

Morphological features and risks of outbursts of glacial lakes 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 an overview of glacial lakes and GLOFs. The study area covers eastern Nepal, Sikkim, Bhutan, and their north sides in Tibet. In these areas many glacial lakes have appeared and therefore risks of GLOF are increasing year by year.

1. A definition of glacial lakes is that lakes owing to their existence to the present glaciers and/or past glaciations.

2. Glacial lakes are divided into three groups with their locations to the glaciers: 2-1 distal lakes, 2-2 proximal lakes, and 2-3 ice contact lakes. This report refers 2-2 proximal lakes and 2-3 ice contact lakes, because only these glacial lakes are hazardous. 2-1: Distal lakes are located far distance from existing glaciers and in glaciated terrains occupied by past glaciers. 2-2: Proximal lakes are located near the existence glaciers. 2-3: Ice contact lakes are situated at marginal, proglacial, supraglacial, englacial, and subglacial positions.

3. Development of glacial lakes. The Himalayan glaciers are divided into two groups: small mountain glaciers with clean ice (debris-free) tongues and large debris-mantled valley glaciers. The different features of these two groups of glaciers reflect to the glacier lake development and this corresponds to the two types of glacial-lakes development in the Himalayas.

3-1: Circular lakes type. Smaller glacial lakes with circular plan forms and formed between glacial fronts and frontal moraines after retreating of the glaciers. In general, the debris-free glaciers react sensitively upon climatic change so that these glaciers have retreated rapidly and the lakes have started to develop earlier. The older lakes are separated from existing glaciers and ice cores in the moraines still disappeared. The circular lakes are divided into two: 3-1-1 ones with steep glaciers such as hanging glaciers, and 3-1-2 ones with gentle sloping glaciers.

3-2: Rectangular lakes are large ones and show slender rectangular in plan forms. Melting of the debris-mantled glaciers are restrained by thick debris mantles so that glacier margins keep to contact with marginal moraines, instead melting occurs in the middle parts of the debris mantled areas where the debris mantles are relatively thin. Many small thaw lakes were formed in the middle parts of the debris-mantled areas. These thaw lakes spread independently, join each other, and form to make a large lake. Because the restrain effects of debris mantles delay the glacier melting, most of rectangular lakes are younger than the circular lakes. In many cases, ice cliffs are formed at the upper ends of the lakes and water depth is greater than that in the lower ends. At the lower ends the lakes terminate with relatively thin frontal moraine-dams but inside of the moraine dams there exist stagnant glacier ice with considerable volumes. The rectangular lakes are divided into two types: 3-2-1 the lakes occupy the whole width of the glacier snouts between both lateral moraines, and 3-2-2 the lakes occupy only in the central part of the glacier snouts and considerable debris-mantled areas exist between the lakes and the lateral moraines.

4. Types of glacial lakes and glacier lake outbursts. Thirty-four examples of outbursts of glacial lakes listed by Dr. A. Sakai, however, causes of outburst of the lakes are not known except in a few cases. In these few cases, glacial avalanches or ice-block falls are the most frequent cause occurring for outburst of the 3-1-1 type circular lakes with steep glaciers such as hanging

glaciers. In this case, prediction is very difficult because glacial avalanches and icefalls occur suddenly and unexpectedly. Moraine dam vulnerability is the second frequent cause for the 3-2-2 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.

Keywords: Glacial Lake Outburst Floods, Circular lakes, Rectangular lakes, glacial avalanches, Moraine vulnerability