Peak Discharge Estimates of Glacial Lake Outburst Floods

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KEYWORDS
GLOF, Peak Flood, Normalized difference water index, Potentially dangerous glacial lake, Teesta

ABSTRACT

In Himalayan region, several water resources projects are under operation and many more are coming up to harness the available water resources. These water resources projects are of considerable national and local importance in terms of hydropower generation, irrigation, flood control and subsequent socio-economic development of the region. Proper planning and management of these projects depends on correct assessment of basin yield and design flood. Many glacial lakes are known to have formed in the Himalaya in the last few decades, and a number of GLOF events have been reported in the region. Global climatic change during the first half of the twentieth century has had a significant impact on the high mountainous glacial environment. In this paper, the methodology for simulation of glacier lake outburst floods has been discussed. Further, potentially dangerous lake falling in the catchment of a water resources project site in Teesta basin has been identified. Further, GLOF due to identified potentially dangerous lake has been computed both at lake site and project site. The study indicates that the computed flood peaks at the lake site and project site are 2611.14 cumec and 1766.71 cumec, respectively. The results indicate, that, in addition to the "classical" flood flow analysis, GLOF analysis should be considered for derivation of design floods of projects located in glacier dominated basins.

1. INTRODUCTION

In the Himalayas, Glacier thinning and retreat due to changing environment and various other reasons has resulted in the enlargement of existing lakes and /or formation of new glacial lakes due to the accumulation of meltwater behind loosely consolidated end moraine dams. Such lakes are inherently unstable in nature and can be subject to catastrophic drainage, which is a potential source of danger to the hydro power projects, people and property in the valleys below them. Outburst of a glacier lake causes all of a sudden large river flow which is generally termed as glacier lake outburst flood or GLOF. Glacial lake outburst flood (GLOF) may be caused by the failure of the damming moraine due to its own instability or glacier and/or snow collapse into the lake and may lead to overtopping and eventually to failure of the damming barrier. Consideration of potential glacier lake outburst floods is, therefore, of essential importance for the design and constructing any infrastructure, especially water resources projects, located downstream of hazardous glacier lakes and would be the prime target in case of GLOF. In Himalayan region, several water resources projects are under operation and many more are coming up to harness the available water resources. These water resources projects are of considerable national and local importance in terms of hydropower generation, irrigation, flood control and subsequent socio-economic development of the region. Proper planning and management of these projects depends on correct assessment of basin yield and design flood. Many glacial lakes are known to have formed in the Himalaya in the last few decades, and a number of GLOF events have been reported in the region. Global climatic change during the first half of the twentieth century has had a significant impact on the high mountainous glacial environment.

2. STUDY AREA

In the present study GLOF (Glacial lake outburst flood) risk assessment has been carried out in the Teesta river basin located in the Sikkim state of India. River Teesta or Tista is said to be the lifeline of the state of Sikkim, flowing for almost the entire length of the state and carving out verdant Himalayan temperate and tropical river valleys. The emerald-coloured river then forms the border between Sikkim and West Bengal before joining the Brahmaputra as a tributary in Bangladesh. The total length of the river is 315 km (196 mi). The river Teesta originates from Cholamo Lake in North Sikkim at an elevation of 5,330 m (17,487 ft) above sea level in the Himalayas. This lake lies to the north of the Donkia pass near Shetschen, where the summit of the pass is about eight kilometres north-east of Darjeeling. Potentially dengerous in the basi has been identified and the GLOF is routed from the lake to the outlet using the river cross-sections (Figure 1) delineated from the DEM.

3. METHODOLOGY

GLOF modeling may be carried out by either i) scaled physical hydraulic models, or ii) mathematical simulation using computer. A modern tool to deal with this problem is the mathematical model, which is most cost effective and reasonably solves the governing flow equations of continuity and momentum by computer simulation. Mathematical modeling of dam breach floods can be carried out by either one dimensional analysis or two dimensional analysis. In one dimensional analysis, the information about the magnitude of flood, i.e., discharge and water levels, variation of these with time and velocity of flow through breach can be had in the direction of flow. In the case of two dimensional analyses, the additional information about the inundated area, variation of surface elevation and velocities in two dimensions can also be assessed. The study includes accurate mapping of the glaciers and glacial lakes using multispectral satellite images. Detail analysis of these lakes has been carried out for raking them on the basis of their vulnerability. For identifying the potentially dangerous glacial lakes, a digital database of glaciers and glacial lakes is necessary. As it was not possible to survey the detailed geometry in the field, all topographic information required for the study was derived from a digital elevation model (DEM). Image enhancement techniques are generally useful for the identification of the individual glaciers and glacial lakes. Further, with the support of the visual interpretation method and knowledge and experience of the terrain conditions, glacier and glacial lake inventories and monitoring can be prepared. Using the combinations of different spectral band in false colour composite (FCC) and in individual spectral bands, glaciers and glacial lakes can be identified. When applying basic techniques of multispectral classification similar to those used for the normalized difference vegetation index, NDVI (Hardy and Burgan 1999), a normalized difference water index (NDWI) for lake detection was used (Huggel 1998).

$$\mathrm{NDWI} = \frac{B_{NIR} - B_{blue}}{B_{NIR} + B_{blue}} \tag{1}$$

Sometimes, due to spectral reflection, some self shadowed areas are misclassified as lakes. Verification of identified lakes can be done by overlying the DEM on NDWI image.

4. RESULTS & DISCUSSION

For identifying potentially dangerous glacial lakes remote sensing data in conjunction with Google Earth have been used. Various lakes were mapped and recorded in the inventory. Now for selecting potentially dangerous lakes following parameters have been used.

- Lakes of area smaller than 0.1 Km^2 are considered as harmless owing to the less volume of water contained by it (area and volume are statistically related by Huggel's formula, discussed later).

- Lakes which are still attached or are near to the parent glaciers or at the snout of the glaciers are considered as more dangerous as they are capable of expanding. Lakes which are isolated are stagnant and do not expand and pipes their volume of water in most of the cases rather than bursting. For this purpose glacier map was overlaid on Lake Map to check for the position of lakes with respect to lakes.

- Glacial lakes were also checked for the presence of supraglacial lakes around them, or for the lakes which fall in their down steam area. These lakes are interconnected in the sense that busting of one lake causes bursting of another.

- Lakes were also checked for the steep slopes around them (which can cause influx into them) and conditions of the moraine (thick or thin).

Breaching of the biggest lake has been considered for demonstrating the simulation of GLOF at the selected site in the study area. Arc-GIS and ERDAS Imagine software were used to delineate cross-sections of the stream. For this purpose the vector layer of the stream and the buffer lines along the stream on the both side of stream at the distance of 1 km were created. ERDAS Imagine Software was used to overlay DEM of basin and vector layer of cross-section. The Spatial Profile Viewer in ERDAS allows to visualize the reflectance spectrum of a polyline of data file values in a single band of data (one-dimensional mode) or in many bands (perspective three-dimensional mode).

There is no estimate available for the estimation of volume of glacial lakes in Himalaya from their water spread areas. However, Huggel et al. (2002) has given some estimates for glacial lakes in Swiss Alps. In the absence of information on the volume of potentially dangerous glacial lakes, it is considered appropriate to use the same relationships developed for the lakes in Swiss Alps for estimating the water volume for the lakes in this area. The estimation of GLOF (Sharma et al., 2009) provides the flood hydrograph of discharge from the dam breach and maximum water level at different locations of the river downstream of the dam due to propagation of flood waves along with their time of occurrence. The essence of dam break modelling is hydrodynamic modelling, which involves finding solution of two partial differential equations originally derived by Barre De Saint Venant in 1871. These equations are:

$$(\partial Q/\partial X) + \partial(A + A_0) / \partial t - q = 0 \qquad \text{(continuity equation)} \qquad (2)$$

$$(\partial Q/\partial t) + \{ \partial(Q^2/A)/\partial X \} + g A ((\partial h/\partial X) + S_f + S_c) = 0 \text{ (Momentum equation)} \qquad (3)$$

where, Q = discharge; A = active flow area; A_0 = inactive storage area;

h = water surface elevation; q= lateral flow; x = distance along waterway; t = time;

S_f = friction slope; S_c = expansion contraction slope and g = gravitational acceleration

The mathematical models which approximately solve the governing flow equations of continuity and momentum by computer simulation are the cost effective modern tool for the dambreak analysis.

GLOF SIMULATION FOR BIGGEST LAKE

The area of the biggest lake i.e. lake 140 was 1.168 km^2. The resulting dam breach flow, i.e, GLOF has been routed through Teesta River. The Teesta river from glacial lake location down to the outlet (total length 160 km) has been presented by the model by a number of cross sections at an interval of 1 km, developed from the DEM (Fig. 1). The lake volume and depth has been found from equations given by Huggel et al. (2002).

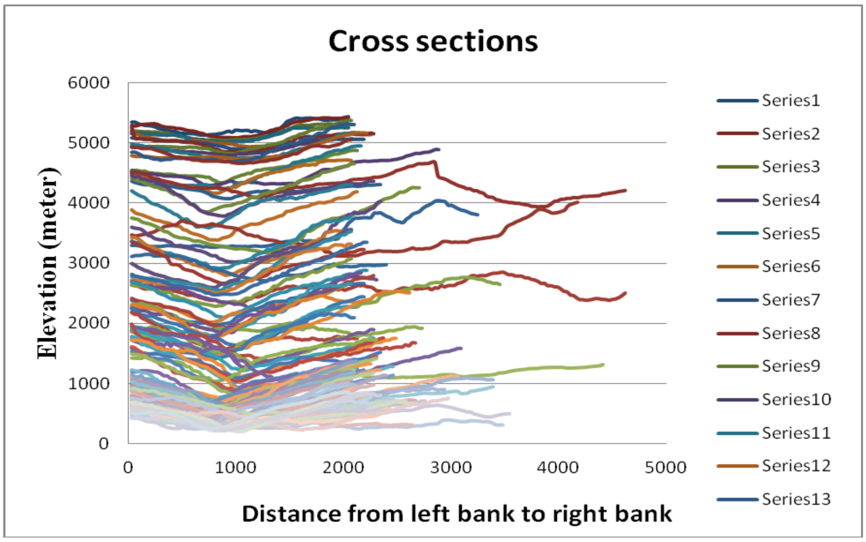

Fig. 1: Cross sections from lake to the outlet

The altitude of the potentially dangerous lake is 5188 m. As discussed in the last chapter, the breaching starts at top of the dam and continues up to the breach invert level. The mode of failure for glacial lake outburst considered is overtopping. The volume and depth of the lake are calculated using Equation developed by Huggel et al. (2002) and it comes out to be 42.93 Mm^3 and 37 m, respectively. The breach invert level should be taken as two-third to three-fourth of the height of dam below its top level, therefore breach depth has been taken as 28 m which is approximately three fourth of 37 m. The average breach width is computed as 76 m. The side slope has been taken as 1H:1V. The Manning's roughness coefficient 'n' determines the sub, super or critical flow condition that determines the flood height. The value of n has been taken as 0.05 considering the boulder beds and hilly terrain of Himalayan Rivers in Sikkim and also large debris flow associated with GLOF. As the lake water level continues to increase, the lake might fail through overtopping flow incising and destroying the dam

MIKE 11 software was applied for generation of flood hydrograph for breach width of 76 m. The flood hydrographs at just downstream of the lake and near basin outlet are shown in Figure 2. The total flood peak and its travel time from GLOF site is given in Table-1. It can be seen from the Table-1, that the GLOF peak is 2611.14 cumec at lake site and the same get mitigated to 1766.71 cumec at the outlet for breach width of 76 m. The time of travel of flood peak from the lake site to project location is about 2 hour 30 minutes.

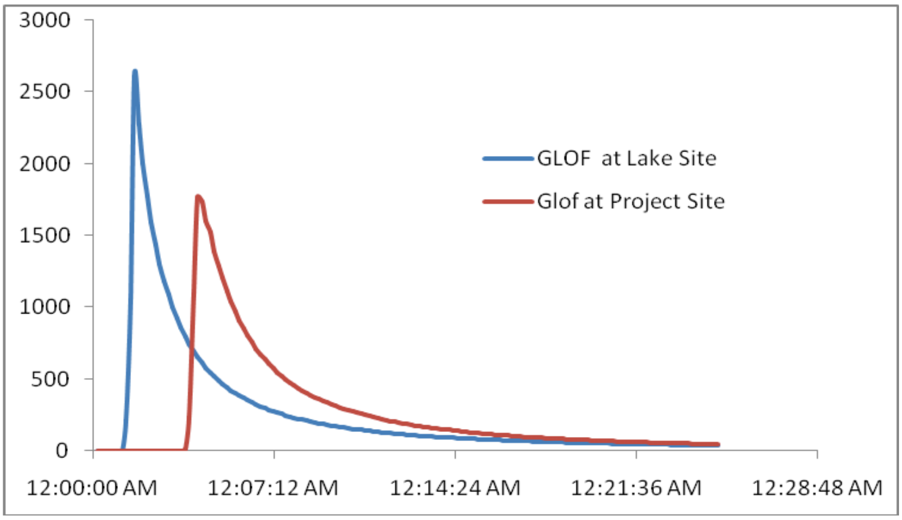

Fig. 2 Flood hydrograph due to GLOF

Table 1: Flood peak at Lake and project site

Location	Distance (km) from Glacial Lake	GLOF peak (m^3/s)	Travel time (hr-min)
Just d/s of lake	0	2611.14	00-00
Project site	100	1766.71	02-30

5. CONCLUSION

In the Teesta basin glaciers lakes have been identified using topographical data, remote sensing data and GIS. Glacial lake outburst flood modelling for the biggest and potentially most dangerous lake has been carried out to demonstrate the impact of GLOF at project site. For GLOF study, MIKE 11 software has been used. The flood peak at the lake site is 2611.14 cumec for breach width of 76 m. Peak flood discharge at project site due to GLOF only is computed as 1766.71 cumec. As evident that the peak flood discharge at project site due to GLOF is a significantly high value. It is therefore required to consider the GLOF while designing water resources projects in the area where potentially dangerous glacial lakes exist.

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