Pakistan case study: catastrophic floods

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INTRODUCTION

Within the highly glacierized Karakoram Himalaya situated largely within Pakistan, there have been many cases of catastrophic floods, some the result of river damming by landslide, others the result of river damming by glacier ice with subsequent dam failure. The purpose of this case study is to show, by reference to one particular example, the magnitude and consequences of a glacier outburst flood and possible ways of alleviating the social and economic impact of such floods. This case study is taken from a much more extensive paper on the subject by Hewitt (1982).

THE SETTING

Thirty-five destructive outburst floods have been recorded in the past 200 years. Thirty glaciers are known to have advanced across major headwater streams of the Indus and Yarkand Rivers. There is unambiguous evidence of large reservoirs ponded by eighteen of these glaciers. Meanwhile, a further thirty-seven glaciers interfere with the flow of trunk streams in a potentially dangerous

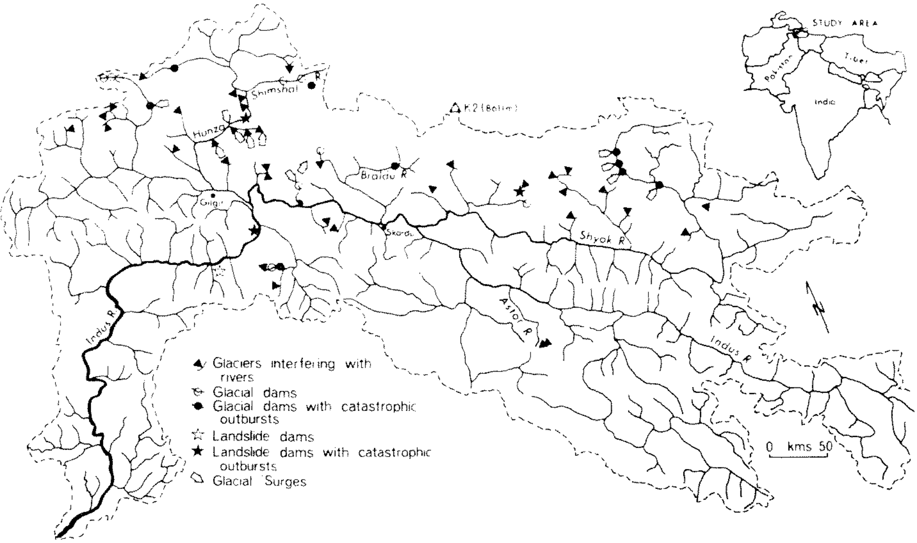

FIG. 1 Distribution of glacier dams and related events in the Upper Indus Basin (after Hewitt, 1982).

way. There is geological evidence of other dams and numerous reports of glaciers across main river channels which they were not actually damming. These also may be potentially dangerous. The distribution of these dams is shown in Fig. 1.

During the late Pleistocene and Little Ice Age large-scale damming was more extensive than recently. The relative lack of dam formation in the past 50 years is probably associated with general glacier recession in the area, in turn linked to the general climatic amelioration experienced here, as in many mountain areas of the world. Indications of climatic changes likely to result in glacier advance, especially if applicable to the Karakoram region, may herald an era of renewed damburst floods.

THE EXAMPLE OF THE CHONG KHUMDAN DAM

Glacier survey activity in the upper Shyok River basin in the late 1920s (see Fig. 1 for location) led to the discovery and monitoring of a large ice dam across the Upper Shyok River. This was formed by the advance of the Chong Khumdan Glacier, a tributary of the Shyok. The filling of the reservoir, the timing and magnitude of the resulting outburst floods in 1929 and 1932 and the movement of the flood waves down-valley were well documented by Gunn (1930) and Mason (1932). The characteristics of the dam and lake are summarized in Table 1.

The 1929 outburst flood of Chong Khumdan Glacier was monitored from near the glacier for over 1500 km downstream (Gunn, 1930; Mason *et al.*, 1930). Along with some comparative observations for the smaller 1932 outburst (Mason, 1932), this gives a unique record of flood-wave behaviour on the Upper Indus (Table 2).

TABLE 1 Chong Khumdan Dam and Glacier

Glacier Dam (1929)		*Chong Khumdan Glacier*	
Length of lake	*16 km*	*Orientation*	*E*
Average width	*1.6 km*	*Max. length*	*20 km*
Slope of valley floor	*1 in 130*	*Width, lower ablation zone*	*2.5 km*
Depth at dam	*120 m*	*Terminus, altitude*	*4715 m a.m.s.l.*
Volume	$1.5 \times 10^9 m^3$		
Width of ice barrier	*2.4 km*	*Highest point on basin*	*7530 m a.m.s.l.*
Area of basin above barrier	*25 500* km^2	*Firn line*	*5250 m a.m.s.l.*
Water supply: summer discharge Chip Chap River	$5.1 \times 10^6 m^3/day$	*Basin area*	*140* km^2
Rates of rise of lake, August	*0.3-0.45 m/day*		

TABLE 2 Progress of the 1929 outburst flood on the Upper Indus (After Gunn, 1930; Mason et al., 1930)

Location	*Distance from dam (km)*	*Maximum flood rise (m)*	*Rise to peak (h)*	*Duration of wave (h)*	*Rate of travel (km h-1)*	*Travel time from dam (h)*
Sasir	*16*	*26.0*	*4.0*	*40*	*8.3*	
Khalsar	*217*	*19.2*	*2.0*	*10*	*20.0*	*22*
Skardu	*499*	*7.6*	*3.5*	*28*	*22.0*	*38*
Partab P.	*719*	*13.7*	*8.0*	*60*	*13.2*	
Bunji	*731*	*10.6*	*5.9*	*50)*		*52*
Chilas	*803*	*16.1*	*4.0*	*40)*	*18.8*	
Tarbela	*1120*	*7.0*	*12.0*	*50)*		
Attock	*1194*	*8.1*	*17.0*	*70*	*5.9*	*81*

Gunn (1930) estimated the reservoir to have contained almost 13.5 x $10^8 m^3$ (1.1 million acre feet). Some 3 x $10^5 m^3$ of ice were also carried with the flood and stranded on large blocks in the valley below the dam. If loss to channel storage and seepage is somewhat greater than gains from inflows below the dam, the complete draining in 48 h suggests an average discharge between Sasir Brangsa and Khalsar in the region of 7100 $m^3 s^{-1}$ (250 000 cfs). At the peak of the steeply rising and falling main flood peak however, water discharges in excess of 22 650 $m^3 s^{-1}$ (800 000 cfs) are indicated. That equals the largest discharges measured for the entire Upper Indus at Attock. The Upper Shyok drains less than two percent of the basin, and most of its area is arid.

The mode of dam failure is critical to the size and shape of the flood wave. All we know of the 1926, 1929 and 1932 Khumdan outbursts is that breaching began through subglacial tunnels, but then carried away the entire thickness of ice above. Gunn (1930) describes the breach of 1929 as having: "...burst along a curving line from the near right-hand bank of the lake on the northern side through the highest portion of the dam, nearly to the left bank of the river on the south side. The cut ... was about 400 ft [120 m] wide (and 500 ft^+ + [150 m+] deep) and the ice stood vertically on either side. The lowest-portion of the dam along the cliffs was unaffected."

The flood peak was highest at Sasir Brangsa, but the 1929 wave showed remarkable recuperative power in the Indus gorges, below Skardu. As the flood waters gathered in, then left intermontane basins such as at Skardu, they re-enacted a pseudo-dam break.

The significance of these floods lies especially in the exceptional risk to human communities or installations, and also in their role in erosion and sedimentation. Over much of their course in the mountains, the recorded floods reach heights well above peak discharges from summer melting. Their dynamic character greatly magnifies their erosional competence and capacity. These two matters are of singular importance in the erosional context of the Karakoram valleys, and sediment transport into downstream reservoirs.

Sediment yield from the Upper Indus Basin represents the highest known rate of regional erosion over such an area, of about one metre per thousand years (Hewitt, unpublished). Data for the tributaries where the dams occur suggest rates in excess of 1.8 m per thousand years. Nevertheless, average sediment concentration upon which rating curves are based may be several orders of magnitude lower than the highest concentrations for given discharges. These exceptional concentrations generally occur in association with flood waves. What is reflected here is a highly constrained sediment availability in the fluvial zone. The humid, glacial areas not only provide most of the water, but also most of the seasonal debris transported.

The great height and erosional energy of dam-burst flood waves especially allows them to reach and cut into the abundant lag deposits in or stranded upon, arid river terraces. Huge numbers of landslides have been reported on terraces and valley sides after the passage of damburst floods. Substantial channel widening, deepening and even changes of course have been reported.

If one extrapolates the existing sediment rating curve for Darband - or Attock before the Tarbela Dam was built - the 1929 flood curve would have carried the equivalent of one average year's sediment yield. With greater concentrations of sediment and enhanced bedload this would be much higher. Moreover, the mobilization and sluicing of transportable sediment into stream channels would tend to increase total yields for some months or years after a major outburst.

In the event of a phase of recurrent damming such as occurred prior to 1940, these erosional events could increase the rate of sedimentation in artificial dams on these rivers, and reduce their economic lifetimes.

PROBLEMS OF MONITORING AND FORECASTING

The locations of past ice dams in the Upper Indus Basin range over an area comparable to that of the entire European Alps. The Karakoram, Hindu Kush and Nanga Parbat Ranges involved have much greater altitude and ruggedness. Their ice cover is about ten times greater in extent and proportion of area than the Alps. The altitudes of ice dams themselves range from 2800 m to 5000 m a.s.l. Thus, geophysical conditions alone create exceptional problems of monitoring. Heavy cloud cover, ruggedness and the usual problems of detail in snow-covered terrain also greatly limit the usefulness of the satellite imagery presently available.

Human circumstances indicate difficulties that may be harder to overcome. While the deeply dissected fluvial tracts of the Upper Indus are populated, most ice dams occur many kilometers from permanent settlements. The records we have of the past come mainly from travel, trade and European expeditions. These in turn often gleaned their information from local villagers who use the high alpine pastures in summer. Today, however, these sources are less reliable than ever. Travel is very restricted, the old trade routes closed and the summer grazing economy in decline. New political boundaries create a serious difficulty. For example, the Shyok dams originate in Indian- or Chinese-held territory. They threaten mainly the settlements and installations of Pakistan.

Satellite imagery is, obviously, an attractive solution. It was used to identify the recent large dam on the Upper Yarkand River. However, the dam had been in existence some months, at least, before a suitable ERTS image was obtained, and many more months passed when the dam's behaviour could not be followed. Along with the problems mentioned earlier, this makes early warning and continuous monitoring of dangerous conditions quite unreliable, unless such imagery can be supplemented. Meanwhile, we do not have reliable topographical maps or elementary glaciological information for more than two or three of the potentially dangerous glaciers.

All of this indicates that, if a recurrence of damming is the serious threat to life and property it seems, ground level surveys of the danger areas remain essential. The matter of warning networks also requires a system on the ground. Moreover, it requires some extension of the terms of, say, the Indus Waters Treaty, to allow for outburst floods that would cross international boundaries.

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