The Kedarnath disaster: in search of scientific reasoning

The unprecedented Uttarakhand floods of June 2013 generated a large volume of scientific literature and easily the most important of these papers were published in *Current Science*[1–7]. They offered clear technical explanation to the media-reported sequence of events, often in a historical perspective[2,6].

Some ambiguities, however, remained in some of the works. For example, Dobhal *et al.*[1] described that starting from 06:45 on 17 June 2013, the Chorabari lake catastrophically emptied within 5–10 min. Although their work stated two back-to-back 12-hourly rainfall figures up to 17:00 of 16 June 2013 from the Chorabari Glacier Camp of Wadia Institute of Himalayan Geology (WIHG), Dehradun, it did not mention anything about the crucial precipitation amount that occurred in the subsequent 12 h period that led to the breaching of the moraine dam and draining of the lake. Another equally important information that went missing from the stated eyewitness account of WIHG staff is the approximate water level achieved prior to the dam burst. It was also not made clear how the moraine ridge gave way – due to overtopping or because of debris slide.

Apart from the above, inappropriate use of scientific concepts or terms is noticed in some papers. Dubey *et al.*[5] stated that the 'reactivated' Main Central Thrust and Main Boundary Thrust govern the 'orographic behaviour of the monsoons in the Himalaya'. Obviously, thrusts are not topographic elements and cannot have any role in controlling the behaviour of Himalayan rainfall per se. They[5] also stated that the rainfall amount of 325 mm in 24 h mentioned by Dobhal *et al.*[1] 'easily classifies' the Kedarnath event as a cloudburst. The term 'cloudburst' generally connotes very high rates of rainfall within a short time that can locally reach up to 100 mm h^{-1} (refs 8 and 9). The average 24 h rainfall rate recorded at the ground-based station in Chorabari was just 17 mm h^{-1} (ref. 1) and can hardly qualify as cloudburst. More specific satellite-based hourly analyses showed that within a 5 km square grid, the rainfall rate stayed mostly below 10 mm h^{-1} in the Kedarnath region during the 72 h period of 15–17 June 2013 and barely crossed 20 mm h^{-1} only on two occasions[3].

A number of questions arise, particularly on the paper by Durga Rao *et al.*[7] that discusses simulation of floods in the Mandakini basin. First, in the index map of the hydrological set-up (figure 4 of Durga Rao *et al.*[7]), the positions of Chorabari lake and Kedarnath were erroneously shown on the Kali Ganga river instead of the Mandakini. This may have compromised the accuracy of the model.

Secondly, the cross-section of the Chorabari lake (figure 3 of Durga Rao *et al.*[7]), did not extend up to the top of the moraine ridge both in the satellite image as well as in the digital elevation model. It only covered the flattish lake bed, represented by a few ephemeral channels in the dry season Cartosat image. The c. 170 m section line represented the width of the normal wet season extension of the lake (figure 5 *b* of Dobhal *et al.*[1]), which is a fraction of the full capacity of the depression. This largely disregarded the contribution of exceptionally high rainfall in rising the lake to above-normal levels.

Thirdly, according to Durga Rao *et al.*[7], the volume of water accumulated in the lake prior to its release is 0.40×10^6 m^3. The inset hydrograph of figure 5 in their paper indicates that the water which drained from the lake reached the Madhyamaheshwar Ganga confluence near Guptkashi (the estimation point of the simulated hydrograph) at about 07 : 40 and represented passage of at least 0.87×10^6 m^3 of water during a 37 min period. The volume of Chorabari waters at the estimation point was not stated by the authors[7], but can be estimated by assuming a constant discharge at half of the peak value of 783 cumecs. More accurate estimations were not possible from this figure as its apparently linear abscissa, representing 37 min, did not show 12 values in a random order. It is difficult to explain how the simulated volume of water became nearly double within the hour it took to reach Guptkashi from Chorabari lake, some 35 km upstream. More importantly, in the same figure, the main flood hydrograph registered a drastic reduction in discharge after passage of the Chorabari waters for no apparent reason. Before this drop, it represented a fairly steady discharge of c. 1060 cumecs for nearly 20 h from 11 : 40 of 16 June 2013, followed by the sudden 12 min rise to 1800 cumecs. It may also be pointed out here that the work did not attempt to incorporate the flash flood event that struck Kedarnath at 17:15 of 16 June 2013 (ref. 1), probably due to unavailability of empirical data. Finally, it is felt that logical explanations to these observations would have enhanced the reliability of the formulated model.

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