Sustainable Humanity, Sustainable Nature: Our Responsibility
Pontifical Academy of Sciences, Extra Series 41, Vatican City 2014
Pontifical Academy of Social Sciences, Acta 19, Vatican City 2014
www.pas.va/content/dam/accademia/pdf/es41/es41-kulkarni.pdf

Glaciers as Source of Water: The Himalaya

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Introduction

The Himalayan region has one of the largest concentrations of glaciers. Major rivers such as Indus, Ganga, Brahmaputra and their numerous tributaries originate from the glacier bound terrain. The contribution of glacier melt in annual stream runoff is substantially higher in Indus basin as compared to Ganga and Brahmaputra (Immerzeel *et al.*, 2010, Singh and Jain 2014). However, well-developed canal network in the Indus basin produces almost 96% and 26% of food production of Pakistan and India respectively (RBI report 2011, Khan *et al.*, 2010). Therefore changes in runoff pattern in Indus basin due to melting glaciers can significantly influence the water and food security of India and Pakistan. Recent studies suggest that rapid mitigation of Green House Gas (GHG) emission i.e. shift from RCP 8.5 pathways to RCP 2.6 could help in conserving Himalayan glaciers and also help in maintaining present pattern of stream runoff (Chaturvedi *et al.*, 2014).

Observed changes in Himalayan glaciers

In Indian Himalaya, glacier inventory is carried out by numerous agencies and based on data as topographic maps, aerial photographs and satellite images. Our best estimate for areal extent of glaciers in the Indian Himalaya is 25,041±1726 sq. km (Kulkarni and Karyakarte 2014). In the Himalaya, the glacier covered area is approximately 60,054 sq. km (Bajracharya and Shresta, 2011). The estimated total glacier water stored in Indian Himalaya is 3600 to 4400 Gt (Kulkarni and Karyakarte 2014).

The observations on glacier retreat and possible reasons behind these changes are important to assess future changes in the Himalayan glaciers. In Himalaya, extensive investigations have been carriedout to estimate the loss in glacier length and areal extent. The long-term retreat of 81 glaciers, where position of terminus is measured using field data, suggests mean retreat of 621±468 m between year 1960 to 2000 (Kulkarni and Karyakarte 2014). The large standard deviation suggests large variation in the glacier retreat in different regions (Figure 1).

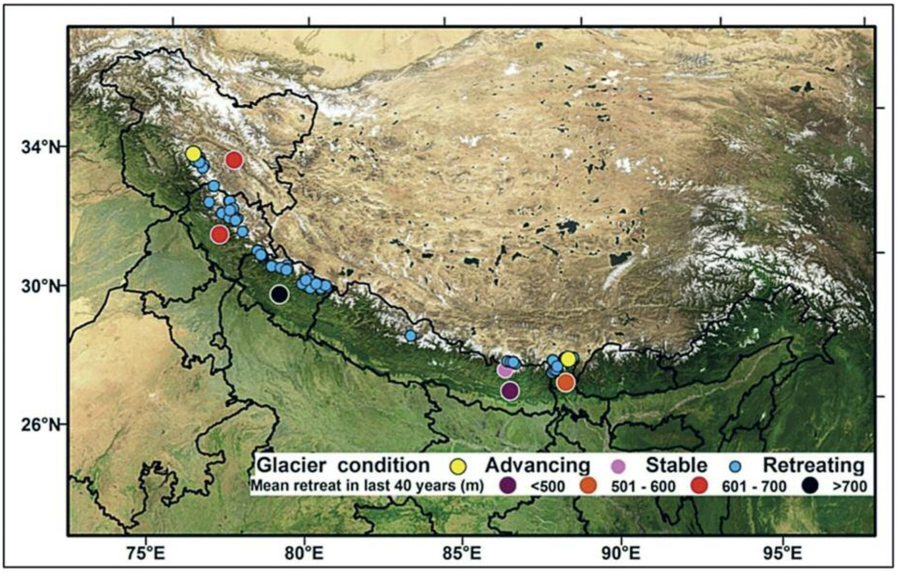

Figure 1. Location of glaciers and amount of retreat between 1960 and 2000. The data suggest that except three, all remaining glaciers are retreating. Limited field data is available in Karakoram, Bhutan and Arunachal Pradesh.

The loss in area is mapped for almost 11,000 sq. km in the Himalayan (Figure 2). The studies suggest almost 4–30% overall loss in glacier area in the last 40 years, depending upon numerous terrain and geomorphological parameters. The field and satellite based investigations suggest that most of the glaciers in the Himalaya are retreating except in Karakoram (Tobias *et al.*, 2012; Scherler *et al.*, 2011). However, conclusions based on monitoring of only the snout could be misleading, as slope and length can influence retreat, even if loss in mass is the same. This was used to explain differential rate of retreat of Zemu and Gangotri glaciers (Venketesh *et al.*, 2011). In addition, if glacier snout is covered by debris, it can decrease melting at the snout but continue to have increased melting at higher altitudes leading to fragmentation or disintegration of glaciers (Kulkarni *et al.*, 2007). This phenomenonhas now been observed not only in the Himalaya, but also in other parts of the world (Zemp *et al.*, 2009).

In order to understand changes in rate of retreat in Indian Himalaya, we have undertaken a program to monitor glacier changes in Baspa and Tista Basins in western and eastern Himalaya, respectively. The investigation has shown that the rate of retreat has accelerated in the present decade. In the

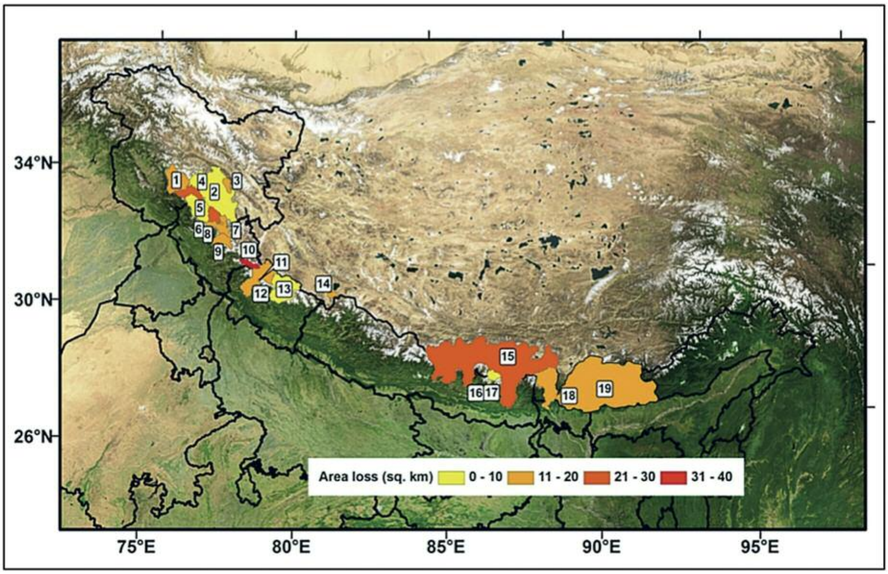

Figure 2. Glacial area loss (%) in different regions of the Himalaya from 1960 to 2000. The loss in glacier area is estimated using satellite images. The name of basins and regions are 1. Bhut, 2 Zasker, 3 Kang Yatz Massif, 4 Warwan, 5 Miyar, 6 Bhaga, 7 SamudraTapu, 8 Chandra, 9 Parbati, 10 Baspa, 11 Bokriani, 12 Bhagirathi, 13 Alaknanda, 14 Naimona'nyi region, 15 Mt. Everest region, 16 AX010, 17 Sagarmath national partk, 18 Tista, 19 Bhutan Himalaya.

Western Himalaya increase in temperature and decrease in snowfall was observed, suggesting influence of global climate change (Shekar *et al.*, 2007). However, retreat could have also been influenced by regional factors, in addition to global climate change. A total glaciated area of 173 km^2 was mapped in Baspa Basin (Fig 3). In year 2009, Baspa region experienced extensive forest fire and northern Indian biomass burning resulting in deposition of black carbon. The mean drop in reflectance due to deposition of black carbon in the accumulation area was observed to be 21±5% and maximum drop as high as 50±5% resulting in accelerated rate of retreat. The study suggested that anthropogenic activity can influence glacier mass balance (Kulkarni *et al.*, 2013). In case of Sikkim, a total glaciated area of 202 km^2 was mapped. The rate of retreat was observed to be higher in present decade. This acceleration is possibly due to the formation of glacier lakes. The presence of debris and subsequent differential melting has resulted in the formation and expansion of supraglacial lakes. Further, the merging of these lakes over time has led to the development of large moraine-dam lakes (Basnett *et al.*, 2013). These investigations suggests that in addition to temperature and precipitation changes, regional factors like formation of moraine dammed lakes and deposition of black carbon are playing important role in glacier retreat.

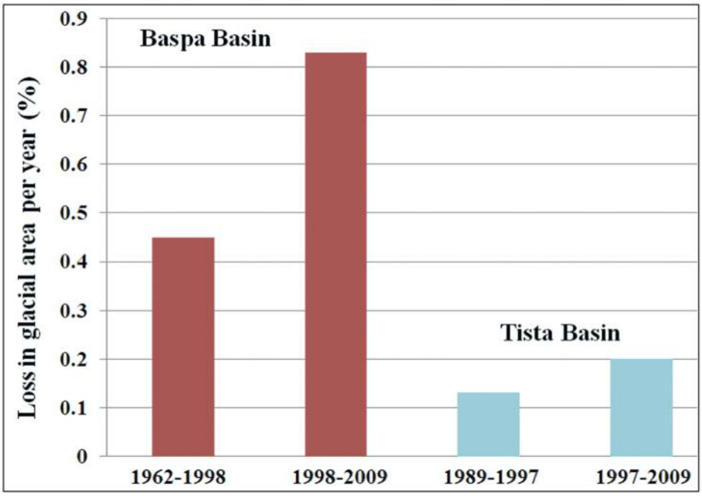

Figure 3. The rate of retreat in Baspa Basin was observed to be 0.45% per year between 1962 to 1998 and it has increased by 1.55 times after 1998 i.e., 0.83% per year.

Glacial response to climate change

The response of glaciers to the ongoing climate change is complex and the impact of projected climate change on KH glaciers is poorly understood. An erroneous statement by the Intergovernmental Panel on Climate Change (IPCC) on the fate of Himalayan glaciers further highlighted this knowledge gap. Therefore, this study focuses on the potential future changes in glacial mass balance in the KH region, where now reliable glacier inventory data is available. The impact of future climate change on the glaciers in the Karakoram and Himalaya (KH) was investigated using Coupled model inter-comparison project model (CMIP5) multi-model temperature and precipitation projections and a relationship between glacial accumulation-area ratio and mass balance. CMIP5 based climate change projections over the KH region were estimated under different Representative Concentration Pathways (RCP) for 2030s, 2050s and 2080s

The study provided a 'broad order-of-magnitude' estimate of the glacial mass balance towards the end of the 21st century. The current i.e., year 2000

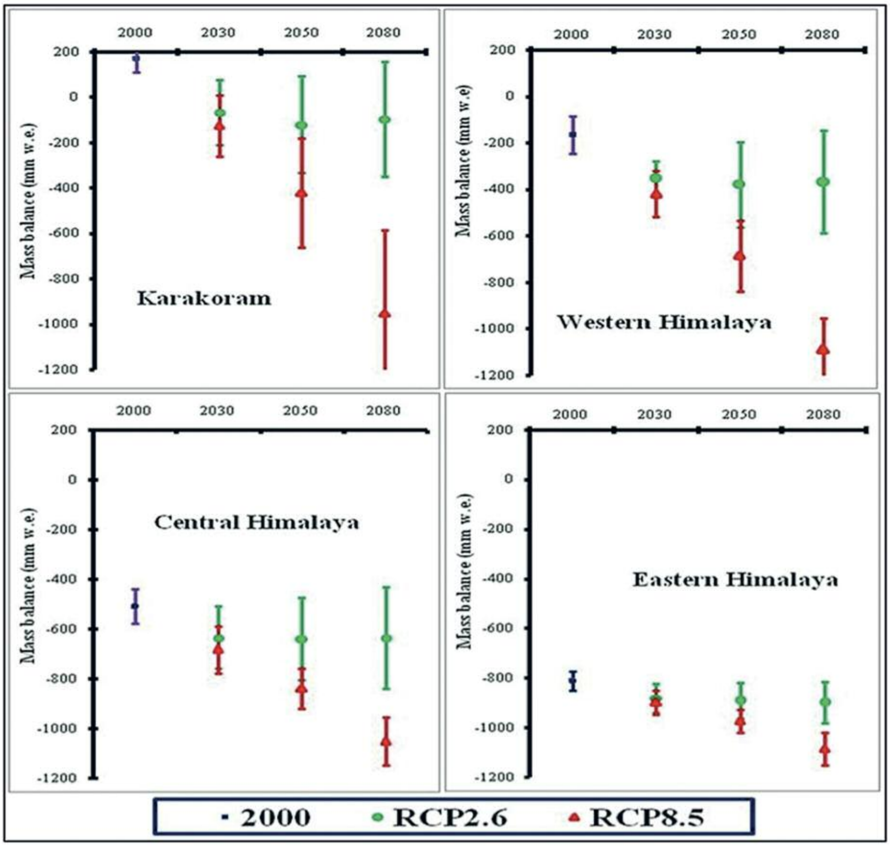

Figure 4. Glacier mass balance for year 2000 and the impact of climate change on the glacial mass balance of Karakoram-Himalaya under RCP2.6 and RCP8 for year 2030, 2050 and 2080 (Chaturvedi, 2014).

glacial mass loss was estimated as -6.6±1Gt yr. The mass loss is projected to increase to -12±1 and -14.4±1 Gt yr-1 in 2030s, and -12±2 and -35.5±2 Gt yr-1 in 2080s, under the RCP 2.6 and RCP 8.5 scenario, respectively. The analysis clearly suggests that a rapid mitigation of Green House Gas emissions i.e. a shift from the RCP 8.5 pathway to RCP 2.6 could prevent more than 16% of the KH glaciated area from 'eventual disappearance' towards the end of this century. Therefore, present pattern of stream runoff and availability of water resources could be largely maintained, if lower emissions pathways are followed in future.

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