

Landslide

Introduction

Landslides constitute a major geologic hazard in South Asia, as they occur in seven out of eight countries, namely Afghanistan, Pakistan, India, Nepal, Bhutan, Bangladesh and Sri Lanka mainly due to the unique combination of active but diverse tectonic setting, high rates of weathering, abundant rainfall aggravated by human interference in the form of rapid urbanisation and development of infrastructure adversely affecting the fragile ecosystem of mountainous terrain. Furthermore, due to climatic changes and increase in the frequency of extreme events the problem of landslides has aggravated in South Asia as well as world over. As per a study^{1,2,3} on the global occurrence of fatal landslides, a total of 394 fatal landslides have been recorded, amounting to a death toll of 3,017 worldwide during 2007 (Figure 10.1, Table 10.1).



Figure 10.1: Global distribution of landslides during 2007

A major share of these landslides and resulting fatalities is from South Asia, which accounts for 38.8 per cent of fatal landslides and 34.3 per cent landslide deaths (Figure 10.2). It is interesting to note that in developed regions, the average of fatalities per landslide is very low (N. America 1.2, Europe

Table 10.1: Global distribution of fatal landslides and fatalities during the year 2007

Sl. No.	Area	Number of fatal landslides events	% of fatal landslides events	Number of recorded fatalities	% of all landslide fatalities
1.	Europe	17	4.3	28	0.9
2.	Africa	13	3.3	120	4.0
3.	Middle East	5	1.3	40	1.3
4.	Central Asia	8	2.0	57	1.9
5.	South Asia	153	38.8	1036	34.3
6.	East Asia	60	15.2	673	22.3
7.	South East-Asia	78	19.8	721	23.9
8.	Australia	5	1.3	17	0.6
9.	North America	5	1.3	6	0.2
10.	Central America/Caribbean	30	7.6	183	6.1
11.	South America	20	5.1	136	4.5
	Total	394	100	3,017	100

Landslide

1.6, and Australasia 3.2) as compared to 11.27 in E. Asia and 6.77 in South Asia. In South Asia the Hindukush-Himalayan landslide belt is quite conspicuous on a global scene as per landslide events in 2007 (Figure 10.1). There is a very high concentration of landslides along the southern edge of the Himalayan chain, extending from Afghanistan through Pakistan, India, Nepal, Bhutan and Bangladesh. This belt is responsible for major landslide activity in six of the eight SAARC countries. The second concentration of landslide events can be seen along the west coast of India with in the rugged Western Ghat hill ranges. The third concentration of landslides is in the hilly areas of Sri Lanka

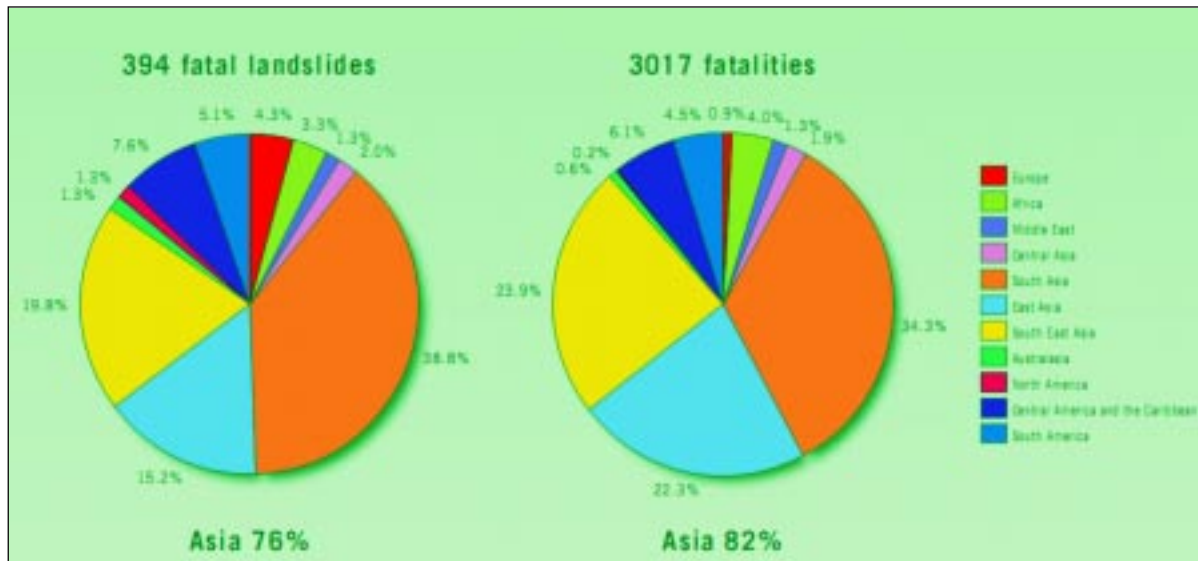


Figure 10.2: Global distribution of fatal landslides and fatalities during the year 2007. Note that the largest segment in the rose diagram (orange colour) represents South Asia

(SOURCE: Prof. David Petley and Dr. Nick Rosser, Institute of Hazards and Risk Research, Deptt. of Geography, Durban University, UK).

An important factor responsible for landslide occurrences is the triggering mechanism. Worldwide statistics shows that 89.2 per cent of fatalities were caused due to landslides triggered by intense and prolonged precipitation. The remaining can be attributed to other triggering processes like construction leading to undercutting of slopes, mining and quarrying, earthquakes, etc.

Table 10.2: Global distribution of landslides as per the trigger mechanism during 2007

Sl. No.	Activity	Number of landslides	Number of fatalities	% of Fatalities
1.	Intense rainfall	319	2,690	89.2
2.	Construction activities	25	101	3.3
3.	Mining & quarrying	17	53	1.8
4.	Riverbank processes	5	23	0.8
5.	Earthquake	5	20	0.7
6.	Snowfall	2	9	0.3
7.	Volcanic Eruption	1	8	0.3
8.	Unknown	20	113	3.7
9.	Total	394	3,017	100

The common triggering factor of landslides in SAARC region is the monsoon rainfall, as evidenced by high concentration of landslides during the months of June (12.7%), July (25.1%) and August (10.5%). The remaining months' fatalities do not exceed 10 per cent. The other causative parameters namely: physico-chemical properties of the rock mass, topography relief, slope, aspect, geomorphology, land use/land cover, vegetation cover, geological structures,

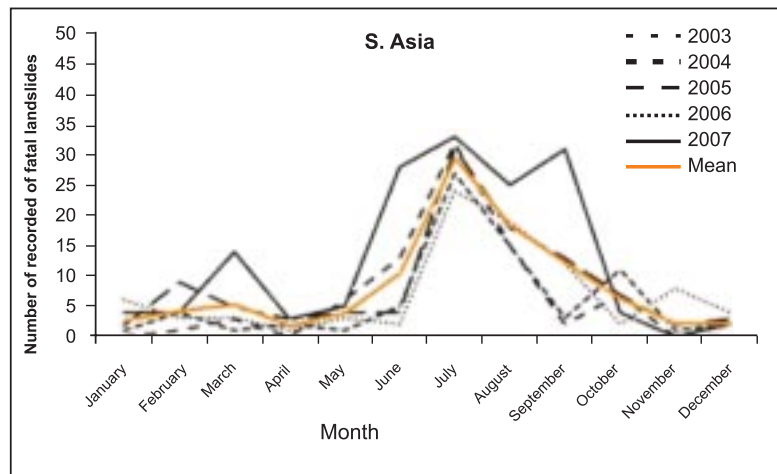


Figure 10.3: Temporal distribution of fatal landslides in South Asia from 2003 to 2007. Note that the mean shows a peak around the month of July.

anthropogenic causes, etc. are unique to each domain. The temporal occurrence of landslides with a peak in the month of July (Figure 10.3) is suggestive of their strong linkage with the meteorological phenomenon such as Asian monsoon. Hence meteorological forecasts may be useful in deducing some early warning signals about rainfall-triggered landslides in South Asia

One important observation is that during 2007 there was no major earthquake directly triggering landslides in the mountainous region of South Asia as experienced during the 2005 Kashmir earthquake, which had generated at least 2,400 landslides^{4,5,6} causing immense death and destruction. However, it is important to note that due to major earthquakes, in addition to failed slopes, numerous hill slopes develop deep fractures that can facilitate water percolation leading to landslides in subsequent years. Second, some of the minor earthquakes with a magnitude ranging from 4 to 6 also cause landslides or ground fractures in mountainous terrain that often go unreported unless these happen very close to human habitation. In any case, in the subsequent rainy season, landslide activity increases, facilitated by such ground deformation. However, these polygenetic landslides are classified as rain induced unlike the seismicity-induced landslides that occur during or just after a major earthquake event.

Landslide events in SAARC Region during 2007

In 2007 the SAARC region faced severe loss of life and property due to landslide during the monsoon season between April-May to September. However, some landslides incidences have also taken place during the month of January associated with winter rainfall in the region. It is important to note that some of the important global databases like EM DAT on disasters are unable to record the smaller events due to less number of fatalities associated with a single event. However, the mountainous terrain in South Asia is characterized by landslides that are smaller in dimension but larger in number, hence their cumulative effect is more in terms of damage extent and environmental degradation. Therefore, in the present study various sources were scanned to record some of the smaller landslide events (Appendix-V). Still, there are chances that some of the unreported landslide incidences might have been missed in the present study.

Impending landslide disaster in northern Afghanistan

Mountainous parts of northern and northeastern Afghanistan are prone to disasters such as earthquakes, floods and landslides. Eight members of a family were killed during July 2007 when a landslide caused by melting snow hit a village in the Takhar province. During the same period, a landslide in Kunduz province, northern Afghanistan struck a wedding party and killed six children. Badakhshan province in the north-east of Afghanistan is identified as one of the most landslide-prone region wherein a joint survey conducted by the Afghan Red Crescent Society (ARCS), the UN and the provincial government found that seismic activity is widening fractures in the middle of Sia Shakh mountain in the Batash area of Faizabad city, the provincial capital of Badakhshan. This movement could dislodge large boulders, which would cause severe damage to settlements below.

Accordingly, it was recommended that all residents should be evacuated from the area as during winter, rain and snow can cause landslides that would block access to rural areas in Badakhshan's Hindukush and Pamir mountain ranges. In addition, extreme weather conditions would increase the probability of landslides and avalanches.

Though Badakhshan is sparsely populated, it is estimated that about 2,000 people in Badakhshan live in high-risk areas with respect to landslides and avalanches. These people had been advised by aid agencies and authorities to move to safer locations as the risk of being hit by landslides



Figure 10.4: Photo on the left shows heavy snowfall which blocks access to many rural areas in Badakhshan province during winter months (IRIN). Photo on the right shows the populated unstable slopes inhabited by about 2,000 people exposed to landslide risk in Badakhshan province.

and avalanches was very high. Hundreds of families who could afford to move have already left the mountainside. However, around 300 destitute families still live in the area, as they could not afford to abandon their homes and livelihoods and move to other locations permanently.

It is important to note that from time to time, Afghanistan has experienced seismicity induced landslides (SIL) in the northern part of the country. In 2002, due to a 7.2 magnitude earthquake, a huge landslide buried nearly 60 to 100 homes in Darun-i-Zao village killing at least 60 persons and plugged a 200-yard-wide gorge and dammed the Samangan River.

Landslides at Baglung and Bajura, Nepal, 12-13 July 2007

Intense and prolonged monsoon precipitation during the second week of July 2007 triggered landslides in the far western and western region of Nepal, particularly affecting the Baglung-Bajura, Jajarkot, Puythan, Dolkha, and Ramechhap areas. As per the information of Nepal Red Cross Society (NRCS), 35 people have died and over 4,286 families have been affected, 39 are injured and in total 24,961 people were affected throughout the country.

In one of the significant events, heavy rainfall on July 12, 2007 triggered landslide at Gwalichaur VDC ward nos.1, 5, 7, 9, and Jaljala VDC ward nos. 2, 4, 6, 8, 9 of Baglung. According to the Nepal Red Cross Society (NRCS) DC report, 24 people were dead, 404 people living in 62 houses were affected by the incident. Ten houses were completely damaged and 52 houses were partially damaged. The site of the mishap is some 60 km away from Bagulang Bazar, the district headquarters. In another event, intense rainfall starting from 12 July 2007 caused a landslide at Brahmatole VDC ward no.1, Bajura district. A total 2 persons were killed and 5 injured.



Figure 10.5: Location map of Baglung landslide, Nepal

In response to these events, the Ministry of Home Affairs (MOHA) together with DAO, Govt. of Nepal and NRCS had carried out relief and rescue operations. Rescue teams comprising the Nepal Army and Nepal Police personnel had reached the incident sites, and initiated rescue operations in spite of continuous downpour affecting their operations. Injured people were evacuated to district headquarter by NA chopper, and then NRCS DC evacuated injured to Pokhara for further treatment. MOHA, in collaboration with NRCS distributed relief materials to affected families.

(Source: GLIDE- LS-2007-000101-NPL, NRCS)

Chittagong Landslide, Bangladesh, 11 June 2007

The Chittagong region of Bangladesh is highly susceptible to landslides triggered by intense rainfall on hill slopes altered by human interference, mainly due to soil erosion, adverse hydrological conditions and unplanned land use pattern. In a catastrophic event on 11 June 2007, intense and prolonged precipitation caused mudslides that buried shanties at the foothills near Chittagong Cantonment. It killed at least 91 persons including 59 children, injured 150 and affected 1,926 families. Many residents were rendered homeless and took refuge in local mosques. The torrential rain and

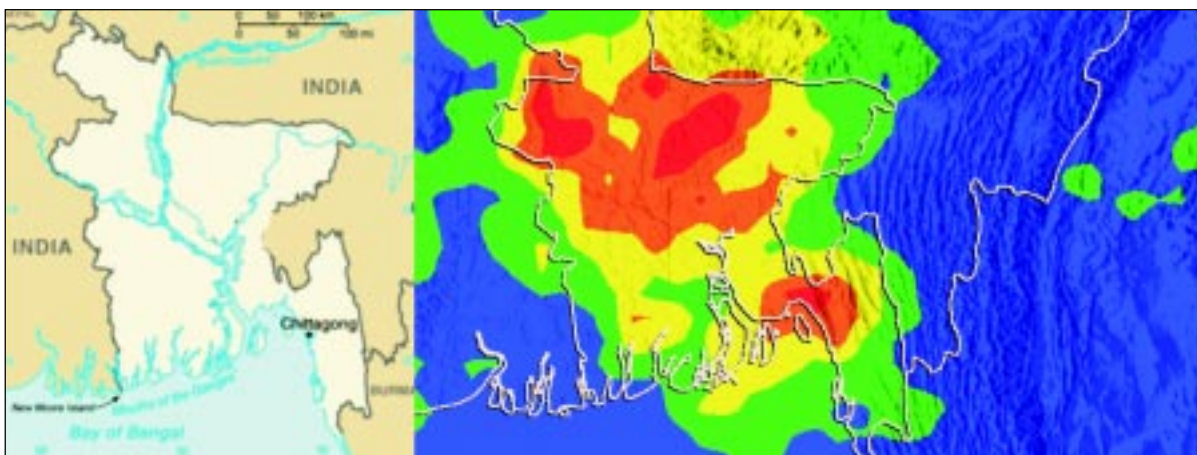


Figure 10.6: Maps showing location of extreme precipitation totals over Bangladesh from June 4 through June 11, 2007, based on measurements from the Tropical Rainfall Measuring Mission satellite. The heaviest rainfall up to 500 mm (20 inches) is shown in red; orange, yellow, green and blue indicate rainfall up to 400, 300, 200 and 100 mm respectively.

mudslides plunged the country's second largest city into chaos. Power supply was disrupted and the airport was closed as residents fled to safer areas. A local radio station was forced to suspend broadcasting as its headquarters was damaged. The direct losses due to the event was estimated as US\$ 13.2 million while indirect losses were much more because the country's largest port was closed and the city's industries came to a standstill following the Chittagong disaster.

Army personnel and fire brigade responded to the emergency call and carried out joint rescue operations. Massive relief and rehabilitation work had been carried out under the auspices of the administration, which provided food, clothes and other logistics to the distressed people. Government officials have determined a course of action to meet the ongoing needs of those living in the disaster areas. Police, military, fire fighters and volunteers struggled to locate survivors, but heavy rainfall, ongoing flooding and lack of equipments hampered the rescue efforts. People living on nearby hill slopes in and around the city were evacuated because of fear of additional mudslides.



Figure 10.7: Search and rescue workers try to retrieve bodies from a hill area in Chittagong on June 13.

Causes of disaster: One of the immediate causes of the disaster is attributed to toe(?) cutting for making level ground required for housing despite repeated warnings from experts. The Ministry of Environment and Forest and the Chittagong Development Authority (CDA), in order to protect hill slopes, issued a circular in 2005 prohibiting hill cutting in the district. The CDA and Department of Environment filed around 100 cases in connection with hill cutting but no further steps were taken. Lalkhan Bazar, one of the worst damaged areas in the mudslide, has been identified as one of the worst affected by hill cutting. Professor of Geography and Environmental studies in Chittagong University Shahidul Islam explained, "The only reason for Monday's mud slide in the cantonment area is cutting hills indiscriminately. We were warning about this risk for decades, and this event has proved our fears." The situation was further aggravated by intense monsoon of 2007 that started with unusually heavy rain, intensified by a storm from the Bay of Bengal on June 9-10, 2007. By June 11, more than one-third of the southeastern coastal city of Chittagong was under water. Finally, the prolonged intense rain triggered devastating landslides on the deforested/barren hill slopes. In a recent



Figure 10.8: Toe cutting and removal of support of hillslopes in Chittagong city leads to massive mudslides. On the right side, the rescue workers search for bodies of landslide victims in Chittagong. Up to 8,000 people living in slums at the foothills in the port city of Chittagong will have to be rehabilitated after landslides claimed at least 91 lives in 2007



Figure 10.9: Hill slope in Khagrachhari shows early signs of collapse and a multi-storey building in high-risk zone at the bottom of a hillside in Chittagong (IRIN)

scientific study the causes of the landslides in Chittagong area are summarized⁷ as follows:

1. Indiscriminate hill cutting is one of the major causes of landslide in Chittagong city. The Chittagong city is densely populated, for accommodation people build houses on the top of the hills or on the foothills without following the existing rules and regulations. The hills were cut with steep slopes of 70–80 degrees, which fail during heavy rains due to loss of strength.
2. Deforestation in the hill area further loosens the soil on the slopes.
3. The high rainfall is one of the major triggering factors. The average yearly rainfall of Chittagong is approximately 3000 mm. The highest rainfall occurs in the month of June and is responsible for highest number of landslides in the same month. The present landslide occurred during this type of intense rainfall in Chittagong city (Figure 10.6)

Rehabilitation: Just after the incident, the local administration started evacuating people living on the slopes of different hills. The government asked authorities to immediately evacuate 8,000 people from the Lebugagan area, the worst hit place in Chittagong landslides. The government initiated a process to identify hillsides and valleys, where landslides are possible, as “Red Zones”, and evacuate people living in those areas and bring those areas under afforestation. However, this exercise was not very successful as some of the relocated people returned to original places, indicating that the relocation was not a sustainable solution as far as economic reality was concerned.

Remedial Measures: On the basis of the scientific analysis of the causes of landsliding in Chittagong, the following mitigation measures are suggested.⁷:

1. Landslide vulnerability assessment and zoning, taking into consideration different types of land use/ land cover.
2. City planning must adhere to the recommended land zoning and relevant policy and legal provisions.
3. Relocation of the foothill slums to safe places.
4. Compliance of existing legal provisions – landslide-related hazards can be reduced if hill cutting is prohibited. Where hill cutting has already taken place, sustainable structural measures may be adopted.
5. Increasing public awareness about the harmful effects of hill cutting, proper land use and associated legal restrictions.
6. Real-time monitoring and early warning - as most of the landslides are triggered due to intense precipitation, the monitoring of rainfall in the area can be used to forecast the possibility of landslides in the area.
7. Establishment of the emergency response and recovery team.
8. Addressing poverty issue - poor people are living in the landslide-prone areas, who cannot afford a safer place to stay.

Dharla Village landslide (Himachal Pradesh), India, 14-15 August 2007

Hilly areas of Himachal Pradesh, India were devastated by a massive landslide due to intense monsoon precipitation during the first and second week of August 2007. In one catastrophic event, at least 62 people died on August 14 at Dharla village (185 km from Shimla) due to a massive landslide triggered by cloudburst in the area. The calamity struck without warning. It was a huge mass of slush and rubble that hurtled down from the heights uphill Dharla village at a terrific speed, wiping out everything that came in the way, and left a trail of misery. More than two-third of the population has perished and in most cases entire families have been wiped out. The death toll was high as people were forced to stay indoors due to heavy rain. A majority of the victims were women, schoolchildren and workers who had returned home early because of the downpour. The fact that the calamity was confined to a small area indicated that it might have been caused due to a temporary blockade of a small stream by a landslip, impounding the storm water, which suddenly gave way. The sliding mass of boulders and slush hit the village from two sides providing no time to escape.



Figure 10.10: Dharla Village landslide (Himachal Pradesh), India, that occurred during 14-15 August 2007 (Source: *Tribune*)

The army was called in to look for bodies after a cloudburst hit Dharla village. But heavy rain hampered the rescue work. As per official sources, 62 persons died and 14 houses and a primary health centre were buried. After the incident, it was reported that many residents of Dharla village had fled and took shelter in forests due to the fear of another cloudburst. At an altitude of around 8,000 feet, the villagers were without adequate facilities. Living in makeshift tents in the forest areas, villagers faced great difficulty due to cold weather conditions. They were reluctant to stay in the village as the ground was reported to have settled some 3-4 feet below the existing level.



Figure 10.11: Rescue in progress in Himachal Pradesh, India

As a part of relief and rehabilitation measures, each victim was given Rs. 10,000 and two blankets by the state Government. Officials said permanent homes are being constructed for the victims, but would take about another month to complete. The government's main aim was not to provide them with temporary tents, but to give them some permanent set-up as per the local officials (source ANI).

Homeless people and the people of Dharla village who were feeling unsafe in their houses and those who fall in the danger zone have been shifted to safe areas. Army had also put up five tents for such people and had provided blankets, tarpaulins and cooking utensils. CGI sheets were distributed to the affected people to construct temporary accommodation. A medical team had been stationed at Ghanvi to provide first aid and other medical support to the people.



Figure 10.12: Damage to Koti railway station in Himachal Pradesh, India

In another disastrous landslide-related event, a prominent television reporter of Zee TV was killed while a cameraman and driver were injured near Chattru in Lahaul and Spiti district. Following heavy rains in Himachal Pradesh, many road bridges had collapsed including the strategic Bathu bridge near Ranital.

In parts of northwestern Himalaya, landslides have been reported during winter and summer rains in 2007. Particularly the Jammu-Srinagar highway was blocked at several places due to severe landslides and snow avalanches. It is worth mentioning that the Ramban-Banihal stretch of the highway has become one of the most affected portions. This nearly 25-km stretch has more than 13 landslide-prone points that abruptly block the highway in the event of landslides. On February 27, due to heavy rains the previous night, many landslides were triggered at Panthal on the Jammu-Srinagar highway. At many places, the Amarnath yatra (pilgrim tour to a famous Hindu shrine) was interrupted due to landslides on the trekking route.



Figure 10.13: Collapse of strategic road bridge in Himachal Pradesh, India

In the hilly state of Uttarakhand, landslides have wreaked havoc during the monsoon of 2007 and have left nearly 75 persons dead. During intense rain of the first and second week of August, many landslides had occurred along the Rishikesh–Badrinath road. A disastrous landslide occurred at village Baram in Pithoragarh, 40 km ahead of Tehsil Dharchula. The area lies in the higher reaches of Garhwal Himalaya in a high seismic zone where landslides are common. About three families consisting of 19 people had been buried under the debris of landslide. Fourteen people died and 5 were rescued safely with multiple injuries. Besides loss of human lives, more than 30 cattle heads have also perished. The landslide was triggered following heavy rains on the morning of 6 September 2007. Landslides were also reported from Higher Himalaya. A red alert was sounded on the evening of 1st August when a glacier suddenly rolled down into the river near Mana village, Badrinath which formed the artificial lake upstream of the river. Finally, the glacier broke down, releasing all water that took away the age-old Manna bridge. In Uttarakhand, landslide-related motor accidents caused death of 45 and 18 persons in two separate incidents on October 11 at Vishnuprayag and on March 13, 2007 at Naulib, Rudraprayag, respectively.

In Sikkim Himalaya, close to alpine zone and in areas adjoining to Gangtok, landslides were observed following pre-monsoon and monsoon precipitation in 2007. In one incident nearly 1,300 tourists were trapped by a huge landslide while returning from Changu Lake on the way to the Nathula Pass, but were rescued and safely transported back to Gangtok with the help of the administration. In Gangtok town itself a major landslide occurred, affecting nearby settlements. In the far northeast, nine people were killed when a mudslide had pushed three dwelling houses into a swirling river at Rishipara near Nakham Bazaar in Tura, Meghalaya. In Aizwal, Mizoram itself, around 27 cases of landslide have been reported, mainly triggered by heavy rain and at many places have disrupted traffic along the National Highway 54 that connects Mizoram to Assam. On 19 July 2007, seven persons

Landslide

were killed in a landslip that occurred in Guwahati. The 2007 monsoon has also played havoc in adjoining Bhutan Himalaya resulting in landslides, flood water, land sinking and blockade of highways at many places although only two deaths have been reported. Most of the landslides in Bhutan occur in the eastern and southern foothills where the terrain is very steep and rocks are highly fractured. These slides frequently disrupt the highways, particularly the Phuentsholing Thimphu national highway, hampering the transportation of vital goods.



Figure 10.14: Rescue operation is in progress
(Source: BBC)

In the western and southern part of India, landslides were reported mainly from the Mumbai-Pune highway, Konkan region and Nilgiri hills. Two persons died in a landslide in Chembur, Mumbai in the last week of June 2007. About 20 landslides have been reported in the Nilgiris district of southern state of Tamil Nadu, India due to heavy rains in the month of October. It caused a major landslide on the Udthagamandalam-Coonoor road on 27 October, killing a 35-year-old woman and injuring two children as the whole house was caught in the landslide.

Doba Syedan Landslide, Pakistan, 21 March 2007

Landslides occurred on 21 March 2007 in the Doba Syedan village in the Pakistan-administered Kashmir following a four-day-long spell of torrential rain and snow. Landslides hit the mountainous hamlets and blocked the roads at numerous locations. The region was already devastated by a massive earthquake of 7.6 magnitude in October 2005, resulting in several ground fractures, that were anticipated to cause/facilitate landslides in subsequent years.⁴ The death toll caused by recent landslides in this quake-affected Pakistan-administered Kashmir rose to 46 on 22 March 2007.

In a swift action, three helicopters participated in emergency operations - one each from the Pakistan army, the international Aga Khan Development Network charity and the United States Agency for International Development (USAID). They brought tents, food and medicines to about 350 stranded families in Doba Syedan, which is at an altitude of more than 1,500 metres above sea level. Access to landslide-hit villages remains almost impossible by land. Road authorities and army engineers have been working to open roads. The International Organization for Migration's (IOM) Rapid Response Team was dispatched immediately to the calamity-hit village to carry out a detailed assessment of the needs of the stranded families and evaluate options for their evacuation and further assistance. The IOM team has moved the landslide survivors to relatively safe places, provided medical aid to survivors and helped to organize the distribution of the relief materials to some 350 affected families. Preparations were also made for a makeshift settlement at Hattian Bala, in case the Doba Syedan villagers needed to be evacuated.

In another event, on 25th March, a landslide in the Neelum Valley hit three houses in Lilam village killing seven people and injuring four others. With no road access, the Pakistan Army carried out rescue operations and provided first aid to the injured. With the possibility of further rain and snow in the coming days resulting in more landslides, the authorities have planned a risk assessment of

the area with the help of geologists. IOM RRTs, which include doctors, rapid assessment experts and mountain rescue guides are expected to play a major role and hope to be integrated into future disaster response plans drawn up by the Pakistan government to cope with disasters in future.

Landslides in Walapna and Hanguranketha, Sri Lanka, 10-15 January 2007

During the last North-East rainy season from 10 to 15 January 2007, a significant number of landslides have occurred in the hilly areas of Sri Lanka, especially in Walapane and Hanguranketha divisions of Nuwara Eliya District. On 12 January 2007, a severe landslide in Ladupita-Kiriwanella-Munwatta caused eleven casualties. Furthermore, it is recommended by government to evacuate 23 families at Walan Kele and 3 families at Galagoda Yaya. In 1986, due to landslide risk at Katayampathana, Rambuka and Mulhalkele, families living there have been relocated to Akkara Seeya and Mahawewa. Again, during 11 and 12 January this year, 72 more families from Akkara Seeya and 35-40 families from Mahawewa were suggested to be relocated. In addition, landslides have reactivated at Rambuka and Mulhalkele. Due to a major landslide along Rabuka, 27 families were suggested to be relocated. Following are some of the prominent landslides that have occurred during 10-15 January storm event, as reported by National Building Research Organisation (NBRO), Sri Lanka.



Figure 10.15: Location of the landslide-affected area in Sri Lanka during 11-12 January 2007

The Ritiella landslide occurred on 11 January 2007 in Walapane subdivision of Nuwara Eliya district. Nine houses were completely destroyed and 86 families were affected. Preliminary investigation reveals, this area consist of colluvium soil materials deposited by old landslides in the past. Ground shows multiple fractures mostly in the head



Figure 10.16: Following the landslides in the Walapane, Maturata and Hanguranketha areas, hundreds of villagers have fled their homes for safety. Figure on the right shows Kiriwana ella area of Walapane where five houses were buried in a landslide.

area with aperture and subsidence of few centimetres to one foot. Mudwater springs were also observed during the rainy season. Based on the field evidences, it is suggested that it is a rotational type of landslide with a much deeper slip surface.

The Akkara Seeya landslide occurred in the Hanguranketha subdivision of Nuwara Eliya district on 11 January 2007. Six houses were heavily damaged and 72 families were affected. Preliminary investigation reveals that unstable area is extending from Hope Estate through Darawa to destroyed Rikillagaskada-Deltota main road. The whole area is underlain by a thick colluvium soil layer with huge boulders. Tension cracks have developed all over the slope and as a result houses, roads and other structures are heavily damaged. In the upper region of the slope, some of the surface water

sources have dried and at the same time new springs have appeared in the toe region of the slope. It is a typical rotational type of landslide with deep slip surfaces developed within the thick soil overburden. Intensive rainwater infiltration has induced the failure. Absence of a surface drainage system, disturbances caused to the existing soil slope due to construction activities, and soil erosion were the major causes of the prevailing situation.

The Mahawewa landslide occurred in the Walapane sub-division of Nuwara Eliya district on 11 January 2007. As many as 35 to 40 families were to be evacuated due to this landslide and about 56 families were affected. Preliminary investigation reveals that most of the houses and grounds have developed cracks due to both vertical and horizontal movements. Newly-formed springs and underground flow paths were observed in the main landslide body. This is a rotational slide with a high level of risk as this area consists of debris of very old landslide showing evidences of creeping and subsidence in the recent past.

Landslide Hazard Mitigation Measures:

Site-Specific Mitigation Measures: In view of the widespread fatal landslide incidences in the South Asian region, it is necessary to adopt suitable mitigation measures to minimize the devastating effect of landslides. Various site-specific remedial measures can be adopted after a detailed examination of the site conditions, as suggested below:

1. Proper drainage management: Water infiltration in the overburden during heavy rains and consequent increase in pore pressure within the overburden reduces the strength of the material and causes sliding of the landmass. This can be minimized by reducing infiltration by providing adequate drainage network. In this regard, a dual-pronged strategy must be adopted such as reducing flow of water into the vulnerable slope material by constructing interceptor drain, trench drain, diverting side drains and by channelization of all drains and second, by draining out the remaining water by horizontal to sub-horizontal drainage system (using perforated pipes) including construction of collection chamber and diverting the water to existing channel and removal of any blockade to existing drainage system. Most important, all drainage systems need regular maintenance and surveillance for detecting any change in the flow pattern or pore water pressure by installing inexpensive piezometers at selected locations.

2. Bio-engineering/Afforestation: It is a well-understood fact that tree cover largely increases the stability of the underlying ground by increasing root strength, intercepting direct effect of precipitation and reducing pore water pressure by evapotranspiration. Therefore, bio-engineering methods including that of large scale afforestation and protection of existing vegetation cover needs to be adopted in the landslide-prone areas. The selection of suitable plant species should be such that can with stand the existing hydrological conditions of the terrain.

3. Early Detection: Early detection is the key to any effort towards minimizing loss and implementing remedial measures. As landslides normally occur in far-flung areas, wherein local population is first to witness and face consequences, it is imperative that they should be made aware of the slope conditions and some of the natural phenomena which precede major landslide events. Some of the noteworthy symptoms are given below:

- a. New fractures or unusual bulges in the ground, street pavements or sidewalks;
- b. Soil moving away from foundations, and ancillary structures such as decks and patios tilting and/or moving relative to the house;
- c. Sticking(?) doors and windows, and visible open spaces on floors and side walls;
- d. Broken water lines and other underground utilities;
- e. Leaning telephone poles, trees, retaining walls or fences and houses;
- f. Sunken or dropped-down road beds;
- g. Increase in stream discharge, possibly accompanied by increased sediment load;
- h. Sudden decrease in discharge level even though rain is still continuing or just recently stopped;
- i. Minor rockfalls or debris slides

4. Slope stability measures: In addition to all suggested measures related to proper drainage management to reduce pore water pressure, structural measures need to be adopted after detailed investigation of the site. These measures include providing buttresses, shear keys, sub-drains, soil reinforcement, surface protection, slope modification, retaining walls, gabion wall, breast wall, etc.

Landslide Hazard Mitigation Programme: In order to prevent and mitigate the landslide risk, national initiatives are required or strengthened to address the following aspects:

1. Landslide Hazard Zonation (LHZ): LHZ at different scales, i.e. starting from country scale, regional scale to site-specific scale serves various purposes as per the intended application. Recent advances in data acquisition techniques based on remote sensing as well as ground-based instruments provide ample data that can be processed, modeled and analysed using statistical as well as deterministic modeling techniques in GIS and prepare the quantitative landslide hazard zonation maps.

2. Mapping and monitoring of active landslides/vulnerable slopes: Mapping and monitoring of active landslides as well as vulnerable slopes and associated potential danger such as landslide blockade lake formation can contribute immensely in any effort related to landslide hazard mitigation. In this regard field investigation, mainly related to early detection, and earth observation techniques can play a significant role, particularly in inaccessible areas, where physical monitoring is not possible nor very cost effective. Early detection not only averts disaster, but also requires low-cost remedial measures for stabilizing the slope.

3. Early Warning Systems: As landslides are very localized and confined to intense monsoon periods, it is envisaged that an early warning system would provide immense benefit in alerting people living in high hazard areas. There have been some attempts based on rainfall threshold as experimented by Indian Institute of Remote Sensing (National Remote Sensing Centre, ISRO) using data acquired through automated weather stations (AWS). Similar instruments are also used by SASE (DRDO, India) for snow and avalanche prediction. However, these studies are at a very nascent stage and need to be developed fully, taking into advantage of numerical weather prediction (NWP) modeling using Doppler Weather Radar (DWR) data. Additionally, any technology that provides information on slope

deformation such as DGPS, InSAR, Total Station based real-time modeling need to be deployed at high risk areas.

4. Awareness generation: Experience has shown that a high level of awareness and proper communication with local population can avert disaster due to landslide. During the Uttarkashi landslide event in 2003 (Uttarakhand, India), due to a high level of awareness by the efforts of scientists and administration, not even a single life was lost although property worth millions of rupees was buried in the rubble. Therefore, it is important to take up awareness programmes in the hazard-prone areas to apprise local population and all stakeholders about the landslide risk in the region, possible causes of landslides, preventive measures (including bio-engineering methods), early detection and monitoring methods as well as remedial measures. It is important to generate awareness at various levels starting from school to college level through media campaigns, development and distribution of leaflets and posters, meetings, seminars, workshops on a regular basis.

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