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Water-Induced Disasters in the Himalaya: Case Study of an Extreme Weather Event in Central Nepal

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A cloudburst over the central region of the Bagmati catchment on 19-20 July 1993 caused catastrophic landslides and debris flows. The flood, estimated to be about 16,000 cumec, damaged the Bagmati barrage and flooded Sarlahi and Rautahat districts in the Terai. Tistung and Hariharpur Garhi recorded the highest point values for 24-hour rainfalls, of 540 mm and 483 mm respectively. Mountainous catchments are vulnerable to such events, which are quite frequent but still unpredictable.

This paper provides information about water-induced disasters in Nepal in general and the 1993 Bagmati event in particular, and discusses the contributing factors and implications for future planning.

Introduction

The rivers in Nepal are categorised into three grades, based on their sources and dry season flow. The first-grade rivers – namely the Karnali, Narayani, and Sapta Kosi – originate north of the Himalayan range and have substantial dry-season flow. Second-grade rivers, such as the Bagmati, originate further south (mostly in the Mahabharat range) below the snowline and are fed by groundwater and springs in the dry season. Third-grade rivers, originating in the lower Siwalik (Churia) Range, have very low annual discharges and can even dry up in the dry season. The annual mean streamflow in Nepal is about 200×10^9 cu.m, of which about 72% is contributed by the first-grade rivers. About 75-80% of the total annual surface water flow out of the country occurs during the monsoon season.

The present case study pertains to the extreme weather event of 19-20 July 1993 over the Bagmati River watershed in central Nepal (Figure 6.1).

Floods, Debris Flows, and Landslides Triggered by the Extreme Weather Event of 19-20 July 1993

The rainfall event that occurred over the Kulekhani portion of the Bagmati watershed on 19-20 July 1993 produced Nepal's highest-ever recorded 24-hour rainfall. During the 1993 monsoon period in Nepal, more than 1,300 people lost their lives and 60,000 hectares of arable lands were damaged. About 67 small and large irrigation projects, 337 km of highways, and many bridges were also destroyed (DPTC 1994).

Some observations and conclusions made from a reconnaissance study fielded by ICIMOD (Dhital et al. 1993) in the worst-affected regions are important. Table 6.1 summarises past landslides and floods in some of the study areas. Such disasters are clearly quite frequent but occur irregularly.

Meteorological Aspects of the Event

A monsoon trough which developed over the foothills of central Nepal on 19-20 July 1993 brought record-setting rainfall to the upper regions of the Mahabharat Range of Makawanpur and Dhading

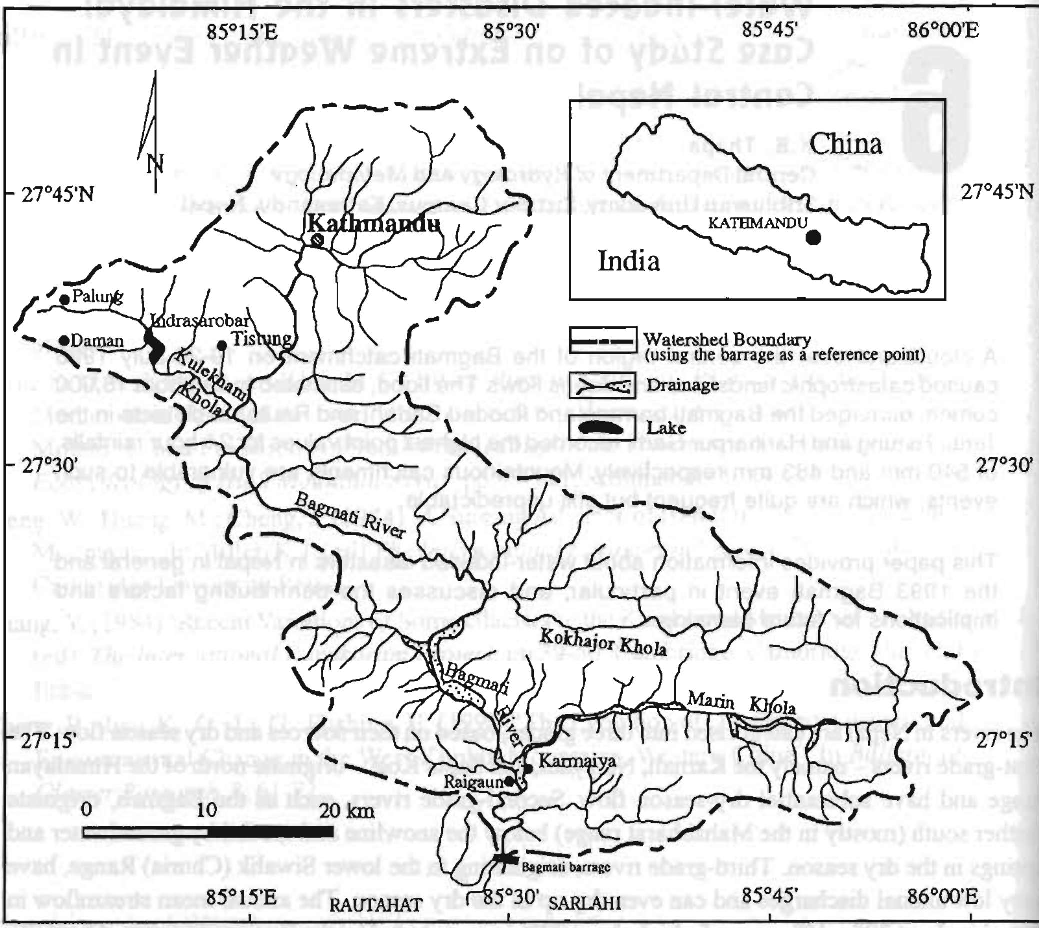

Figure 6.1: The Bagmati watershed

Table 6.1: Major landslides and floods associated with high-intensity rain in the study area (Dhital et al. 1993)

Place	Major events
Daman- Palung	1915 (more or less equal to 1993 event), 1954, 1979, and 1993
Phedigaun-Agra	1954, 1970, 1971, 1974, 1985, and 1993
Milche	1954 (bigger than the 1993 flood) 1970, 1971, and 1981 (more sediment and logs observed than in 1993 event)
Saldhara	1954 and 1970 (many landslides on the upper slopes of the Mahabharat Range)
Baldeu	1970 local rain (a bigger flood than the 1993 event)
Raigaun	1954 (more or less equal to the 1993 event), 1970 (no local rain but large flood), 1984, and 1993 (heavy local rainfall with thunderstorms and landslides)
Bhimphedi	1915, 1954 (Dhorsing Bazaar and Pati Bazaar swept away), 1973, 1984, 1986, 1990, and 1993
Manahari	1954, 1961, 1970, and 1984 (slightly smaller than the 1993 event)
Bhandara-Khumroj	1970, 1979, 1990, and 1993

districts. Disastrous floods, debris flows, and landslides were observed all over the Bagmati, Trisuli, and Rapti watersheds.

In the 24 hours from 8:00 am on July 19 to 8:00 am on July 20 1993 400-450 mm of rain (average isohyetal values) fell in the northern regions of the Kulekhani watershed and the central region of the Bagmati catchment (Figure 6.2). During the evening of July 19 incredible rainfall of 540 mm at Tistung and 483 mm at Hariharpur Garhi (single point measurements) were recorded, which are respectively the highest and the fourth highest rainfalls ever recorded in Nepal. Tistung and Simlang received 65 mm and 73 mm of rainfall respectively in just one hour. The Bagmati catchment as a whole (2,720 sq.km upstream of the barrage) received intense rainfall.

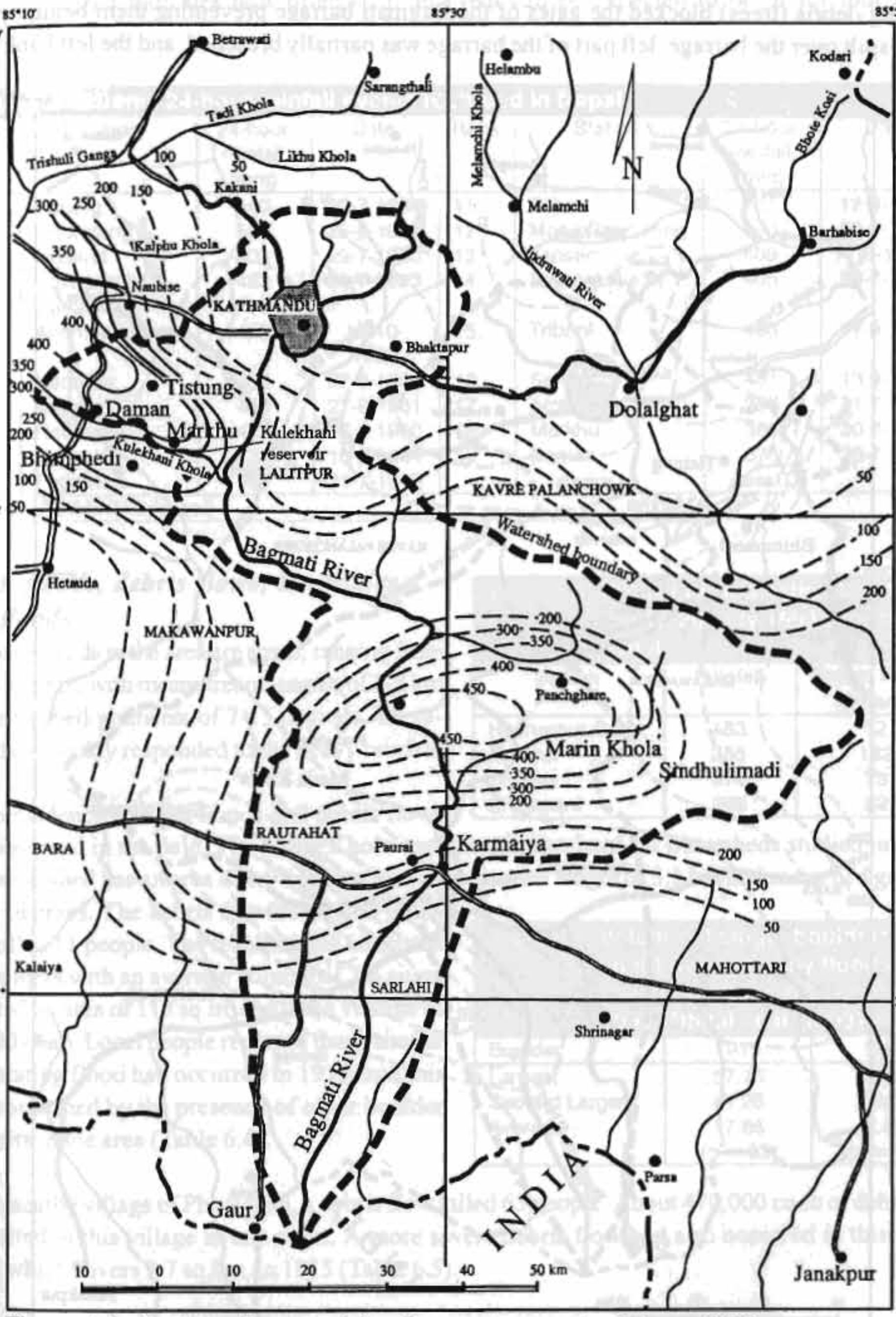

Figure 6.2: **Isohyetal map of the Bagmati watershed from 8:00 am on July 19 to 8:00 am on July 20 1993 (isohytes in mm)**

The following day (8:00 am on July 20 to 8:00 am on July 21 1993) this intense pocket of rainfall shifted over to a region about 25 km to the east of the Bagmati Barrage (Figure 6.3) (Shakya 1995). It appears that that as the flood swept downstream the intense rainfall pocket also shifted downstream towards the south, resulting in coincident arrivals of various tributary floods with the main stream flood course.

Floating debris (trees) blocked the gates of the Bagmati barrage preventing them being opened. Water spilt over the barrage, left part of the barrage was partially breached, and the left bank of the

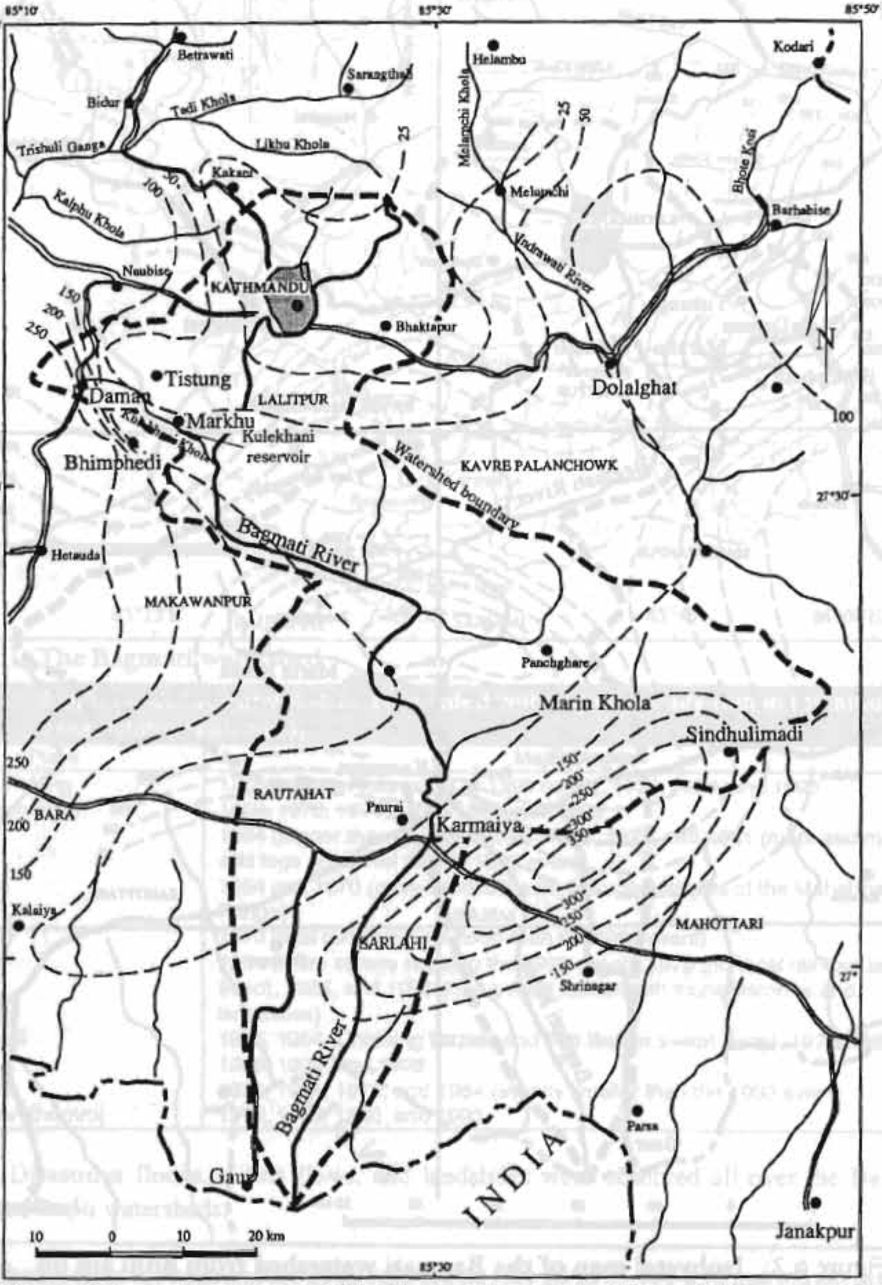

Figure 6.3: **Isohyetal map of the Bagmati watershed from 8:00 am on July 20 to 8:00 am on July 21 1993 (isohytes in mm)**

river and was disrupted at midnight on the 20 July – which resulted in major flooding in Sarlahi and Rautahat districts to the south in the Terai.

Table 6.2 puts the 1993 Bagmati event in context: of the 19 24-hour rainfalls registering 375 mm or greater that have been recorded by meteorological stations in Nepal, six occurred during this one event. Table 6.3 indicates how often such an event can be expected to occur for four of the stations.

Table 6.2: Extreme 24-hour rainfall events recorded in Nepal

Rank	Station	24-hour rainfall (mm)	Date	Rank	Station	24-hour rainfall (mm)	Date
1.	Tistung	540	20-7-1993	11.	Bajura	431	12-9-1980
2.	Ghumtang	505	25-8-1968	12.	Mane Bhanjyang	420	30-9-1981
3.	Musikot	503	29-7-1960	13.	Tansen	409	7-9-1959
4.	Hariharpur Garhi	483	20-7-1993	14.	Barahakshetra	405	28-7-1974
5.	Anarmani Berta	473	10-10-1959	15.	Tribeni	403	17-9-1984
6.	Hetauda	453	27-8-1990	16.	Semari	401	13-9-1982
7	Batuwa	446	27-8-1981	17.	Amlekhganj	399	21-7-1993
8.	Hetauda	438	27-8-1990	18.	Markhu	385	20-7-1993
9.	Kankai	437	16-9-1984	19.	Daman	375	20-7-1993
10.	Patharkot	437	21-7-1993				

Source: (DHM/HMG/Nepal)

Flash floods, debris flows, landslides and floods

The watersheds in the area are small, ranging from 2 to 50 sq.km, with mean stream lengths of 3-8 km and mean bed gradients of 7-15 degrees. Therefore they quickly responded to the heavy rainfall.

Table 6.3: Return-period estimation for the 19-20 July 1993 rainfall event

Station	Rainfall	Return Period (Years)
Hariharpur Garhi	483	52
Markhu	385	132
Daman	375	78
Chisapani	295	52

Much evidence of flash floods and debris flows was observed in the field. The Kitini Khola was one of a few hard-hit watersheds studied in detail. The watershed has an area of 1.9 sq.km with a mean stream length of 3.1 km and mean bed gradient of 11 degrees. The debris flow destroyed farms and killed 11 people. The resulting fan consisted of boulders with an average volume of 7.6 cu.m, covered an area of 118 sq.m, and had a volume of 59,000 cu.m. Local people reported that a similar devastating flood had occurred in 1915, and this was confirmed by the presence of older boulder deposits in the area (Table 6.4).

Table 6.4: Volume of single boulders (in cu.m) deposited by floods on the Kitini Khola in 1915 and 1993 (Dhital et al. 1993)

Boulder	1915	1993
Largest	57.75	17.64
Second Largest	41.26	16.60
Average	17.86 (n = 33)	7.56 (n = 32)

In the nearby village of Phedigaun, a debris flow killed 65 people. About 470,000 cu.m of debris was deposited in this village in one night. A more severe debris flow had also occurred in this watershed, which covers 3.7 sq.km, in 1915 (Table 6.5).

A debris flow along the Agra Khola, in an adjacent watershed, washed away four piers of a bridge on the Prithvi Highway. The peak discharge was estimated to be about 1,800 cumec. A field survey

Table 6.5: **Volume of single boulders (in cu.m) deposited by floods on the Phedigaun Khola in 1915 and 1993** (Dhital et al. 1993)

Boulder	1915	1993
Largest	109.8	52.5
Second Largest	57.98	20.4
Third Largest	46.62	11.9
Fourth Largest	5.07	11.8

indicated that debris had raised the bed by 5m along a reach of 17 km (average width 40m).

The debris flow on the Jurikhet Khola, with a 9 sq.km catchment area, destroyed the Kulekhani penstock pipe (the water conduit from the intake to the turbines in a hydroelectric plant). Large boulders, 5-10m in diameter, filled the channel. Further downstream, a tributary of the Mandu Khola destroyed a village and the intake of a second Kulekhani hydropower project.

Many regions of the Bagmati catchment were more or less saturated with antecedent rain from May and June, and the intense rain of 19-20 July triggered uncountable landslides. There were more than 2,000 landslides along the Tribhuvan Highway alone. Landslides, rockslides, bank collapses, and gully erosion created sources for debris flows. Undercutting of steep bank slopes triggered more landslides.

The Kulekhani reservoir received a very large amount of sediment from the nearby watersheds that received the cloudburst. Many landslides and remnants of debris flows were observed all along the field route from Palung to Raigaun. Flood marks 10m above the normal river level were observed near Raigaun. The Kokhajar and Marin Kholas, tributaries of the Bagmati river (Figure 6.1), contributed substantially to the flood event. The peak flood estimated at Pandhero Dobhan, about 1.5 km upstream of the Bagmati barrage, was 16,000 cumec; the barrage was designed for a maximum flood of 8,000 cumec.

Discussion

Although the major factor that precipitated the 1993 disaster was climatic – exceptional rainfall of high intensity – there were many other contributory factors, some unavoidable, some that could have been influenced or foreseen. The major factors that together contributed directly or indirectly to the occurrence of the disaster, and its extent and impact, (and could play a role in the development of other similar disasters in the region) can be summarised as follow.

Natural causative factors

Geological

- The tectonically active mountain system – the mountains are rising, thus they have very steep slopes and intense down-cutting activities, and there is much reworking of materials previously deposited along streams. Most large, deep landslides are located along streams; recently formed fans are more vulnerable.
- Weak geological structure – joint systems of rocks produce large boulders.

Climatic

- Seasonal and daily temperature variation
- Monsoon rainfall

Hydrological

- Sharp bends in river courses causing partial damming and deposition of bed materials (areas where tributaries merge more or less at right angles are much more vulnerable to flooding)

Past events
- Earthquakes, precipitation, and landslide activities (reinitiating landslides)

Other factors

Population pressures
- Encroachment on marginal and forest lands as a result of rapid population growth (cultivation on very steep slopes – up to 45° – and maize-based subsistence agriculture, both of which increase slope instability)
- Free access to common lands (no need to grow trees on farmland)
- Deforestation and frequent forest fires
- Lack of long-term understanding of the environment in recently inhabited areas, particularly in the Siwaliks (Churia), Bhabar, and Inner Terai
- Construction of private and public buildings on unsuitable land, particularly in accessible areas, without regard for potential risks
- Extraction of sand and gravel along streams (building materials)

Development activities
- Horticultural farms in previously forested areas
- Kulekhani hydro project (forced people to encroach on marginal land)
- Road construction (pressure on forests)
- Quarrying on steep slopes and on steep stream banks (causing a rise in bed levels and lateral erosion)

Technical shortcomings
- Lack of historical records and their application in designing major construction works like the Bagmati barrage, penstock pipes, the check dam on the Rapti, and many bridges
- Lack of communication systems (information exchange and warning)

Lessons Learnt

To avoid disasters on this scale in the future, it is important that steps are taken to ensure that constructions are less vulnerable and that people can be warned of the situation. It is essential for the proper design of infrastructure such as bridges, dams, and barrages that rainfall frequency analyses are made and that there is a sufficiently good network of hydrometeorological stations to enable rainfall-runoff studies. Warning stations should be installed so that people can be warned about approaching floods, and debris lying idle in channels upstream of the infrastructure mapped so that potential debris flows during flash floods can be predicted.

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