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Role of extreme meteorological anomalies in initiating the Darbang Landslide, Dhaulagiri Himal, Western Nepal

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ABSTRACT

A catastrophic landslide occurred at midnight of 20 September 1988 at a small village of Darbang (1130 m above mean sea level) in western Nepal. The village is situated approximately 40 km northwest of the district capital Baglung. Farmhouses spread out on both sides of the Myagdi Khola, a main tributary of the Kali Gandaki River.

An overly steep and more than 800 m high northern flank of a mountain collapsed spontaneously. Approximately 5 million m³ of the displaced material blocked the valley of the Myagdi Khola and dammed the river for 6 hours. The eventual breakup of the landslide dam caused extreme flooding in the lower reaches. Many houses of Darbang, particularly on the right bank of the Myagdi Khola, were destroyed. More than 100 persons lost their lives. This catastrophic event could be interpreted as a revisit of the devastating landslide of 1926, which killed more than 500 villagers.

Diverse lithology (phyllites, schists, and quartzites), presence of the MCT in the vicinity, extremely high relief, and environmental degradation (e.g., deforestation), are regarded as the primary causative factors of the Darbang Landslide.

Yet the decisive factor behind the massive landslide of 1988 was the unique meteorological situation of that year. The meteorological data show that, during the pre-monsoon months of April, May, and June 1988, the maximum temperature was 2° C higher than the average for the decade. Monthly precipitation measured in May and June of 1988 showed the totals respectively 37% and 24% below the decade-average. It led to extreme aridity in the period preceding the onset of the seasonal monsoons. Soils dried out and deep cracks were formed in this process. During the heavy summer rainfall of 1988 the cracks functioned as conduits of water. The bedrock contained numerous fractures and joints, through which the water seeped deep into it. Extremely heavy precipitation in August, with rainfall of up to 17% above the decade-average, aggravated this delicate situation. In the first half of September 1988 precipitation peaked. These meteorological conditions, coupled with the already saturated bedrock, and deteriorated natural vegetation lead to the collapse of the mountain flank.

Primary causative factors and environmental degradation over a longer period were underlying reasons for the initial weakening of the site, but the unique weather situation in 1988 was the main trigger of this catastrophic event.

INTRODUCTION

Within the last few decades numerous attempts at geomorphic mapping have been made throughout Nepal. The purpose of most of these investigations was to point out different geomorphic features in relation to mountain hazards and slope instability (Fort 1987a,b; Ibetsberger 1995,1996a,b; Ibetsberger and Weidinger 1997; Kienholz et al. 1983, 1984; Schramm et al.1998; Weidinger 1997, 1998; Yagi and Öi 1995; Zimmermann et al. 1986).

The study area (Fig. 1) lies in the Western Development Region of Nepal, approximately 40 km northwest of Baglung, the district capital. Baglung (984 m above mean sea level, amsl) is situated on the higher river terrace on the right bank of the Kali Gandaki. Beni (1020 m amsl) lies 10 km upstream, where the Myagdi Khola, a western tributary of the Kali Gandaki, merges with the main river. Darbang (1130 m amsl), or what remains of this small village within the landslide area, is now confined exclusively to the left bank of the Myagdi Khola. The entire area belongs to the foot of the Dhaulagiri Himal. The northwest/southeast oriented valley of the Myagdi Khola cuts through this hilly region, dividing the Lesser Himalaya in the south from the Higher Himalaya in the north (Dhaulagiri Himal).

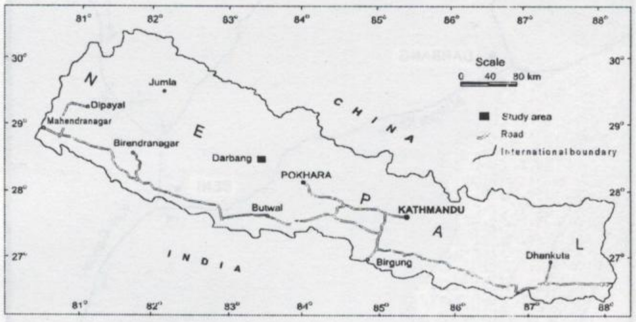

Fig. 1: Location map of the study area

The area under investigation is located close to the northern margin of the Lesser Himalaya and is made up of metasedimentary rocks blonging to the Chail Formation (Fuchs and Frank 1970). It consists largely of quartzites, black phyllites, and slates. The rocks of the Jaunsar Formation (Fuchs and Frank 1970) are observed in the south. They are represented by green and white quartzites, phyllites, and grey-green slates. By taking into account the increase of the metamorphic grade of the series to the north, the location of the Main Central Thrust (MCT) can be inferred (Fuchs and Frank 1970; Yagi et al. 1990). The geological boundary of the Chail Formation and the Jaunsar Formation passes just through the crown of the landslide (Fig. 2).

The catastrophic landslide occurred at midnight of 20 September 1988. A very steep northern flank (Fig. 3) of the mountain range (more than 2000 m high) collapsed spontaneously. The crown was situated on the right bank of the Myagdi Khola at an altitude of 1850 m amsl. The relative difference in elevation from the crown to the toe near the bank of the Myagdi Khola was almost 800 m. The average width of the landslide scarp measured about 500 m. The volume of displaced material was estimated at 5 million m^3. The landslide debris blocked the valley of the Myagdi Khola and dammed the river for 6 hours. Though the breakup of the landslide dam was surprisingly quick, it caused destructive flooding in the lower reaches.

The collapse of the mountain flank also caused enormous damage at Darbang. All houses on the right bank of the Myagdi Khola were destroyed, and more than 100 persons lost their lives. The left bank was also partially damaged by the landslide, which dumped a 10 m thick layer of debris on a vast area of agricultural land. The inhabitants of Darbang were shaken by this catastrophic event, which can be interpreted as a revisit of the devastating landslide of 1926 that killed more than 500 villagers (Plate 1).

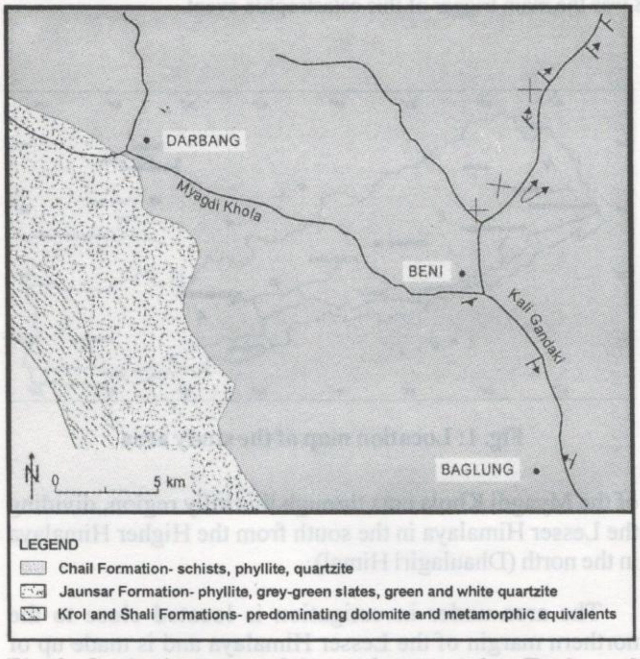

Fig. 2: Geological map of the study area (after Fuchs and Frank 1970)

PRIMARY CAUSATIVE FACTORS

The very steep mountain flank has long been recognised for its prevailing instabilities. The previous landslide scarp of 1926 was smaller and situated about 300 m below the present one. Both events, however, characterise the mountain wall opposite of Darbang as extremely unstable and tending towards recurring collapses. The primary causative factors of these landslides are the following.

Lithology and Tectonics

One reason for the instability of the mountain flank can be discovered in regional geology. Schists and phyllites with almost horizontal foliation plane and alternating with quartzites form the mountain wall. This fragile composition of bedrock is primarily responsible for the instability of the wall. Furthermore, the bedrock contains quartzite bands with thin phyllite or schist partings. These bands are very prone to failures and are also called the horizons of weakness. One of these layers found in the middle of the wall outlines the crown of the 1926 landslide. Yet tectonics also contributes significantly to the instability of the rock in this area. High-grade metamorhic rocks as well as a crushed zone (Yagi et al. 1990) situated near the crown indicates the MCT-related activites in that area.

Land use

Because of favourable climatic conditions, the region of Darbang flourishes agriculturally. Irrigated terraces are rare; more usual are the non-irrigated terraces, owing to sufficient precipitation the year round. Degredation of the environment, including deforestation, is prevalent, above all on the mountain flank at the site of the landslide.

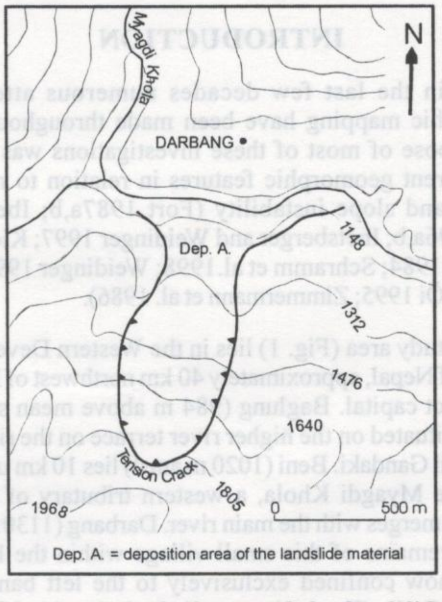

Fig. 3: Geomorphological map of the landslide area of Dhabang, located at the Myagdi Khola

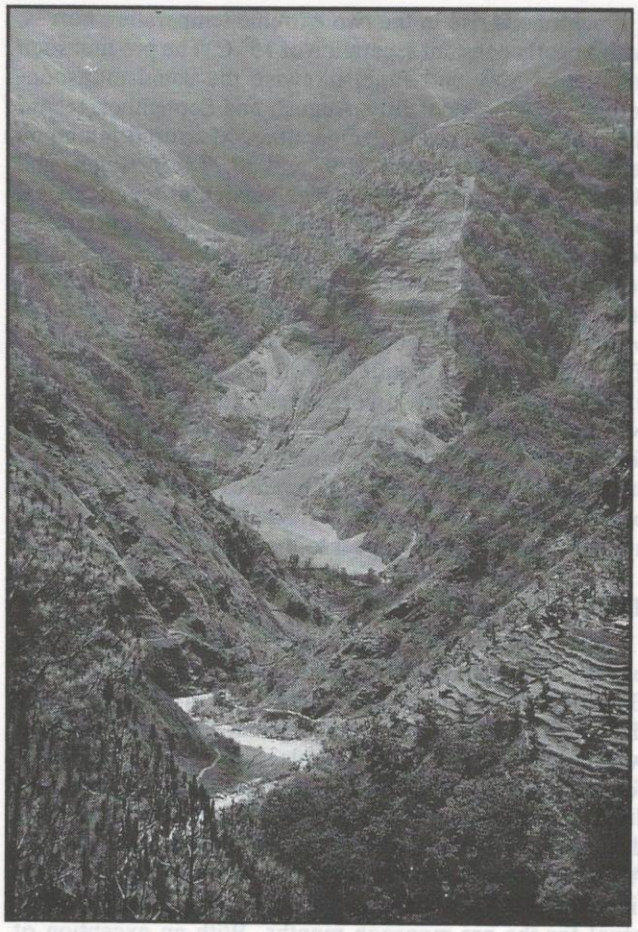

Plate 1: Scarp of the giant Darbang landslide on the right bank of the Myagdi Khola

Only the small gorges bordering the landslide area of Darbang show the natural vegetation with *Pinus roxburghii* and *Quercus semecarpifolia*. Steep slopes are sparsely timbered, with the exception of a few unsuccessful attempts at re-vegetation.

TRIGGERING FACTORS

The climate of Nepal is strongly influenced by monsoon currents. The major topographical barrier, the Greater Himalaya, is responsible for the extraordinarily high orographic precipitation on the southern flanks of the mountain ranges. A "pocket" of extremely heavy annual precipitation (Fig. 4) exists on the southern foothills of the Annapurna and Dhaulagiri Himal. The small village of Lumle (1642 m amsl), located 25 km west of Pokhara, south of the Annapurna massif, has the annual mean (1971-1975) precipitation of 5551 mm. About 25 km SW of Lumle lies the little town of Baglung (28°16'N latitude, 83°38'E longitude; altitude 984 m amsl), with the annual mean (1981-1990) precipitation of 2008 mm. Baglung, the district capital, is the nearest weather station to the landslide area of Darbang (1130 m), which is located 40 km to the NW in the Baglung-Parbat Range, the foothills of the Dhaulagiri massif. The climates of Baglung and Darbang are comparable.

Precipitation during 1981-1990

The annual distribution of precipitation is strongly influenced by the summer monsoon (Fig. 5). During 1981-1990, Baglung shows an annual mean precipitation of 2008 mm. The data reveal the highest monthly means during the months of July (588 mm) and August (4392 mm). The monsoon effects continue into September with decreasing intensity (344 mm). The post-monsoon months of October and November are clear and without noteworthy precipitation (50 and 8 mm, respectively). The winter monsoon activity during December and January is negligible (24 and 26 mm, respectively). During the early spring and pre-monsoon

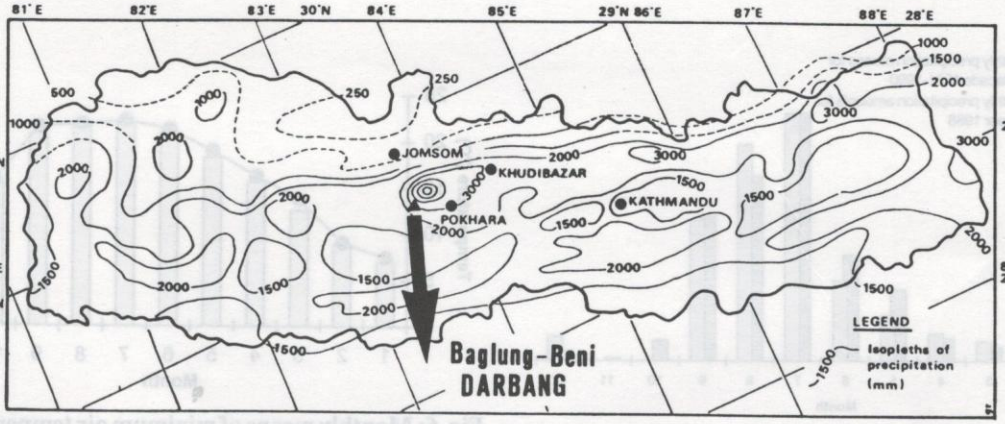

Fig. 4: Mean annual precipition for Nepal (after Ives and Messerli 1989) with personal additions. The "Pocket" of heavy precipitation near Pokhara includes the foothill region of the Annapurna and Dhaulagiri Himal (Baglung-Parbat range) with the villages of Baglung, Beni, and Darbang.

months between February and June, the precipitation rises steadily (February: 22 mm, April: 54 mm, May: 170 mm, June: 252 mm). The curve depicts a unimodal monsoon precipitation pattern.

Precipitation in 1988

The pre-monsoon months of May and June had respectively the rainfall of 108 and 190 mm, and these values are 37% and 24% below the decade-mean. With the onset of the monsoon in July, the amount of precipitation increased rapidly to the level of the decade mean (587 mm). More importantly, however, particularly with respect to the landslide, the month of August recorded significantly heavy precipitation, which was not only 17% above the decade-mean, but also the 3rd heaviest of the entire decade (513 mm). September 1988 conforms to usual patterns, but in contrast to other September months with their steadily diminishing daily rainfall amounts, the precipitation of 1988 shows a marked peak in the first half of the month. After this extreme weather configuration, monsoon activity began to wane. October and November 1988 can be regarded as typical post-monsoon months, with virtually no precipitation. The precipitation curve of 1988 thus rises gradually during the pre-monsoon months, reaches a significantly high peak during the monsoon season, and thereafter falls quickly in early October.

Temperatures during 1981-1990

Baglung shows a decade mean temperature of 22.4° C, whereas the decade means of monthly minima and maxima were respectively 15.1° C and 27.9° C (Fig. 6, 7). During the decade, the lowest monthly minima for December, January, and February were respectively 7.3° C, 6.9° C, and 8.9° C, whereas the lowest monthly maxima were respectively 22.2° C, 20.8° C, and 23.2° C. These extreme values of dry winter months indicate that the temperatures can vary by as much as 20°. The pre-monsoon months from March to May show a synchronous rise in the two extreme temperature curves, with a nearly constant separation of 15° C. The pre-monsoon months of May and June, likewise the usual monsoon-influenced months of July, August, and September, record the highest extremes of temperature. Measured minimum temperatures lie between 21.9° and 20.7° C in August and September, respectively, whereas maximum temperatures, between 32.1° and 30.2° C in June and September, respectively. For these months the greatest point of separation of the extreme temperature curves is relatively small (10° C). Throughout the decade, maximum temperatures of more than 30° C can be observed from April to September. The post-monsoon month of October is characterised by extreme temperature divergences (15.4° C / 28.9° C). November, on the other hand, shows the typical temperature features of the approaching winter season. It is essential to stress not only that seasonal differences in temperature can be observed, but also that daily fluctuations are quite strong, a factor decisive with respect to the climatic process.

Temperatures in 1988

It is informative to compare the decade mean temperature of 1981-1990 (22.4° C) with the annual mean of 1988 (23.6° C). Both of the extreme-temperature curves of 1988 lie above that of the decade mean, proving that the year 1988 was warmer than the decade as a whole. Particularly remarkable for 1988 are the pre-monsoon months of April, May, and June. The measured maxima of April and May exceed the decade mean by more than 2°, whereas those of June by 1°. All of the absolute maximum temperatures of these months lie above 33° C (33.1° / 33.2° / 33.1°), which is in no case usual for the pre-monsoon months. With an exception of August, all the months of the summer monsoon season show higher readings in minimum and maximum air temperatures than the decade as a whole. For the winter months of November, December, and January both of the extreme temperature curves show readings exceeding the decade mean by 1°-2.2°.

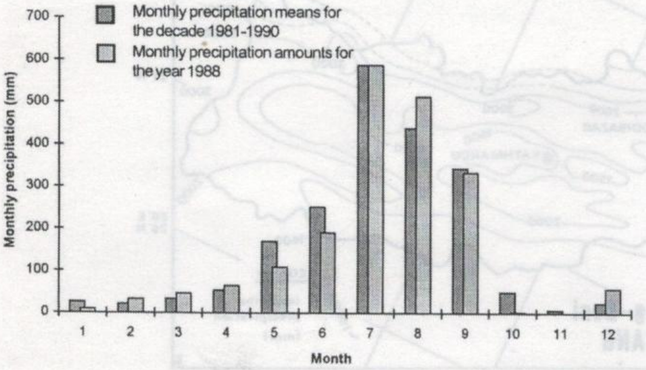

Fig. 5: Comparison of the decade (1981-1990) mean monthly precipitation with the monthly precipitation of 1988 recorded at the Baglung weather station

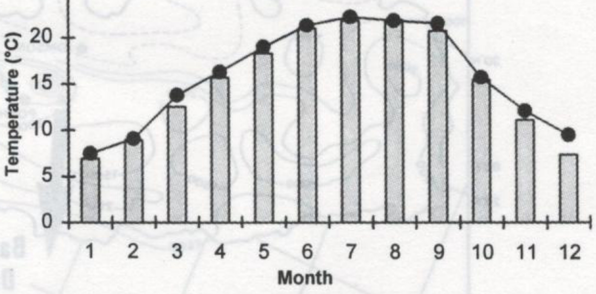

Fig. 6: Monthly means of minimum air temperatures for the decade 1981-1990 (bars) and monthly minimum air temperatures of 1988 (line) recorded at the Baglung weather station

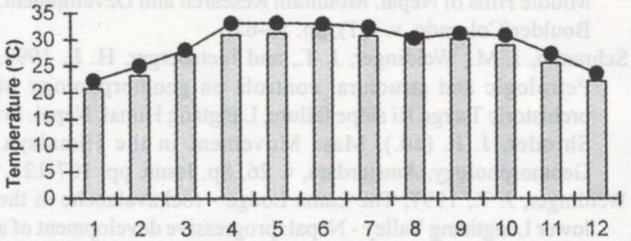

Fig. 7: Monthly means of maximum air temperatures for the decade 1981-1990 (bars) and monthly maximum air temperatures of 1988 (line) recorded at the Baglung weather station

DATA INTERPRETATION

Analysis of meteorological conditions preceding the Darbang landslide allows us to reconstruct the landslide event. The pre-monsoon months of April, May and June 1988 experienced not only maximum temperatures sometimes more than 2° higher than the decade mean, but also diminished monthly precipitation, particularly in May (108 mm) and June (190 mm), with rainfall levels of 37% and 24% below the decade mean. These pre-monsoon weather conditions led to an extreme dryness before the onset of the heavy summer rains of 1988. The entire region of Darbang, already experiencing the adverse effects of intense cultivation of the soils, suffered additionally during the arid and hot pre-monsoon months. Topsoil dried out rapidly, and deep cracks and fissures were formed. These deep cracks functioned as a surface drainage system, above all during severe thunderstorms. With the onset of the monsoon activity in July 1988, surface water seeped through the countless dried cracks directly into the deeper soil. The rainwater from continuing severe monsoon activity penetrated deeper into the cracks, allowing reaching the bedrock. Particularly aggravating the situation was the extraordinarily heavy precipitation in August– the third heaviest of the decade– with total rainfall levels (513 mm) lying 17% above the decade-average. A tectonically stressed area such as the landslide area of Darbang reveals numerous fractures and joints cutting through the bedrock, which in turn allow surface water drained by the deep cracks and fissures to penetrate the bedrock with ease. The horizontally foliated schists and phyllites as well as highly fractured quartzites became completely saturated. As noted above, in contrast to ordinary September months, with their steadily diminishing daily rainfall, the precipitation of 1988 showed a definite peak in the first half of the month. This heavy rainfall, together with the completely saturated soil and bedrock, particularly in an area with deteriorated natural vegetation, caused the collapse of the mountain flank (Plate 2).

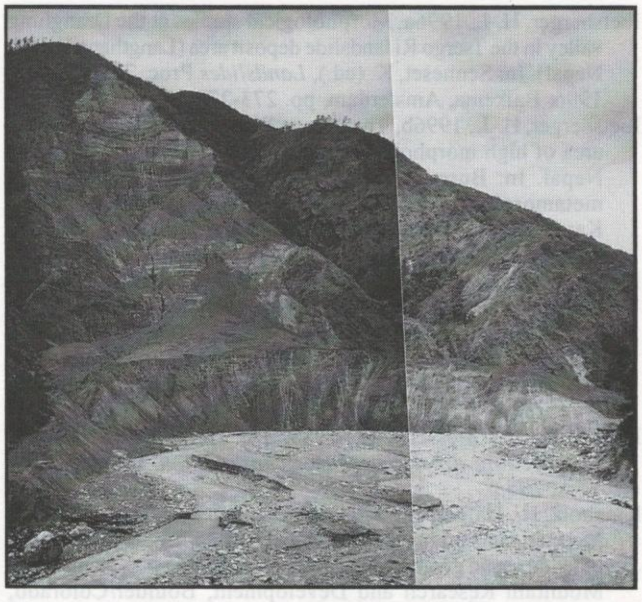

Plate 2: The landslide area of Darbang (1130 m amsl): The broken crest and deposition area with the dispalced material of the collasped mountain flank

CONCLUSIONS

Primary causative factors (i.e., lithology, tectonics, and geomorphology) as well long-term environmental degradation were mutually responsible for triggering the landslide of Darbang. Yet the unique weather conditions of the year 1988 are to be regarded as the actual triggers of this devastating event. Ordinary monsoon activity could scarcely be expected to produce a catastrophe of this magnitude. The present study points out that extreme meteorological anomalies such as excessive monsoon activity can be responsible for the initiation of unexpected mass movements.

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