extends from 33°52′ to 33°59′ North and 73°24′ to 73°31′ East (Fig. 1).

Murree hills are in the climatic division of the subtropical continental highlands. Vast variations in climate are caused by the differences in altitude, amount of winter snowfall, and duration and depth of the snow accumulation. The hill station of Murree receives the highest amount of rainfall in Pakistan (Archer and Fowler 2008) averaging 1,640 mm and approximately 89 mean rainy days per annum (Rabbani 1986; Malik and Farooq 1996). However, different parts of the area receive varying amounts of rainfall. The bulk of precipitation is received during the monsoon from July to August. Landslide activity

Fig. 1 Location map of the study area

largely occurs during the heavy showers of the Monsoon season. However, some occasional heavy rains during the months of January to March also play a significant role.

The population growth of Murree has been inconsistent since independence and recently has been recorded as increasing at a rate of 3.1% per annum (Ishfaq 1999). Similarly, every year more than 1 million tourists visit Murree and this figure is increasing by 5% per year during periods of political calm. As a result, the built-up area has been increasing but at the cost of degrading the natural resource-base. A major problem associated with the population growth and development of tourist facilities is the improper disposal of waste and sewerage water.

Murree area consists of fragile rocks with hard gray to reddish sandstone inter-bedded with soft red calcareous shale (Malik and Farooq 1996; Khan 1992a). These rocks have the highest tendency toward landslides (Pearce 1987; Ishfaq 1999; Khan 1992b, 2000; Abbasi et al. 2002). It has been observed that due to natural conditions, like immature geology and high rainfall, coupled with rapid socioeconomic development and related human activities, that landslide hazard has been a serious concern for the safety of life and property in the area. This paper looks at the current situation of causes and increasingly adverse effects of landslide in the Himalayan region of Murree in particular.

2 Background to landslide hazards in Pakistan

Landslides are very common and recurrent phenomena throughout the mountainous region of Pakistan (Niederer and Schaffiner 1988; Niederer et al. 1989; Said 1992; Thakur 1996; Khan 1994; 2000; Kamp et al. 2008; Khattak et al. 2010). Geologically, the Himalayas constitute the youngest and the most dominating mountain system in the world. They comprise the worst slide-affected area of Pakistan (Kazmi and Jan 1997; Khan and Atta-ur-Rahman 2006). It has been estimated that 30% of the world landslides occur in the Himalayas (Khan 2000). After the Kashmir earthquake of 2005, in Balakot alone 1,293 landslides were identified at 174 locations (Owen et al. 2008).

Landslide hazard depends on a number of concomitant factors such as slope gradient, lithology, land cover, morphology, drainage area and the groundwater setting that brings landslide susceptibility (Hughes 1982; Moughtin 1986; Khan 1992b; Khan and Atta-ur-Rahman 2006; Kamp et al. 2008; Gattinoni, 2009; Khattak et al. 2010). The behavior of landsliding has close relationship to the slope gradient and is an important factor for triggering landslides (Wan et al. 2010; Kamp et al. 2010). The landslide density increases with increase in slope angle (Clerici et al. 2010; Msilimba 2010). Similarly, the landslide susceptibility varies from location to location but the rainfall-induced landslides have the highest frequency of occurrence (Li et al. 2010) particularly in regions characterized by heavy seasonal precipitation (Sengupta et al. 2010). Many disastrous landslides triggered by seismic shaking have been studied throughout the world (Bouhadad et al. 2010; Kamp et al. 2010). Moreover, lithology is widely accepted as one of the most important factors affecting landsliding (Clerici et al. 2010) and subjected to a primary driving force such as rainfall or earthquake excitation for their occurrence (Wan et al. 2010). In addition, factors that can also induce landslide are the anthropogenic factors such as land use and infrastructures (Wan et al. 2010). The forest cover is effectively protecting from landsliding (Kamp et al. 2010). If a road is close to a sample point, the slope line may be destroyed and become unstable due to human disturbance (Wan et al. 2010).

In Pakistan, during the rainy season landslides occur mostly along the highways built in the mountainous terrain (Khan and Atta-ur-Rahman 2006). Similarly, the deforestation has

further accelerated the problem of mass wasting in the hilly areas of north and northwest parts of Pakistan (Khan et al. 1994). However, so far any systematic and detailed study to determine the extent of the problem has not been undertaken. In Pakistan, the subject of landslides has recently been given some importance. The Federal Forest Division, Highway and Mining Divisions are undertaking research and implementing various programmes to reduce landslide hazards through engineering and forestation measures. However, no proper institutional arrangement exists either at federal or provincial level to implement, monitor and evaluate projects concerning the prevention of landslide and disaster response.

The problem of mass movements varies from debris and rock falls to heavy landslides, avalanches, soil creep and mud flow (Said 1992; Kamp et al. 2010). It is a frequent and ever-present geomorphological hazard interrupting the day-to-day activities of the people living in the mountainous areas of Pakistan (Khan and Atta-ur-Rahman 2006). The processes of slope failure, among the geologically young, ragged and jagged foothills of the Himalayas have serious adverse effects, both directly and indirectly, on the living conditions of the people in this area historically (Niederer et al. 1989; Malik and Farooq 1996; Khattak et al. 2010). Landslides in the region frequently cause losses of life, destruction of houses, roads, crops and various other properties. These deteriorating processes in the mountain environment have far reaching negative impacts also extending to the plain areas (Moughtin 1986; GOP 1987; Tylor 1989; Khan 1992b; Owen et al. 2008).

The direct impacts of slope failure and landslides in the mountainous part of Pakistan includes the loss of life, the collapse and partial destruction of houses and various infrastructural damage. It involves the frequent disruption of roads and other means of communication, pipelines, irrigation channels, water supply system and entire human settlements. The International Karakoram Expedition of 1980, in one of their detailed surveys of a 139-km-long strip along the Karakuram Highway (between Gilgit and Gulmit), observed evidence of 335 landslides of a variety of forms, size and periods (Goudie 1983; Miller 1984). Apart from the rapid flowage and sudden movements that lead to the collapse of houses, slow flowage movements such as soil creep occur extensively in the area, which steadily destroys houses and other infrastructure from their foundations (Hewitt 1983; Khan 1992a, 2000).

One of the worst impacts of the landslides in the mountains of Pakistan is the formation of natural temporary dams on the streams and rivers, which ultimately cause damaging floods, resulting in loss of life and destruction of property (Hewitt 1969b, 1983). It is the sudden out-bursting from the failure of these dams and the resulting floods that not only destroy the settlements and all the available patches of agricultural lands in the mountain valleys but also seriously affected the plain areas far below the mountains. The sediments deposited in these huge lakes at different localities in the river valleys of the Himalaya and Karakuram have been recorded as proof of early formation of these lakes (Hewitt 1983; Goudie 1983). The formation of landslide dams and their remnants have been addressed in various studies (Hewitt 1969a; Derbyshire and Miller 1981; Wood 1981; Goudie 1983).

3 Methods and materials

3.1 Field study area

Murree, lovingly called "the Queen of the hills", lies in the sub-Himalayan mountain region (Khan et al. 1994). The Murree area is one of the most famous summer resorts and

one of the most easily accessible hill-station and sanatoriums of Pakistan. Murree is connected through a fine mettle road with Islamabad and Muzaffarabad, at a distance of 50 and 87 km, respectively (Pearce 1987; Khan 2000). Generally, the climate is cooler at higher altitude and warmer at lower ones with a short spring and autumn.

Murree is one of the most developed hill stations in the country characterized by the assets of pine forest, parks, restaurants, chair lifts, cable cars and hiking tracks (Ishfaq 1999). A total of about 1,880 ha of the land is under various uses, out of which 70% is tree cover, 7% agricultural use, 6% allocated for defense purpose and the rest for commercial, civic and residential uses (Khan et al. 1994).

According to the population census of Pakistan, the total number of people at Murree town was 21,371 in 1998, out of which 13,462 resided in the civilian part and the rest in the Murree cantonment (GOP 1999). Beside this, every year more than a million tourists visit Murree area. It is estimated that about 600 hotels cater for this large amount of tourists. The recreational spots, commercial apartments and hotel resorts in this area (Fig. 2) attract a further population, including summer and winter tourists from all over the country.

A slope map was also developed to show steepness in degrees (Fig. 3). In Murree area, the hill slopes are moderately steep and vary from 16° to 30° (Fig. 3). An increase in slope steepness leads to a decrease in the shear strength of the material that triggers landslides (Malik and Farooq 1996). In those areas where the slopes are steep specifically along the streams, roads and disturbed slopes, the problem of landsliding is a recurrent phenomenon as observed during field survey.

Fig. 2 Recreational spots, commercial apartments and hotel resorts are expanding at a rapid pace in Murree

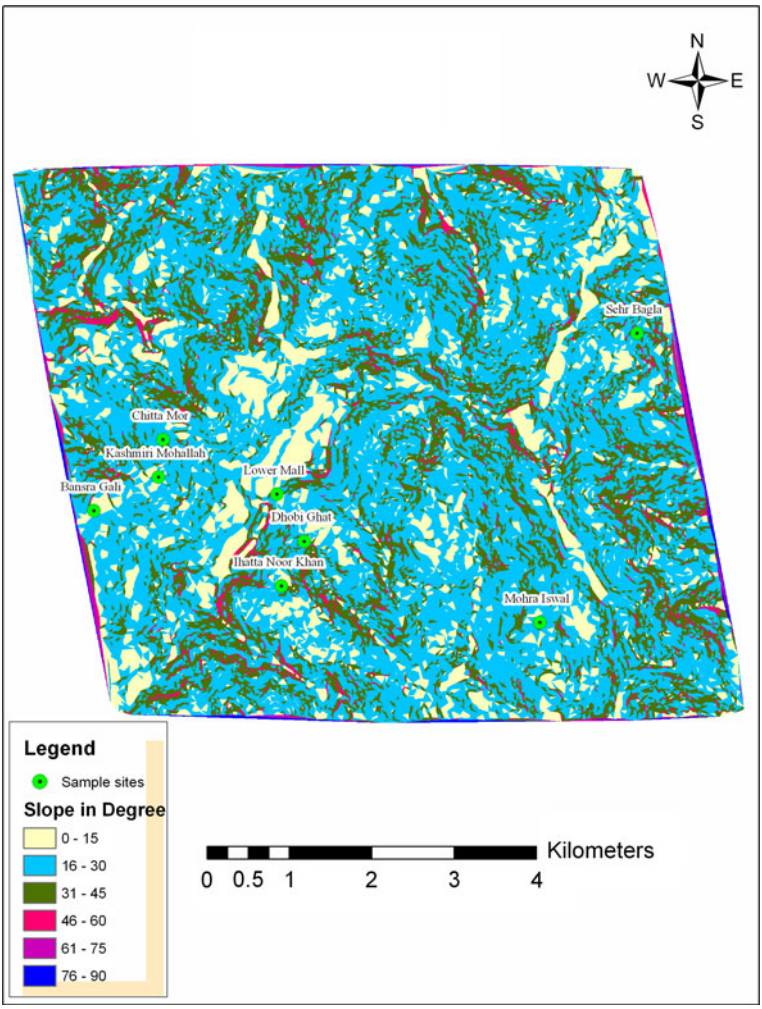

Fig. 3 Murree area slope map

3.2 Data collection

A variety of research techniques were used to collect the required data from primary and secondary sources (Fig. 4). Prior to the field work, detailed reconnaissance visits were carried out to the study area and a review of reports and other records was made. Informal interviews and discussions were also held with government officials of the relevant departments and other key stakeholders. All these activities were aimed at getting a clear picture about the causes and extent of damages to life and property as well as policy responses for the reduction in landslide impacts.

The primary data were obtained through questionnaire survey, interviews and observation. For this purpose, the study area was divided into eight blocks and from each block a sample of locations was selected by random means. This comprised Chitta Mor, Dhobi Ghat, Ihatta Noor Khan, Sehr Bagla, Kashmiri Mohallah, Mohra Iswal, Lower Mall and

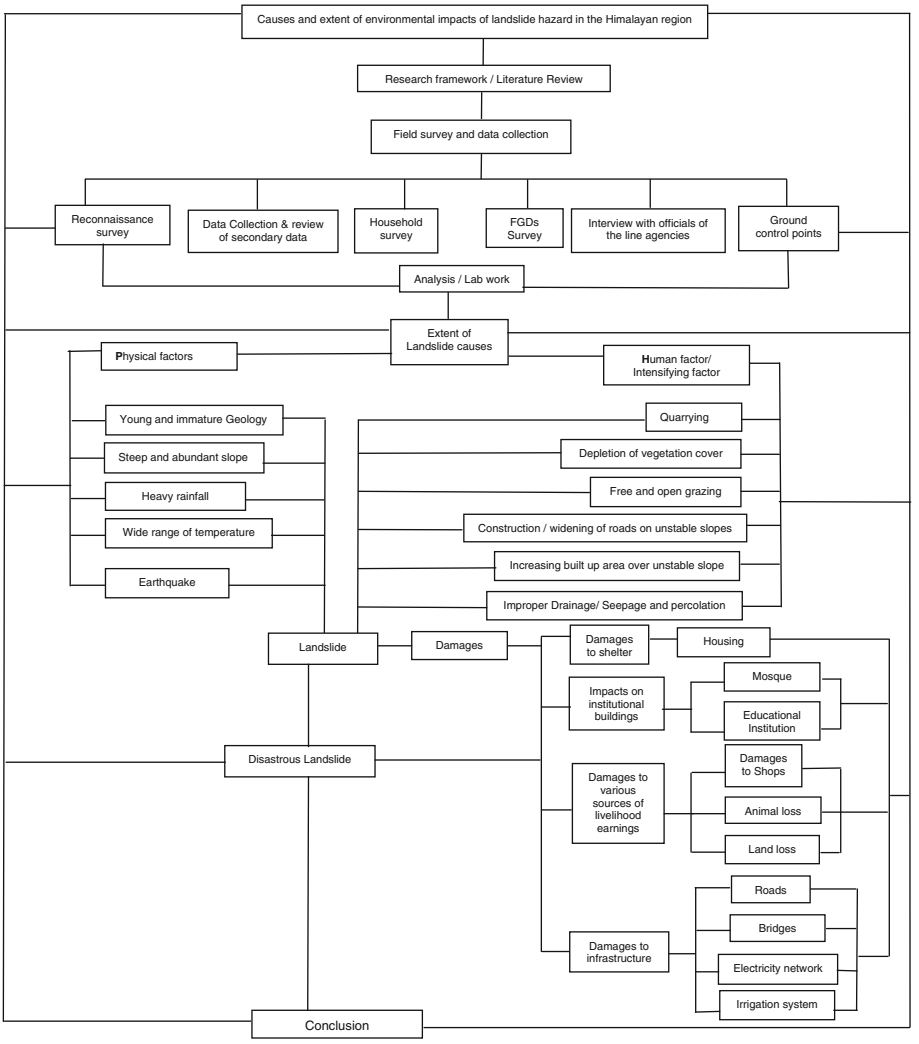

Fig. 4 Research model

Bansra Gali (see Fig. 1). Three types of questionnaires were used in this survey. This included a questionnaire for 200 individual households, focus group discussion (FGDs) and a questionnaire for the line agencies. It was calculated that the household questionnaires were filled in by about 20% of the total household heads in an area. The sample of the respondents selected for interview was diversified and heterogeneous, being guided by the random selection of households, because in sample communities there were scattered houses which confined the researchers to random choice. Similarly, two to three questionnaires were also filled from each sample community during the FGDs survey to grasp the overall landslide problem in each sample locality. It was filled during group discussion with the community members. Likewise, the 3rd type of questionnaires for the line agencies were filled up from the officials of the related government departments. This questionnaire was intended to find the gap between the community role and responsibility

in reducing the landslide risk and the policy response of the line agencies. These questionnaires were designed to collect information regarding locally understood causes and environmental impacts of landslide hazard on the socioeconomic and physical environment of the study area. Landslide experts apply different criteria for the assessment of losses (Liu et al. 2009) but in this paper the losses due to landslide are broadly classified as housing sector, institutional buildings, infrastructure and sources of livelihood earnings. In the test area, the average damage assessment is calculated for the past 20 years irrespective of number of disasters that occurred. Similarly, general observations were also recorded in the form of photographs.

Secondary data were obtained from the population census, topographical sheets, Forest Department, Murree Cantonment Board, Revenue Department, Housing and Physical Planning Department, Murree Kahota Development Authority (MKDA) and Murree Improvement Trust. Data gathered through these techniques were analyzed using the computer-based statistical package and Geographic Information Systems (GIS). These techniques enabled the data to be presented in the form of maps, tables and statistical diagrams. GIS was used to prepare maps from satellite images, tectonic maps and topographic sheets. Finally, the collected data and information were interpreted in light of our knowledge of the socioeconomic and physical environment of the study area. The combinations of primary and secondary data from the methods described above have enabled the production of Tables 1, 2, 3, 4, 5, 6, 7, 8 presented in this paper.

4 Results, analysis and discussion

4.1 Causes of landslides in the study area

Landslide is a very active and recurrent phenomenon in the study area. The analysis revealed that many factors known to cause landslides are present in Murree. These include young and immature geology, highly erodible rocks, steep and abundant irregular slopes, seasonally intense monsoon rainfall, freeze and thaw, earthquake and above all extensive human activities. The latter include deforestation, overgrazing, quarrying, excavation of slope, road construction, increase in the built-up area and improper drainage and sewerage systems.

Among the physical environmental causative factors, climatic elements such as rainfall and temperature are very important. Murree hills fall under the subtropical continental highland climate with cool summers (Khan 2001) and are the wettest station of Pakistan (Fig. 5). In the study area, climate was found the major causative factor behind the landslide problem. The mean monthly rainfall varies between 362 mm in July and 21 mm in November. July and August are the wettest months of the Murree area which correspond to the monsoon season. This seasonally intense high rainfall saturates the soil and as a result the relatively soft and young rocks of the area are severely susceptible to landslide. Therefore, several landslides triggered by rainfall have been noted in the filed. The analysis reveals that landslides most often occur in monsoon period. Similarly, snowmelt during spring season was also found a triggering factor. Consequently, the increasing moisture contents over the potentially unstable slopes play a significant role in generating landslides. The heavy monsoon showers first wet the slopes and then saturate the material at certain depth according to Malik and Farooq 1996. The analysis reveals that rainfall was the major factor responsible for most of the landslides in the Murree area. Therefore, in the study area, rainfall is considered to be the most important causative factor for a landslide

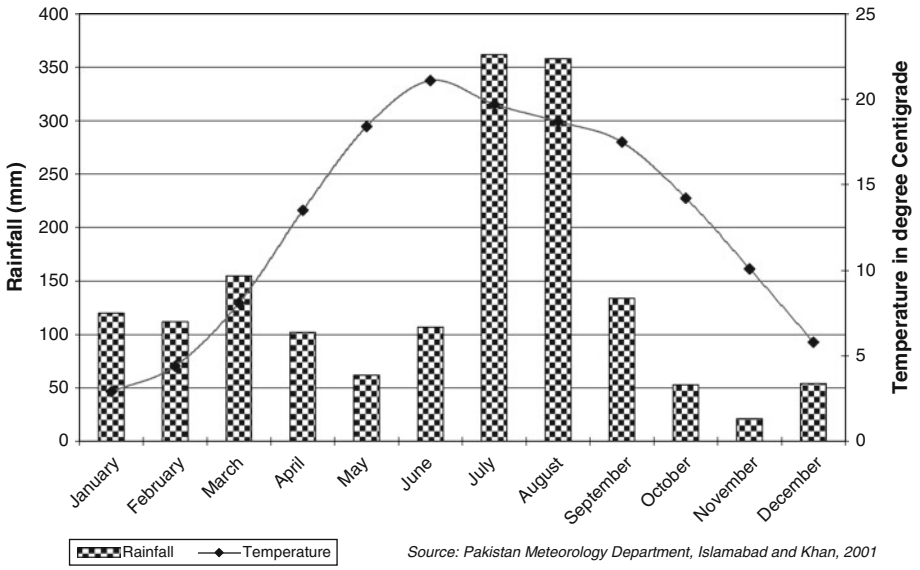

Fig. 5 Mean monthly temperature and rainfall, 1960–2000

problem. Temperature also plays an important role, which rises rapidly from April to July and then steadily decreases from September to January. December, January and February are the coldest months, whereas June is the hottest month (Fig. 5). The mean temperature of the warmest month is 21°C, whereas on many winter days temperature falls below freezing point. There is a very wide range of both annual and diurnal temperature. Due to this wide range of temperature and resultant freeze and thaw, the rocks expand and contract, which ultimately leads to slope failure in the Murree area. This phenomenon is very apparent specifically during winter season.

Besides climate, geology and seismology are other important natural causes for sliding in Murree. Lithologically, Murree area consists of fragile rocks with hard gray to reddish sandstone inter-bedded with soft red calcareous shale (Pearce 1987; Khan 1992a, 2000) of the Murree and Kuldana Formations (Oligocene–Miocene; Abbasi et al. 2002). The rocks are dominated by inter-bedded sandstone, siltstone and shale (Fig. 6) (Abbasi et al. 2002). One- to four-meter-thick colluviums usually cover the bed rock, and many landslides are generated at the contact of colluviums and bedrock (Ishfaq 1999). These are potentially weak zones in the slopes and reduce the rock strength (Abbasi et al. 2002). The siltstone and sandstone constitute most of the Murree area, which are exposed in road cuttings and excavation. These rocks have the highest tendency toward landslides (Malik and Farooq 1996; Khan 1992b). As a whole, almost 70% of the strata is exposed in road cuttings and in built-up environments. Due to high rainfall, there is more and more seepage through the porous beddings of sandstone. As a result, the inter-bedded hard and soft strata also become vulnerable to landsliding. In addition to this, both active and potentially active landslides sites have been drawn from the existing maps (Niederer et al. 1989; Khan 1992a; Ishfaq 1999) and several were also identified in the field and plotted on the map (Fig. 6).

The complex tectonic setup of the study area is another contributing factor for the slope failure. Murree is located south of major Thrust Faults, the Main Boundary Thrust (MBT) and the Main Mantle Thrust (MMT; Fig. 7; Searle and Khan 1996; Monalisa et al. 2008).

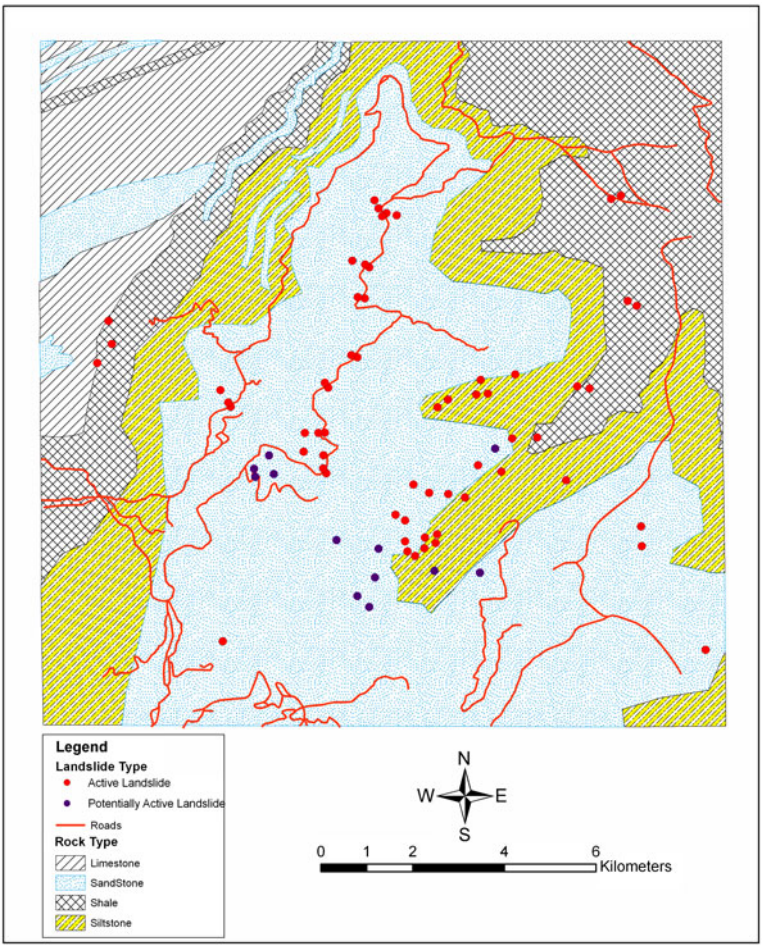

Fig. 6 Murree area surface lithology and distribution of landslides

Some recent workers call the Murree Thrust on both limbs of the Hazara Kashmir Syntaxis as the MBT (Kazmi and Jan 1997; Hussain et al. 2009). In the region, several thrusts have strike slip components including the Jhelum Strike Slip Fault (Monalisa et al. 2009). The Jhelum Strike Slip Fault lies to the east of Murree (Fig. 7), while the active MBT is in the north and northwest. The MBT has been very active in the last few decades as it was activated in 1977 and 2005 (Malik and Farooq 1996; Kamp et al. 2008). Earthquake could accelerate ground movement, produces dynamic load, increasing pore water pressure and shear stress and as a result escalate the problem of slope instability. Similarly, the famous Kashmir earthquake 2005 has reactivated the Bagh-Balakot Fault (Fig. 7; Hussain et al. 2009) and triggered several landslides in the region (Owen et al. 2008). Likewise, Kamp et al. 2008 expect more earthquakes of magnitude above six in this region.

As pointed out earlier, apart from natural environmental causative factors, there are several human-induced causes which also help in triggering various types of landslides in the area. Among these, depletion of vegetation cover resulting from human activities is the

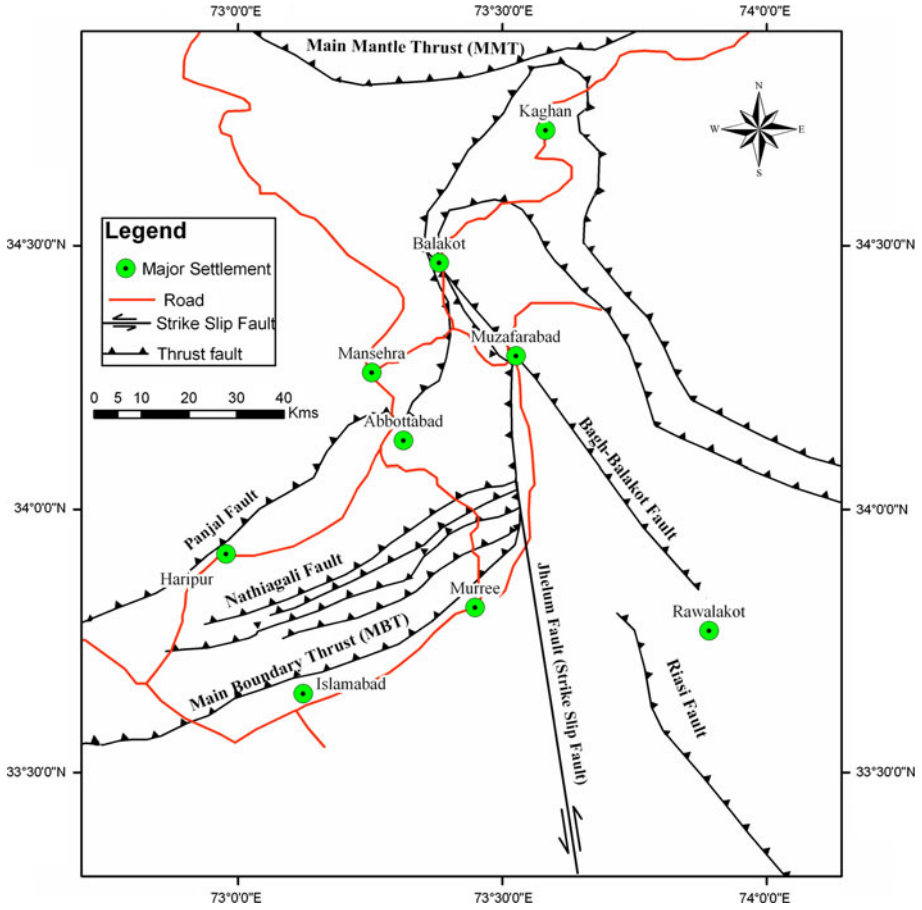

Fig. 7 Tectonic map showing major faults around Murree; modified after Searle and Khan 1996; MonaLisa et al. 2008, 2009

most important one. There is free and open grazing in the surrounding forest except some restricted areas in the cantonment jurisdiction. As a result, the grazing areas are slowly and gradually becoming bare of vegetation, which leads to denudation of the hill slopes. Every year, a large number of sheep and goats invade these areas. Such open grazing has caused extensive damage to vegetation, resulting in slopes becoming unstable that has led to landsliding. Deforestation resulting from forest cutting and forest fire is also going on in the study area. Most of the people use local timber for cooking purposes. The reforestation programme is also affected due to several natural and man-made reasons. Hence, once trees are cut, then that area is colonized by many natural and man-made processes leading to slope instability.

The construction and widening of roads has been an extensive and frequent activity on the unstable slopes of Murree area, which exacerbate the problem of landsliding (Fig. 8). The analysis confirmed that the road density in this highly vulnerable locality is increasing day by day, which leads to the increasing frequency of occurrence of landslides. Some of the major landslide prone areas are located along the major road networks vis-à-vis Jheka

Fig. 8 High-rise buildings are constructed on vulnerable slopes, which increases landslide vulnerability

Gali-lawrence College bypass road, Kashmiri Bazaar, Sehr Hadot, Sehr Bagla and Kasseri road. Similarly, the drains along the roads and streets in the built up area are mostly blocked with debris coming down from the steep scree slopes and solid waste, respectively. Likewise, percolation and seepage from the unlined drains saturate the soil and in effect increase pore water pressure in the steep slopes. This continuous pressure ultimately has led to the problem of slope instability.

In the study area, people are mostly living on vulnerable steep slopes, which are not technically viable for the establishment of human settlements. Besides this, the population of Murree area is increasing at a rapid pace (3.1% per annum). As a result, the built-up area is also multiplying day by day. This expansion of the built-up area has been going on in both a horizontal and a vertical direction. The high-rise buildings are constructed indiscriminately without any care of byelaws and regulations in Murree and the surrounding area (see Figs. 2, 8). Therefore, construction pressure on the slopes has led to the increase in the intensity of landslides.

To find out the perception of people regarding the causes of landslide hazard, a question was asked from the respondents on "what are the causes of landslide in the Murree area?" Out of the total of respondents, more than half replied torrential and prolonged rainfall, 25% said disturbance of slope with human activity vis-à-vis construction, deforestation, sewerage system, quarrying and 20% said melting of snow, whereas the rest (5%) were not sure about the causes of landslide hazard (Table 1). This shows that there exists a basic awareness about the multidimensional causes of landslide in the area, despite the shortage of action to prevent them.

Table 1 Causes of landslides as perceived from the respondents

Responses	Frequency (%)
Human activity	25
Torrential rainfall	40
Prolonged rainfall	10
Melting of snow	20
Do not know	5
Total respondents (*n*)	200

Source: Field survey 2004

4.2 Impacts of landslide hazard in the study area

Throughout the mountainous part of Pakistan, Murree is considered to host the worst slide-affected areas (Pearce 1987; Khan 1992a; Khan and Atta-ur-Rahman 2006). The landslide hazard in Murree, therefore, has been a cause of great concern for the safety of life and property for many years. However, during the past three decades, the extent and severity of the adverse effects of landslides has increased substantially which has seriously endangered the people and their property in the area (Khan et al. 1994). Landslide has destroyed human settlements and agricultural land and cut-off transportation and communication system, which are so vital for region development. Despite these damaging events, landslide incidents and impacts have not been reported regularly. It was found that various line departments dealing with the landslide problem do not keep updated records of their activities and are even not ready to share their limited data and information with researchers. As a result, data about landslide damages and costs incurred through rehabilitation, reconstruction and preventive measures are not adequately available. Despite the limited available secondary information, this study confirmed that landslide hazard in different forms has seriously disrupted the lives of the people and their activities in this area. Considerable damage has occurred to forest, agricultural land, housing, roads, communication lines, electricity and water supply. Field studies revealed that almost 75% of households in the test area have been directly or indirectly affected by the landslide. It was also found that apart from the high expenditure incurred by the nation's building departments, the households also spend a considerable part of their hard earned income on repairing landslide damages particularly of houses and fields. As landslide is a recurrent phenomenon in the area, the annual expenditure incurred on it estimated in the order of many millions of Pakistani Rupees. Apart from property damage, this also includes regular expenditure on different types of retaining structures for the purpose of controlling landslides.

Field studies confirmed that poorly regulated development has resulted in increased public expenditure on remedial and protection measures. A lot of Funds are regularly being spent on reconstruction and rehabilitation of various public utilities and public services on the slide-prone slopes. To give a simple example of only one organization, the Progress Report of Murree Kahota Development Authority (MKDA) from 1986 to 1989 revealed that expenses on landslides reached the level of six million rupees, which is almost 10% of its annual budget. It was found that this money had been spent on landslide problems, excluding forestation and other related measures adopted by the authority (MKDA 1989). Likewise, other concerned line departments are also spending at the same rate on the landslide problem. Apart from the normal budget, Murree has frequently received large special grants, over the past 20–30 years, from the provincial government, especially from the Chief Minister and Governor of the Punjab, for landslide issues (Shiwalvi 1985, 1987,

Table 2 Damages to housing sector, 1984–2004

Village name	No. of houses damaged	Extent of damages		Est. loss (in 000 Pak Rs)[a]
		Fully	Partially	
Chitta Mor	60	50	10	18,000
Dhobi Ghat	46	2	44	16,000
Mohra Iswal	15	–	15	5,500
Kashmiri Mohallah	16	10	6	7,300
Ihatta Noor Khan	50	–	50	6,500
Bansra Gali	70	35	35	11,000
Sehr Bagla	18	16	2	12,000
Lower Mall	3	3	–	2,300
Total	278	116 (45%)	162 (55%)	78,600

Source: Field survey 2004. [a] 58 Pak Rupees = 1US $, Price level, 2004

1990; Khan et al. 1994). This expenditure on landslide-related problems has been increasing at a rapid pace (Khan 1992a). These trends indicate that the landslide problem accounts for a growing proportion of the nation's losses from natural hazards in the Murree hills, and in the hill station of Murree in particular.

4.2.1 Damages to housing sector

Damage to housing as a result of landslides has been very serious in the study area and considered a determinant of adverse effects of landslides. With almost 75% of houses damaged by the landslides during the past 20 years, it is very important to note that all damages to housing were not from sudden landslides. These damages are often associated with slow flowage, particularly soil creep. Field observation revealed that the impact of soil creep on housing and other structure is slow and steady, with dangerous consequences. According to the residents, cracks and bulges appear in the walls and floor of houses as a first sign. These cracks and bulges gradually expand with time and ultimately lead to partial and/or total collapse of houses as well as other buildings like mosques, educational institutions and shops. According to the household survey, among the affected households 45% of houses have totally collapsed at least once in the past 20 years. The remaining 55% were partially damaged (Table 2). This partial damage is varied between collapse of walls and rooms as well as cracks, bulges, floor sinking and floor seepage. The total estimated damage to housing sector exceeds 78 million Pak rupees[1] in the past 20 years.

4.2.2 Damages to institutional buildings

In the study area, Mosque and schools were the two institutional buildings reportedly damaged by the recurrent problem of landsliding. The analysis revealed that during the past 20 years three mosques have been completely collapsed and two have been partially damaged in the study area (Table 3). The estimated cost as a result of damages to mosques is two hundred and twenty thousand Pak rupees. In addition to mosque, schools have also been damaged. It was found that five educational institutions of primary and middle level have also been damaged in the past 20 years (Table 3). The total estimated damages in the education sector are Rs. 185,000.

[1] *58 Pak Rupees = 1US $, Price level, 2004.*

Table 3 Extent of damages to institutional buildings, 1984–2004

Sample sites	Damages to mosques			Damages to educational institutions		
	Fully	Partially	Est. loss (in 000 Rs)	Fully	Partially	Est. loss (in 000 Rs)
Chitta Mor	1	0	50	0	1	15
Dhobi Ghat	0	1	7	0	0	0
Mohra Iswal	0	1	12	0	1	10
Kashmiri Mohallah	0	0	0	0	1	10
Ihatta Noor Khan	2	0	220	0	0	0
Bansra Gali	0	0	0	1	0	100
Sehr Bagla	0	0	0	0	1	50
Lower Mall	0	0	0	0	0	0

Source: Field survey 2004

4.2.3 Damages to various sectors of livelihood earnings

In the mountainous area such as Murree, damage to scarce agricultural land, livestock and other sources of income is considered to be very important. This is because of the scarcity of land and the hard work involved in preparing agricultural fields in this rough terrain. The analysis revealed that in the sample sites more than 18,500 Marla[2] (Table 4) of scarce and precious land has been destroyed due to landslides in the past 20 years. To get a clear and detailed picture, it was considered appropriate to classify the land into fore st, cultivated, uncultivated and cultivable wasteland. This provides a clear picture of the extent of damages in different land-use categories in each sample community (Table 4). The estimated recovery cost per Marla is Rs. 1,000 as calculated during field survey from the respondents.

Similarly, in the sample communities a total of thirteen shops have also been damaged (eight fully and five partially) as a result of landslides. The estimated cost of damages to shops is Rs. 317,000 in the past 20 years. Besides Human casualties, livestock also suffer seriously from the landslides. In the sample communities, it was found that almost 1,048 cattle had been buried under debris and more than 324 injured in the past 20 years, as detailed for each sample locality in Table 4.

4.2.4 Extent of damages to infrastructure

Murree is one of the easily accessible hilly summer resorts, with a dense road network. A number of roads, bridges, irrigation channels and electricity network have been washed away by landslide in the past 20 years. It has been estimated according to the local organization responsible for maintenance that the cost of ten meters of mettled road is Rs. 50,000 and unmettled road is Rs. 10,000. At several places, the road is broken and wide cracks were found in the premises nearby. The analysis revealed that in the sample area the damages to mettle and unmettled road networks are in the order of millions of rupees (Table 5).

[2] One Marla = 272 sq. feet.

Table 4 Extent of damages to various sources of livelihood earnings, 1984–2004

Sample sites	Damages to shops			Loss of livestock			Land losses	
	Fully	Partially	Est. loss (in 000 Rs)	Death tolls	Injured	Est. loss (in 000 Rs)	Total land lost in Marla[a]	Est. loss (in 000 Rs)
Chitta Mor	0	0	0	12	10	50	6,514	6,514
Dhobi Ghat	0	1	12	4	2	25	500	500
Mohra Iswal	0	0	0	15	0	30	940	940
Kashmiri Mohallah	0	0	0	8	5	55	3,160	3,160
Ihatta Noor Khan	0	2	35	1,000	300	4,000	500	500
Bansra Gali	0	2	20	7	3	85	70	70
Sehr Bagla	3	0	100	2	8	50	6,900	6,900
Lower Mall	5	0	150	0	0	0	32	32

Source: Field survey 2004. [a] 1 Marla = 272 sq. feet, 20 Marla = 1 Kanal

Table 5 Extent of damages to road infrastructure, 1984–2004

Village name	Damages to mettle road (m)			Damages to unmettle road (m)		
	Fully	Partially	Est. loss (in 000 Rs)	Fully	Partially	Est. loss (in 000 Rs)
Chitta Mor	0	0	0	2,000	0	20,000
Mohra Iswal	0	0	0	1,500	0	15,000
Kashmiri Mohallah	0	30	150	0	0	0
Ihatta Noor Khan	10	0	50	1,000	0	10,000

Source: Field Survey 2004

It was also found that more than a dozen bridges of various sizes and strengths have been damaged due to landslides in the past 20 years (Table 6). The estimated cost according to the organization concerned for bridges is more than 6 million rupees. Landslide hazard has also greatly disrupted other services in the study area. It has frequently and severely damaged the electricity network (Table 6). At several locations, landslide has damaged electric poles and supply lines. The total damages incurred to the electricity network as per the information provided by WAPDA was ~4.3 million Pak rupees.

As shown in Table 6, landslides have also caused enormous damages to irrigation networks which are of great importance for the scarce agricultural patches in this mountainous tract. It was found that these irrigation channels were disrupted and completely damaged by landsliding frequently throughout the past 20 years. The number of irrigation channels together with the estimated loss is shown in Table 6. The total estimated loss to irrigation channels exceeds Rs. 450,000 in the past 20 years.

4.2.5 Gross economic loss

In the study area, gross economic loss to all the four sectors exceeds 158 million rupees in the past 20 years. The Table 7 reveals that housing is the most severely affected sector, while damages to institutional building are the least. In all the sample communities, Chtta

Table 6 Extent of damages to other infrastructure, 1984–2004

Sample sites	Damages to bridges			Damages to Electricity network			Damages to Irrigation network	
	Adobe	Concrete	Est. loss (Rs. 000)	Fully	Partially	Est. loss (Rs. 000)	No of irrigation Channels varying in length from 1 to 10 meters	Est. loss (Rs. 000)
Chitta Mor	0	4	3,100	2	0	450	8	98
Dhobi Ghat	1	0	12	24	0	2,300	1	10
Mohra Iswal	0	0	0	0	1	5	1	15
Kashmiri Mohallah	2	1	160	6	0	210	5	100
Ihatta Noor Khan	0	0	0	0	0	0	1	9
Bansra Gali	0	3	2,800	0	4	20	10	150
Sehr Bagla	2	0	35	3	0	920	2	75
Lower Mall	0	0	0	2	0	430	0	0

Source: Field survey 2004

Mor is the severely affected sample site where estimated cost of landslide related damages is 41.8 Million Pak rupees. However, Lower Mall is the least affected sample community (Fig. 9). Digital elevation models (DEM) or digital terrain models, which provide digital representations of the terrain surface, have wide applications here, such that a large amount of derivative information on slope steepness, slope aspect and angles was obtained. In the Murree area, we interpolated contours such that a DEM is generated (Fig. 9) and sample communities with estimated cost of landslide damages to all sectors during 1984–2004 have been displayed to clearly understand the type of terrain and the extent of damages.

4.2.6 Human casualties

The literature confirms that there are no standardized formulae to measure human losses in monetary terms, people's lives being priceless (Liu et al. 2009). If severe injury occurs instead of death, the corresponding loss is considered less. However, this is again problematical, as any physically injured or physically non-injured person may also carry psychological damage, which can last for years and can affect other people. Though related loss may be extensive, though hard to evaluate, casualties remain part of the consequences of landslide in these areas. In the present study, numbers of casualties have been used for measuring the severity of landslide phenomenon.

The human injuries and deaths from landslides have serious social and economic implications in this study area beyond their physical impact. The deaths and injuries for different sample localities are shown in Table 8. Death and injuries are mostly associated with the partial and total collapse of buildings.

5 Summary and conclusions

This paper examined the current causes and extent of landslide damage in the Himalayan region of northwest Pakistan, with particular emphasis on the Murree area. It was found

Table 7 Estimated cost of landslide damages to the study area, 1984–2004 (Cost in 000 Pak Rupees)

Sample sites	Damages to shelter	Impacts on institutional buildings		Damages to various sources of livelihood earnings			Damages to infrastructure				Total
	Housing	Mosque	Educ. Inst.	Shops	Animal losses	Land losses	Roads.	Bridges	Electricity network	Irrigation network	
Chitta Mor	18,000	50	15	0	50	6,514	20,000	3,100	450	98	48,277
Dhobi Ghat	16,000	7	0	12	25	500	0	12	2,300	10	18,866
Mohra Iswal	5,500	12	10	0	30	940	15,000	0	5	15	21,512
Kashmiri Mohallah	7,300	0	10	0	55	3,160	150	160	210	100	11,145
Ihatta Noor Khan	6,500	220	0	35	4,000	500	10,050	0	0	9	21,314
Bansra Gali	11,000	0	100	20	85	70	0	2,800	20	150	14,245
Sehr Bagla	12,000	0	50	100	50	6,900	0	35	920	75	20,130
Lower Mall	2,300	0	0	150	0	32	0	0	430	0	2,912
Total	78,600	289	185	317	4,295	18,616	45,200	6,107	4,335	457	158,401

Source: Field survey 2004

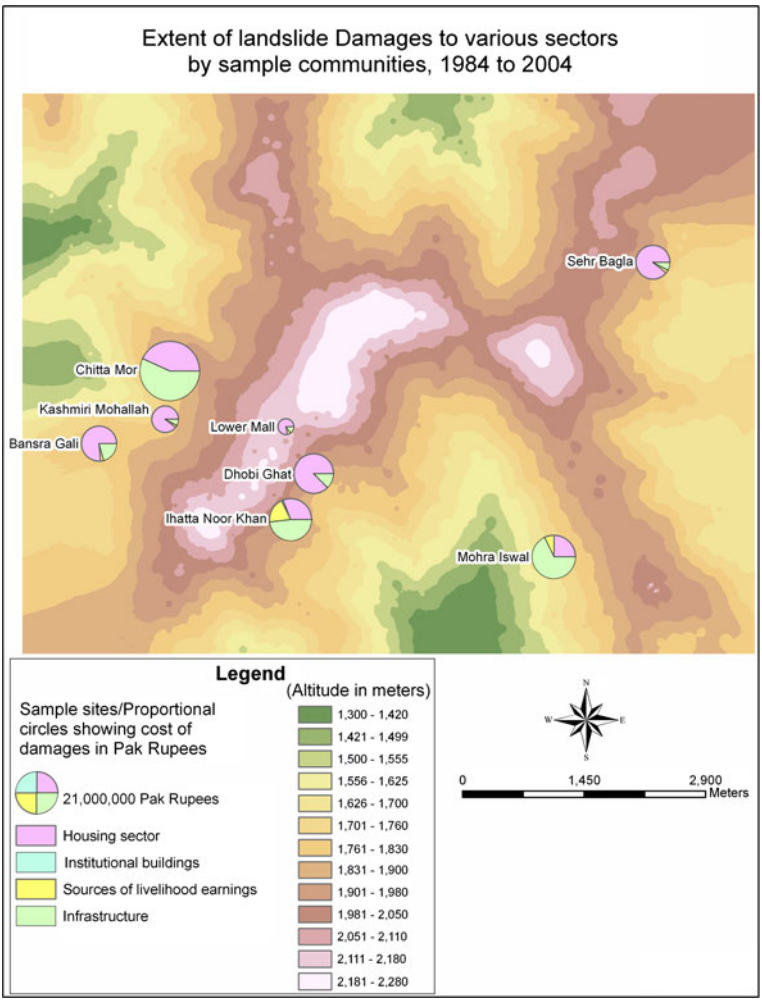

Fig. 9 Extent of landslide damages to various sectors by sample communities, 1984–2004

that physical environmental and man-made factors are known to cause landslides in Murree. Landslide is a dominant hazard in the area, and the dwellers of the region are very well aware of the damaging effects of slope instability.

The instability in the Murree area is partly due to its inherited geological characteristics and climatic conditions and partly due to human factors. It is difficult to overcome the natural causes but it is greatly needed and possible to reduce the effects of human activities that contribute to landslide risk. The analysis revealed that causative factors, such as geology, topography and climatic conditions, were already affecting the area and that the problem of landslide has a long history. However, in the past it was not impacting on the area to the extent that it is at present. The study found that in the past few decades there has been an increase in the severity of damages caused by landslides. The major reasons for this increasing trend are the ecological and environmental imbalances from human activities. The study confirmed that not only did the population and occupancy of the

Table 8 Human casualties, 1984–2004

Village name	Death tolls		Injuries	
	Male	Female	Male	Female
Chitta Mor	2	4	–	–
Dhobi Ghat	0	6	–	3
Mohra Iswal	2	1	15	15
Kashmiri Mohallah	2	3	10	15
Ihatta Noor Khan	8	5	60	50
Bansra Gali	–	–	15	10
Sehr Bagla	5	6	7	3
Total	19	25	107	96

Source: Field survey 2004

slide-prone slopes expand, but also human ability to change the hill slope at such an unabated speed has produced an entirely anthropogenic landscape. Over the past few decades, residential growth and related development have gone up both in number and in size. As development expands the ruthless felling of ground-holding trees, massive quarrying, construction of more and more roads and heavy concrete high-rise buildings with improper drainage and septic sewerage systems on these vulnerable slopes have seriously endangered the stability of this beautiful hilly area. Where once the scenario was of evergreen-clad mountains dotted by sparsely distributed settlements with light traditionally structured buildings, now it is a juxtaposition of building facades honeycombed with population and intermittently accented by trees.

It has been confirmed from the analysis carried out here that all line departments are taking part in slide control measures, and public expenditure on this problem has increased several folds during the past few decades. However, despite all these efforts, damages due to landslide in the agricultural land, forest, irrigation channels, housing, road network and other infrastructures have proliferated. The analysis revealed that besides more than 200 injuries the death toll as a result of slides reached 44 in the past two decades for these areas alone. It was found that 75% of the houses had been damaged. Apart from these damages, thousands of Marla of scarce agricultural and forest land have also been reported damaged as a result of landslides. The most worrying aspect of the story is that the damages are not regularly reported and even the concerned line departments have neither an up-to-date record of what has occurred as a result of landslides, neither of their own activities regarding landslide control measures. Within the context of an increasing density of commercial and socioeconomic activities and related infrastructure on these vulnerable slopes, the severity of the landslide risk has been increased tremendously. This array of costly and unprecedented problem of landslide has harassed the households and public officials alike. The drastic effects of human actions in putting a progressively high premium on hazardous slide-prone slopes are thought to be particularly strongly illustrated by the Murree region of the Himalayas.

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