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## Basic concepts of disaster prevention for GLOF in the eastern Himalayas

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Based on the 10 years experience working on glacial lakes in the Himalayas, mainly in Bhutan, I report a geomorphological view for risks of glacial lake outbursts and mitigation measures downstream areas. The study area covers eastern Nepal, Sikkim, Bhutan, and their north sides of the Himalayas in Tibet. In these areas many glacial lakes have appeared and therefore risks of GLOFs are increasing year by year.

### 1 Dangerous lakes and their outburst triggers

Two types of glacial-lakes and their triggers for outbursts are identified in the eastern Himalayas.

a) Circular lake type: Smaller glacial lakes with steep glaciers such as hanging glaciers. Glacial avalanches or ice-block falls are the most frequent cause occurring for outburst of the type circular lakes with steep glaciers such as hanging glaciers. In this case, prediction is very difficult because glacial avalanches and ice-fallings occur suddenly and unexpectedly.

b) Rectangular lake type: Moraine dam vulnerability is the second frequent cause for the type rectangular lakes, but only few cases were reported. Melting of ice-cores in the moraines and seepage through the moraines are thought to be triggers of the moraine failures. In this case, prediction may be possible by intensive geodetic and geological inspections of moraine dams, but vast cost and manpower should be needed.

### 2 Features of floods by glacial lake outbursts

1) Peak discharge of the GLOF is very high and sharp, but duration of the flood is short. 2) Water levels of the floods along the river course are the maximum just below the lake and decrease downstream. 3) The flood occurs along the distinct river course originated from the busted lake.

The most dangerous places by the GLOFs are areas along the river courses which originated from the GLOFed lakes, and areas located just below the lakes. These features are very different with floods caused by severe rain of the monsoon or cyclone.

### 3 Expected mitigation measures

1) Prediction of GLOFs (especially when) is very difficult or almost impossible. This prediction can not save economic losses, but only human lives.

2) Mitigation measures in the downstream areas along the river should be done. 2-1) Emergency alarm systems and evacuation schemes should be planned. 2-2) Controls of the local land use and moving of settlements and constructions may be needed.

Making of hazard maps is most urgent measure.

Keywords: glacial lake outburst floods, outburst forecast, risk assessment, mitigation measures