

## **Project Title-Hazard Assessment of Luggye Glacial Lake: An Alternative Long Term Approach for Conserving Aquatic Habitat, Punatshang Chhu, Bhutan**

### **Introduction**

The most recent glacier area in Bhutan Himalayas is reported as  $\sim 642 \pm 16.1 \text{ km}^2$  (Bajracharya, Maharjan, & Shrestha, 2014). The overall area of glacier has decreased but number has increased due to fragmentation, indicating increasing numbers of small glaciers due to glacier shrinkage rather than new development (Veettil et al., 2015; Bajracharya et al., 2014; Karma et al., 2003). A retreating trend was observed for clean glacier, resulting increase of debris-covered area in southern side of Bhutan Himalayas and upward shift in equilibrium-line of altitude (Veettil et al., 2015; Bajracharya et al., 2014). The mass balance record through satellite measurement and modelling indicated mass loss of Bhutanese glacier (Gardelle et al., 2013; Rupper et al., 2012). Furthermore, in-situ measurements have showed greater mass loss than neighbouring glaciers ranging from  $-1.12$  to  $-2.04 \text{ m w.e. a}^{-1}$  (Tshering & Fujita, 2016).

With increasing trend of clean glacier loss and resulting increase of debris-covered area in Bhutan Himalayas (Veettil et al., 2015; Bajracharya et al., 2014), formation and development of glacial lakes were noticed on the debris-covered area and glacier terminus (Ageta et al., 2000; Iwata et al., 2002; Komori, 2007; Ukita et al., 2011). Specifically formation of supraglacial lakes on debris-covered glaciers were restricted to gradients of glacier less than  $2^\circ$  (Reynolds, 200). Further research have revealed that supraglacial lakes tend to connect each other and grow into large lakes rapidly (Ageta et al., 2000; Iwata et al., 2002; Sakai, 2012). Compilations of studies (Ageta et al., 2000; Komori, 2007) revealed three types of glacial lakes in Bhutan Himalayas: supraglacial lakes which are present on the surface of debris-covered glacier, it is often transient due to its small volume but they tend to connect each other to grow into large lakes. It is the initial stage of most large lakes present in Bhutan Himalayas (Komori, 2007). Moraine dammed glacial lakes: it is known by various names such as Proglacial Lake, ice-proximal or ice-contact lake. It is characterised by large volume, potential of GOLFs and often stable in expansion and in-contact with glacier ice. Unconnected lake: lakes are devoid of surrounding glaciers. These lakes are stable and located in cirques or glacial troughs.

Luggye glacial lake is currently under the category of moraine-dammed glacial lake. Its development initially started as supraglacial ponds in 1960s and it has entered into the third stage of glacial lake development indicated by stable expansion (Ageta et al., 2000; Komori, 2007). It is one of the biggest and rapidly expanding moraine dammed glacial lake in Bhutan Himalayas which has the previous catastrophic record of outburst in 1994 (Ageta et al., 2000; Mool et al., 2001; Komori et al., 2012) amounting the GOLF volume of  $17.2 \pm 5.3 \times 10^6 \text{ m}^3$  (Fujita et al., 2008; Fujita et al., 2013). The depth and volume surveyed by Yamada et al. (2004) in 2000 revealed mean depth of 49.9 m and deepest depth of 126 m and water volume of  $58.3 \times 10^6 \text{ m}^3$ . Despite the enormous volume of water it contains which is highly potential of GOLF, a robust study exploring the link between Luggye glacial lake expansion and Luggye glacier changes is

still lacking. In this study, we report changes of Luggye glacier and glacial lake between 1972 and 2015 using satellite. Second we present in-depth inter-annual variations of Luggye glacial lake and Luggye glacial terminus since meteorological data are available (i.e. 2006-2014). Third, we present seasonal variation of Luggye glacial lakes in the year 2014 complemented by SAR data (Sentinel-1). Fourth, we discuss the potential factors controlling the rapid expansion of Luggye glacial lake and future fate of Luggye glacial lake.

### Study region

The study region is Lunana which is located in northern part of Bhutan Himalayas. Numerous sizes and types of glacial lakes are present which feed Punatshang Chhu River directly. In case of sudden glacial lake outburst floods, Punatshang Chu river basin remains to be susceptible to a flood and destruction of important aquatic habitats and habitat for White-bellied heron (*Ardea insignis*) due to absence of concrete flood protection walls along the river bank.

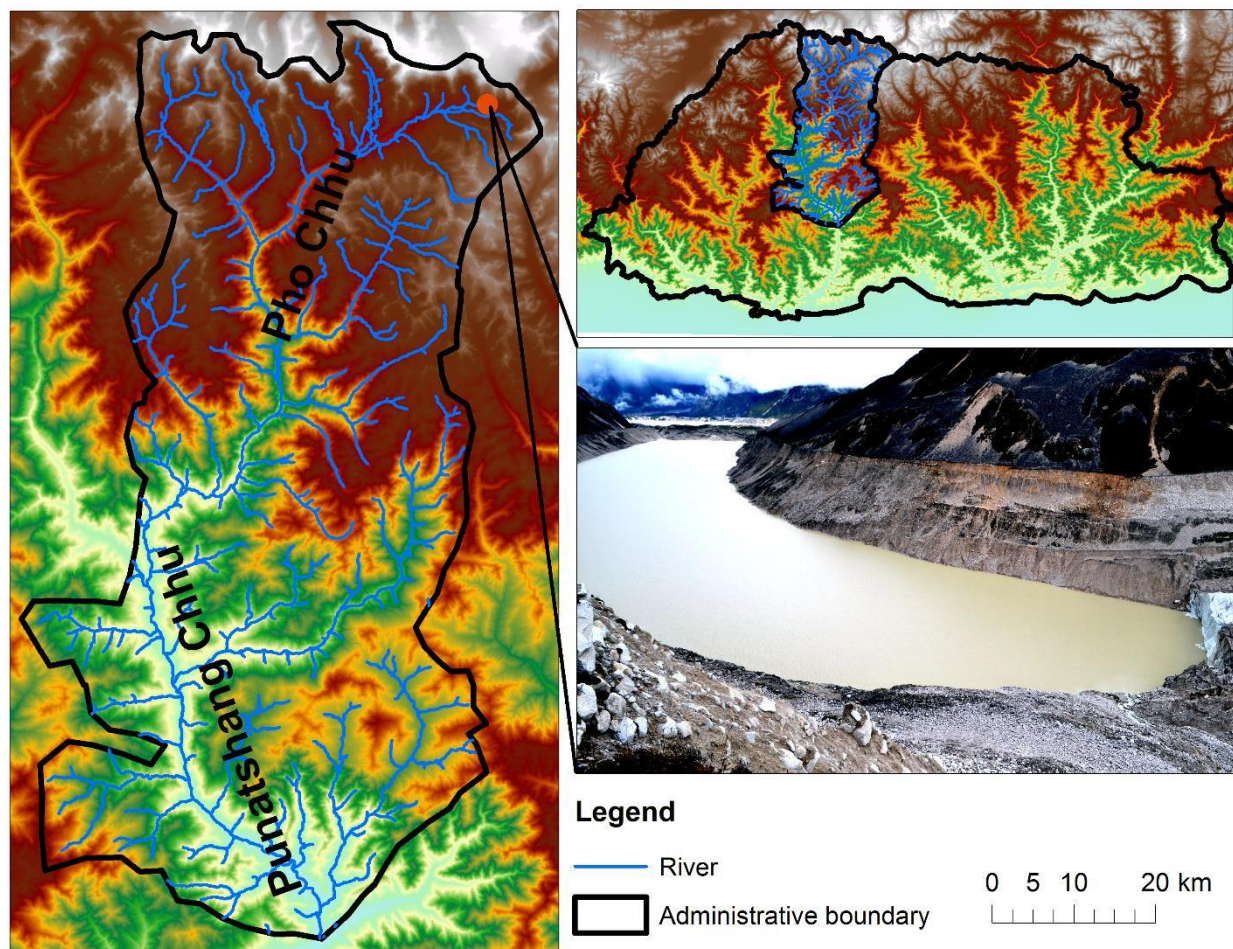


Fig.1. Study area



**Current status of Luggye glacial lake as indicated by photos taken during filed visit.**

The Luggye glacial lake is potentially dangerous due to the following reasons:

**1. Enormous volume of water it contains and rapid expansion**



The water volume it contains is huge. Comprehensive Landsat satellite images analysed since 2000 indicated that current water volume ( $80.02 \times 10^6 \text{ m}^3$ ) is twofold larger than 2000. It has expanded at the average rate of  $0.03 \text{ km}^2 \text{ a}^{-1}$ .



The upper portion of Luggye glacial lake has direct contact with exposed Luggye glacier ice.



The terminus of Luggye glacier has retreated at the average length of  $-43.93 \pm 2.21 \text{ m a}^{-1}$  between 1972 and 2016. Retreat of glacier due to calving mechanism is indicated by arrow.

## 2. Active expansion fronts of the lake



Buried ice cave at the lower portion of Luggye glacial lake was noticed. Disintegration of ice core can undermine the structural integrity of the moraine dam (Richardson and Reynolds, 2000).



Numerous ponds are still present at the lower portion of Luggye glacier. In total 6 ponds were observed during our field visit.



Prominent and extensive evidence of erosion of dam wall was observed around the lake.



### 3. Vulnerability of dam due to erosion of moraines



The colour of the lake has changed to light brown indicating vigorous erosion.



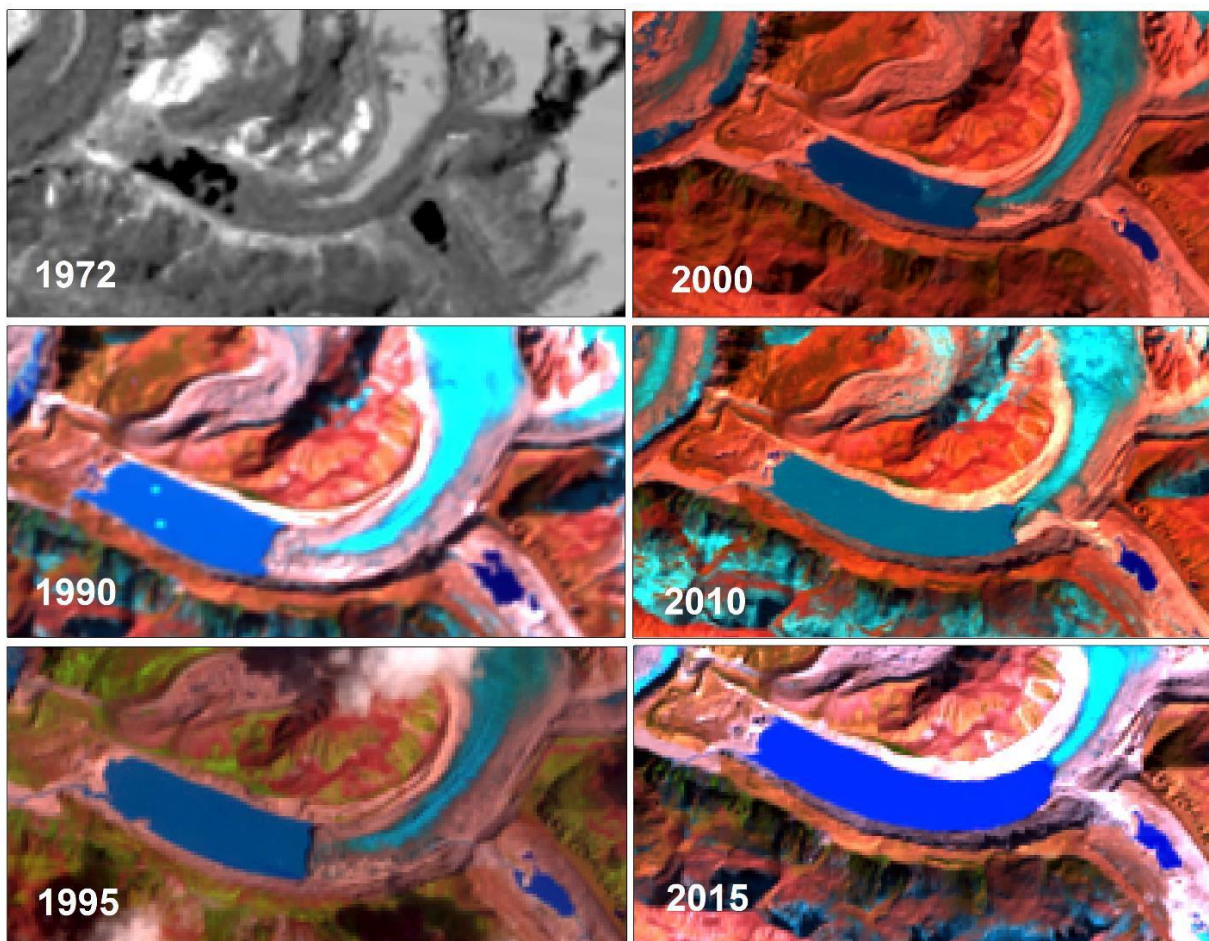
A small glacial lake is present at the headwater of Luggye lake. Satellite images have shown expansion is not significant however it is vulnerable as recent erosion of terminal moraine can be seen. The depth and volume is still not known for this lake.



There is a higher likelihood of rockfall and landslide into a lake which may generate tsunami-like wave capable of flood.

#### 4. Higher probability of mass movement into a lake

Satellite evidence of rigorous expansion of Luggye glacial lake





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**Photos with the team members and crews during a field visit**

