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Rainfall and Related Natural Disasters in Nepal

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Water-induced disasters are common in Nepal, and are usually triggered by extreme weather events associated with heavy rainfall during the monsoon. Floods due to excessive rain, outbursts of glacial lakes and landslide dams, and the failure of dams and other man-made structures are directly or indirectly triggered by extreme weather events. Rainfall events exceeding 300 mm within a 24-hour period, which disturb both slope and channel equilibria on a regional scale, occur frequently in the country. The increasing frequency of such extreme precipitation events, together with changes in snow and ice cover due to global warming and other factors, have led to an increase in the number of natural disasters in the country.

The specific characteristics of slope and channel instabilities depend on the volume and intensity of the precipitation events that cause them. Experience shows that landslides, debris flows, and flood disasters can be accurately predicted based on rainfall characteristics and known thresholds for slope instabilities and floods, which can eventually help reduce damage to life and property. However, the hydrometeorological systems of mountain areas are very complex and poorly understood. Nepal's hydrometeorological network is still poor; the existing observational network is not capable of capturing the diversity of the mountain landscape, and there are difficulties in the generalisation of weather and climate because there is little or no long-term data. Methodological problems in generating data and a poor understanding of flow-path dynamics, water balance, and highland-lowland interaction have created problems in accurately predicting the magnitude of natural hazards. Special efforts are therefore required to improve the understanding of hydrometeorological processes and the thresholds for different types of natural hazards.

Introduction

Mountain environments in Nepal, as in other mountainous regions of the Hindu Kush-Himalaya, are fragile and extremely vulnerable to hazards and disasters, whether natural or man-made. Of the natural disasters occurring in Nepal, those induced by water are the most common. These are usually triggered by extreme weather events associated with heavy rainfall, which cause floods, landslides, debris flows, and widespread damage almost every monsoon. Between 1970 and 1995, an average of 186 people were killed annually and property worth more than US$ 7.25 million was lost as a result of landslides, and 230 people killed, 5,000 houses destroyed, and property worth US$12 million lost as a result of floods in the Terai and Inner Terai districts (Khanal 1996). In 1993, a record year, landslides and floods killed 1,336 people and caused more than US$ 70 million in damage (Khanal 1997).

The different types of landslides that occur in Nepal in the country have been described briefly in the previous chapter (Chalise, this volume). The common types of flood hazard can be described as follows:

- glacial lake outburst floods (GLOFs), such as those that occurred in the Sun Koshi River in 1935, 1964, and 1981, and in the Dudh Kosi in 1977 and 1985;

- floods due to the failure of landslide-dams, such as in the Burhi Gandaki in 1967 and 1968 and in the Tadi river in 1986;
- floods due to excessive rainfall, such as in Lele watershed (Lalitpur District) in 1981, Kulekhani in 1993, and Syangja in 1998; and
- floods triggered by the failure of man-made infrastructure, as in the case of the Bagmati barrage in 1993, the check dams and embankments along the Tinau river in Butwal in 1981, and the check dams along the Rapti river in Chitwan in 1990 and 1993 (Khanal 1996, 1999).

Spatial and Temporal Variation in Precipitation

The average area-weighted annual precipitation for Nepal is about 1,630 mm, with half of the country lying within the 1,500-2,000 mm precipitation zone (Chyurlia 1984). Both the temporal and spatial variations in precipitation are highly pronounced. Nearly 80% of all precipitation occurs during the monsoon (June-September), with 8% falling during the post-monsoon (October-January) and 12% during the pre-monsoon periods (Chalise et al. 1996; Chyurlia 1984).

Spatial variations in precipitation are strongly influenced by elevation and terrain. In Nepal, average annual precipitation ranges from only 163 mm at Lomangthang (Mustang) to 5,244 mm at Lumle (near Pokhara). The Trans Himalayan region, which includes Mustang and Manang, receives annual precipitation of less than 500 mm; the valleys of the Fore-Himalaya 500-1,000 mm; the Terai, Siwalik (Churia) Hills, lower Midlands valleys, and Dun valleys between 1,000 and 2,000 mm; and most slopes in the Midlands, Mahabharat Range, and Higher Himalaya between 2,000 and 3,000 mm (Khanal et al. 1998, and see Figure 3.8 in Upreti, this volume). A few pockets, such as Pokhara (Kaski) and Kanyam Tea Estate (Ilam) receive more than 3,000 mm of annual rainfall. Rainfall events exceeding 300 mm within a 24-hour period, which disturb both slope and channel equilibria on a regional scale, occur frequently (Khanal 1995a, 1995b). Precipitation as high as 540 mm in 24 hours, with a peak intensity of 70 mm per hour, has been recorded (Dhital et al. 1993; Chalise et al. 1996).

Extreme precipitation events and trends

Although the main triggering factor for floods and landslides is the rainfall associated with extreme weather events, a combination of both natural and anthropogenic factors and processes determine the extent and magnitude of such disasters for any affected area.

Table 5.1 summarises data for 24-hour events with rainfall amounts exceeding 100 mm in Nepal for the months from June to October during 1971-80 and 1981-90. Most of these events are confined to the June-September monsoon period, although heavy pre-monsoon showers can also occur in May.

In all four categories of 24-hour rainfall events, the number of events were higher in 1981-90 than in 1971-80 (Chalise 1998) indicating that the number of extreme precipitation events is increasing. Although considerable further work needs to be done to show that this is a real trend, and not

Table 5.1: Number of 24-hour rainfall events (June to October) between 1971-80 and 1981-90 in different categories of total rainfall

	Categories of total 24-hour rainfall amount (mm)			
	100-199	200-299	300-399	>400 mm
Number of events in 1971 to 1980	802	130	22	4
Number of events in 1981 to 1990	938	210	29	8

simply a reflection of improved observation, the impact of an extreme year, or other factors, it indicates the possibility that water-induced hazards and disasters may be increasing.

This trend is in agreement with a recent review of the potential impacts of climate change in the Hindu Kush-Himalaya: "increased monsoon rainfall, increase in rainfall intensity, and melting of snow, ice and permafrost with a consequent decrease in their surface areas" (Chalise 1994).

Studies of Rainfall/Event Relationships

Precipitation thresholds

A 'precipitation threshold' is the level of precipitation (rainfall duration and intensity) needed to initiate a landslide, debris flow, or similar event. The threshold is specific for a particular slope and hazard as it depends on a large number of factors like slope angle, soil type, vegetation cover, and soil saturation, not just on rainfall. However, generalisations can be made for different types of slope in different areas.

There have been no systematic studies on precipitation thresholds for the initiation of landslides and debris flows in the Himalaya that take into consideration all relevant parameters such as slope angle, geology, soil type, vegetation, and soil saturation. However, a number of simple studies have been made of the relationship between rainfall amount or intensity and number and size of landslides and debris flows. The results of some of these in different regions of the Himalaya are summarised below.

According to a Chinese study (Li and Wang 1992), cumulative precipitation of 50-100 mm in one to two days and daily precipitation of about 50 mm was enough to precipitate small-scale shallow landslides in their region of study; two-day cumulative precipitation of 150-200 mm and daily precipitation of 100 mm, was enough to precipitate medium-scale landslides, and two-day cumulative precipitation of more than 250 mm led to an abrupt increase in the number of large landslides of debris and rock. Intense rainfall, even of short duration, caused shallow and quick landslides, whereas prolonged rainfall precipitated deep-seated and slow landslides. Li and Wang used measurements of rainfall intensity over 10-minute intervals (to identify short bursts of intense rainfall), of rainfall on the day before, and of rainfall immediately before an event, to predict the occurrence of landslides and debris flows. Of the 27 landslides and debris flows predicted, 25 actually occurred (Li and Wang 1992). This indicates that with sufficient information and knowledge of the effects of intense and prolonged rainfall it may be possible to predict landslide and debris flow events.

In another study in the Darjeeling area, shallow landslides and slumps on steep slope segments were observed when 24-hour rainfall exceeded 130-150 mm or three-day rainfall 200-240 mm. Slumps, landslides, and debris flows on a larger scale were observed after 24-hour rainfall exceeding 250 mm or three-day rainfall 350 mm. Extensive and simultaneous debris flows were observed after 24-hour rainfall of more than 300 mm or three-day rainfall of more than 600 mm (Froehlich and Starkel 1987; Froehlich et al. 1990).

In a study in the Kolpu Khola area of central Nepal, the precipitation threshold was found to be 100mm of rain within 24 hours. The frequency of landslides was observed to increase later in the monsoon, presumably as a result of increased groundwater levels and soil saturation (Caine and Mool 1982).

Number, area and volume of mass-movements

During a normal year, the erosion rate in the Nepal Himalaya is estimated to be less than 2 mm, in the Darjeeling Himalaya 0.5-5 mm. However, catastrophic occurrences can have a marked impact. During one three-day period in 1968 (3-5 October) between 600 mm and 1,200 mm of rain fell in Darjeeling precipitating some 20,000 landslides. It is estimated that more than 2% of the surface area covered by forest and 20-25% of the surface area under cultivation was transformed by mass-movements, and an average of 20 mm of soil was removed across the region by that single catastrophic event. River channels and valley floors were totally changed, and there were material deposits, of up to 10 metres (Agrawal and Chak 1991; Froehlich et al. 1990).

In 1993 (19-20 July), more than 2,000 small and large landslides occurred along Nepal's Tribhuvan Highway and between 23 and 40% of the total surface area in the vicinity of Okhar Bazaar and Daman villages in the Kulekhani basin was affected by the landslides (Dhital et al. 1993). Similarly, a cloudburst on 30 September 1981 triggered 46 landslides per sq.km in the Lele watershed, south of Kathmandu (Manandhar and Khanal 1988).

On 30 August 1998, a 24-hour rainfall of 238 mm in Syangja triggered many landslides, debris flows, and floods, killing 55 persons and destroying 640 houses. A total of 1,137 landslides was counted within an area of 28 sq.km; 65% were small (average width 12m, length 17m) and the rest were large (average width 30m, length 40m). Thus 2.25% of the total land area was occupied by the landslides initiated by this event. The estimated average depletion-zone depth was 1m, giving an average denudation rate of more than 22.5 mm, with a total estimated weight of 40,500 tonnes per sq. km or 405 tonnes per ha (based on the average soil density of silty gravel of 1.8 mg per cu.m) (Khanal 1999).

Issues

While losses due to natural disasters can be minimised by the better understanding and forecasting of weather, climate, and hydrological behaviour, there are a number of obstacles to doing so in the HKH in general and Nepal in particular. These include the lack of well-developed observational networks and thus of data, and the complexity of and variability within the region.

The region's inaccessibility, remoteness, and hazards pose serious difficulties in maintaining and expanding the observation network. At the same time, lack of funds means that many of the stations that have been established have been abandoned and that others are not operating for a significant portion of the year (Kundzewicz and Kraemer 1998; Chalise and Khanal 1996; Hossain 1998). In Nepal, only 264 pluviometric (precipitation measurement) stations have kept records for more than five years, whereas 600 to 1,500 stations would be required for good representation of the country as a whole (Chalise et al. 1996). This limited pluviometric network is a serious weakness when it comes to estimating the total precipitation (input) for the study of hydroecological behaviour in the river basins of the country. Remote sensing has tremendous potential as an alternative for studying the hydrology in the HKH area. However, the lack of baseline data has made it difficult to calibrate and verify the available remotely-sensed data, while the high cost of such data has inhibited the expansion of the network.

Not only is there insufficient data, the highly variable nature of the region also complicates understanding of the various components and processes of its hydrological systems (Rodda 1994; Lang 1998; Jodha et al. 1992; Chalise 1994, 1998). The region's climate and hydrology are very complex and vary highly within short distances as a result of differences in altitude, and slope steepness and aspect. Moreover, the frequent occurrence of water-related natural hazards such as glacial lake outburst floods (GLOFs), avalanches, landslides, debris flows, and landslide-dam failures have made it difficult to estimate discharges accurately (Lang 1998; Kundzewicz and Kraemer 1998; Khanal et al. 1998; Shah et al. 1998). Systematic wind-induced errors also affect estimates of precipitation input in mountain areas (Lang 1998). It is an unfortunate paradox that the physical difficulties and costs of developing and maintaining an observational network are greatest in mountainous areas – the very place where a dense network is most needed to capture the diversity of the landscape. At present the density of hydrometeorological stations in the whole HKH region is much less than that recommended by WMO (Chalise et al. 1996).

The absence of long-term data and the extremely limited number of meteorological stations – particularly at elevations above 2,500m – have seriously hindered a better understanding of climates in the HKH (Barry 1981; Mani 1981; Das 1983; Chalise 1986; Hofer and Messerli 1997). Reliable data on precipitation is probably the most critical need for proper planning and management of water resources in the region. However, true measurements of precipitation are problematic and of limited value, not only because of the difficulty in installation, maintenance, and running of stations but also because of the only local-scale validity of the observations obtained (Domroes 1979). Little attention has been paid so far to daily rainfall in the Himalaya. In the absence of data, and given the very low density of hydrometeorological stations, it is very difficult to investigate water balance (the input/output/storage relationship of water in a given area) for any watershed. Similarly, lack of adequate reliable data also inhibits systematic assessment of the impact of upland activities and events on lowland areas (highland-lowland interactions) or the base-flow contribution of highland areas (flow from groundwater sources rather than from precipitation events) (Khanal et al. 1998; Hofer and Messerli 1997

The rivers of the HKH are also characterised by very high sediment loads and high bedloads (the solid material like sand, gravel, and sometimes boulders pushed down by rivers rather than being carried in suspension) resulting from landslides, debris flows, and GLOFs. Information on sediment loads, and particularly on bedloads, is very scanty, especially for headwater regions where the measurement of bedloads remains a major challenge (Khanal et al. 1998; Kattlemann 1987).

There are no good models of the climatic and hydrological systems of the HKH mountain basins, partly because the hydrology of high mountain areas is itself not very well developed, and partly because the peculiar combination of extremely high altitudes, steep slopes, and intense seasonal monsoonal rainfall limits and even precludes the application of the hydrological techniques, principles, and models developed in temperate regions. Special efforts are required to develop models specific to this region that can be combined with global models.

Even if we had sufficient data from the past to enable understanding and prediction of the events associated with rainfall, and models of the climatic and hydrological systems, we still couldn't be sure if they would hold true in the future because the potential impacts of climate change remain unknown. Lack of long-term climatological data has hindered the assessment of climate change impacts on the region — a subject that has only recently started to receive some attention (Gupta and Pachauri 1989; Chalise 1994). Most of the information available comes from glacier studies, which have received a lot of attention in the HKH (Higuchi 1978; Mayewski and Jeschke 1979; Miller 1989; Miller and Marston 1989; Zhang 1984; Wang et al. 1984, Chen et al. 1989; Zheng et al. 1990, Young and Hewitt 1993). But further work is necessary to ascertain the relationship between glacial fluctuations and climate change.

The importance of hydrological research has not been well understood at the policy level in the region. This is mainly the result of the inability of regional institutions to influence decision-makers at the policy level, and also partly due to the fact that scientific research in general is not considered a priority by the countries of the region.

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