Glaciers in Ganges basin: an assessment of their dimensions through inventories

Nathaniel B. Dkhar and Shresth Tayal

Abstract— The objective of this paper is to analyse the data available in the glacier inventories published by Geological Survey of India and International Centre for Integrated Mountain Development and make a comparative assessment of the distribution and extent of Himalayan glaciers in the Ganges river system of Indian and Nepal Himalaya.Some interesting conclusions for this assessment were that majority of the estimated glacial ice volume towards the Ganges river system was from the Nepal Himalayas. Also, it was found that smaller glaciers have a larger representation than large glaciers in the Ganges basin.

Index Terms— Ganges, Gangotri, Glaciers, Indian Himalaya, Nepal Himalaya

1 Introduction

The higher altitude range of Himalayas consists of a number of small and large glaciers. Their occurrence is controlled by climatic conditions, which are responsible for accumulation of snow and ablation. The Himalaya has one of the largest concentrations of glaciers outside the Polar Regions and is often referred to as the Third Pole.

The Ganges River system remains the main source of freshwater for about half the population of India and Bangladesh and nearly the entire population of Nepal. The Ganges River originates from the central Himalayas and flows around 2,500 kilometres to the Bay of Bengal. [1]

The Himalayan mountain range spans 2500 km east to west and includes diverse cultures of five countries (Afghanistan, Pakistan, India, Nepal, and Bhutan). [2] The snow and ice present in the Himalaya acts as a huge reservoir for freshwater which makes it a very precious resource. The cryosphere in the Himalayan region are continuously undergoing natural changes. These changes are accelerated by the increasing population, industrialisation, and rising levels of urbanisation.Green House Gas led global warming and related climate change impacts also lead to the enhanced melting of the glaciers. The deglaciation of Himalayan glaciers can be attributed principally to the increasing temperatures linked to global warming due to increase in anthropogenic emission of greenhouse gases. The relatively high population density near the Himalayan glaciers and consequent deforestation and land-use changes has also adversely affected these glaciers. [3] Glacier changes are recognized as high-confident climate indicator and as a valuable constituent in early detection strategies within the international climate monitoring programmes. Fluctuations of a glacier, which is not influenced by thick debris covers, calving or surge instabilities, are a reaction to climatic forcing. Thereby, the glacier length change (i.e., the advance or retreat) is the indirect, delayed, filtered but also enhanced signal to a change in climate, whereas the glacier mass balance (i.e., the change in thickness/volume) is the direct and un-delayed response to the annual atmosphere conditions. [4] The high rate of deglaciation of the Himalayan glaciers is a cause for concern as they form an integral part of the water supply for the downstream areas and its melt water guarantees the perennial supply of water to the rivers. Melting glaciers provide a key source of water for the region in the summer months and as much as 70 percent of the summer flow in the Ganges is contributed by the Himalayan Cryosphere. [5], [6] However the rapid deglaciation of the Himalayan glaciers could subsequently lead to water-related hazards, such as water stress, due to the expected decline in fresh water supplies especially during the dry season and also increase in number of hazardous events like Glacier Lake Outburst Floods (GLOFs). [7]

2 Objective

The aim is to make a comparative assessment of the distribution and extent of Himalayan glaciers in Ganges river system of Indian and Nepal Himalaya.

3 Materials & Methods

Geological Survey India had undertaken the task of compilation of glacier inventory in 1977, immediately after the constitution of the world glacier inventory body at Zurich. GSI's inventory is based on the guidelines provided by the Temporary Technical Secretary (TTS) for the World GlacierInventory (WGI) of the Swiss Federal Institute of Technology (ETH), Zurich.

Geological Survey of India published an inventory of Himalayan glaciers in 2009, which is an updated version of GSI's earlier publication - 'Inventory of the Himalayan Glaciers' (Secial. Publication No. 34) published in 1999. This inventory gives information about the glaciers in Himalaya, specifically for their location, orientation, elevation, length, area and volume, as compiled from the survey of India toposheets of 1960s and 1970s (of scale 1:50,000 and 1:250,000). The compilation of data was also aided by study of aerial photographs and satel-

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lite images wherever available, along with field and compilation work of the officers of GSI. On spot monitoring and analysis for most of the descriptive parameters, which are dynamic in space and time was seen as a requirement for higher accuracy. To accomplish this, regular field checks in various terrains, selected basins, continuous monitoring of different basins with a number of glaciers as a reference base were conducted. [8]

The "Geological Survey of India: Inventory of the Himalayan Glaciers, Special Publication No. 34, 2009" is a reference resource on Indian Himalayan glaciers.

The Inventory of Glaciers, Glacial Lakes and Glacial Lake Outburst Floods: Monitoring and Early Warning Systems in the Hindu Kush-Himalayan Region - Nepal (2001) published by ICIMOD has information on the glaciers of Nepal. ICIMOD used geographic information systems (GIS) to create a comprehensive inventory and GIS database of glaciers and glacial lakes in Nepal using available maps, satellite images, aerial photographs, reports, and field data on different scales.ICIMOD's inventory is also based on the guidelines provided by the Temporary Technical Secretary (TTS) for the World GlacierInventory (WGI) of the Swiss Federal Institute of Technology (ETH), Zurich. [9]

The data presented in the Geological Survey of India inventory and ICIMOD Inventory of glaciers was analysed to make a comparative assessment of the distribution of Indian Himalayan glaciers in the river systems of Ganges, and also to analyse the dimension of Indian Himalayan glaciers.

4. RESULTS

It was estimated that 33,200 sq. km of the Himalaya is glaciated6 and glaciers occupy about 17 percent of the total mountainous area of the Himalaya. [12] As per the survey by Geological Survey of India, Indian Himalaya has a total of 9575 glaciers. Out of these, information related to their length, area and volume are available for 9040 glaciers, which occupy an area of 18527.79 km^2 and have a volume of 1306.1 km^3. Out of these, 94.09 percent of glaciers are smaller than 5 km in length and 92.8 percent of glaciers are smaller than 5 km^2 in area. [8]

In total Indian Himalaya glaciers occupy more than 55.81 percent of the entire glaciated area of the Himalaya.

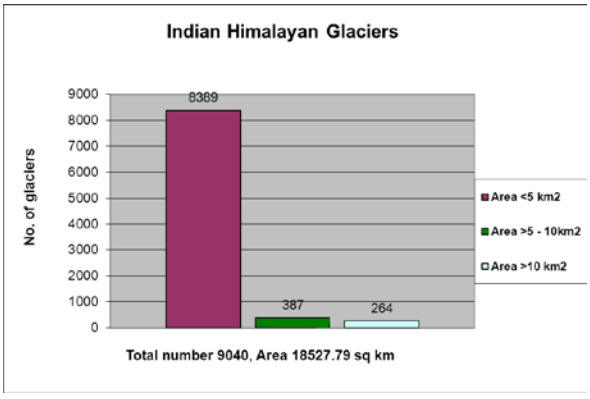

Fig. 1. Indian Himalayan Glaciers [8]

The Ganges River system in the Indian Himalayas can be divided into four major river basins i.e. Yamuna, Bhagirathi, Alaknanda and Ghaghara River Basins. These basins originate from the higher reaches of Uttarakhand.

River Ganga is fed by 10.1 percent of all the glaciers in Indian Himalaya, totaling 968 glaciers which are distributed among 18 sub-basins. 87.7 percent of these glaciers are smaller than 5 km in length and 86.57 percent are small to very small in size ranging from 5.0 km^2 to 0.03 km^2.

Glacial depth is normally related to its area and usually small glaciers have comparatively lesser depth. As glacier response time is relative to its depth it could vary between 4 and 60 years, depending upon glacial size. This could be the fundamental reason for large retreat of small glaciers. [10] The current trend of fragmentation of glaciers to smaller glaciers and separation from glacier to form dead ice will also increase the rates of deglaciation thereby enhancing the impacts of global warming.

The glaciers with a smaller area are more threatened by deglaciation than large glaciers. Loss in glaciated area for large glaciers [area more than 10 km^2] was 12 percent compared to 38 percent for small glaciers [area less than 1 km^2]. A loss of 29 percent and 27 percent of area was also observed for glaciers of the size range of 1-5 km^2 and 5-10 km^2 respectively between 1962 and 2001. [10]

It can also be noted that even though the network of lower latitude small glaciers and ice caps, make up for only about four percent of the total land ice area or about 760,000 km^2, they may have provided as much as 60 percent of the total glacier contribution to sea level change since 1990s. [11]

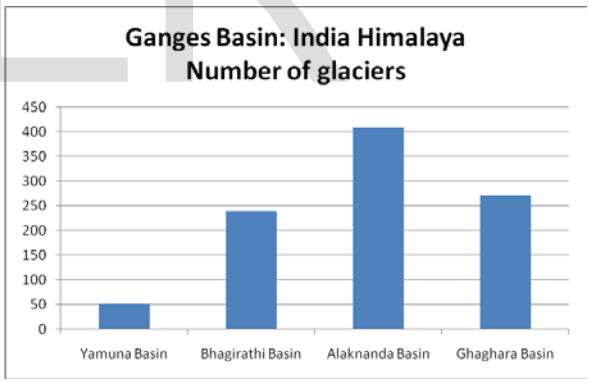

Fig. 2. Ganges Basin: Number of glaciers in Indian Himalaya [8]

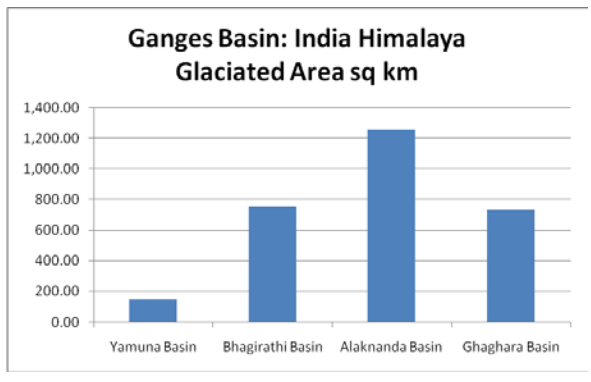

Fig. 3. Ganges Basin: Indian Himalaya Glaciated Area km^2 [8]

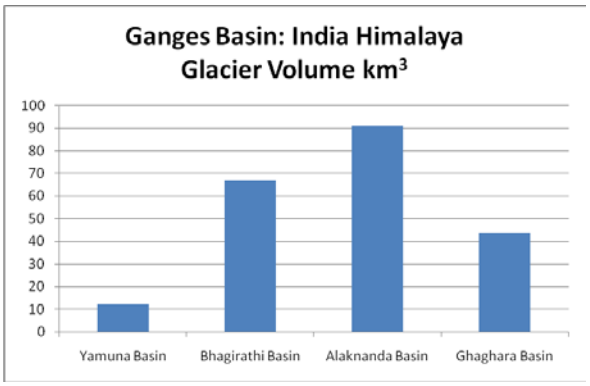

Fig. 4. Ganges Basin: Indian Himalaya Volume km^3 [8]

River flow in Ganga is also supported by 3252 glaciers of Nepal Himalaya with a glacierised area of 5322 km^2 and ice volume of 481 km^3. The Nepal Himalayas area can be divided into four major river basins namely Koshi, Gandaki, Karnali and Mahakali River Basins. It can be noted that even though Karnali basin has more number of glaciers than Gandaki basin, Gandaki basin has a larger glacierised area due to the presence of larger glaciers.

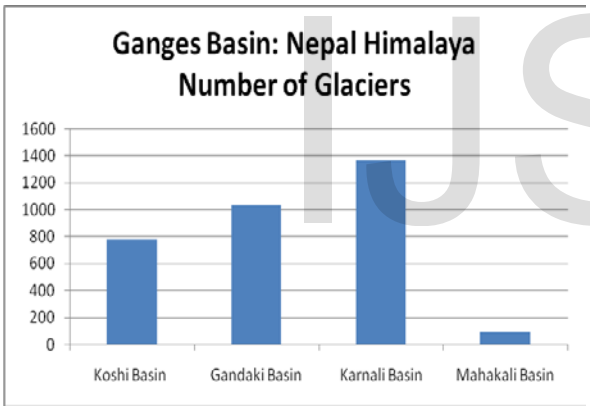

Fig. 5. Ganges Basin: Number of glaciers in Nepal Himalaya [9]

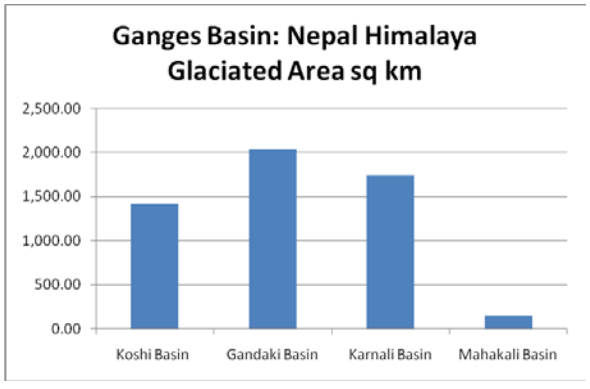

Fig. 6. Ganges Basin: Nepal Himalaya Glaciated Area sq. km^2 [9]

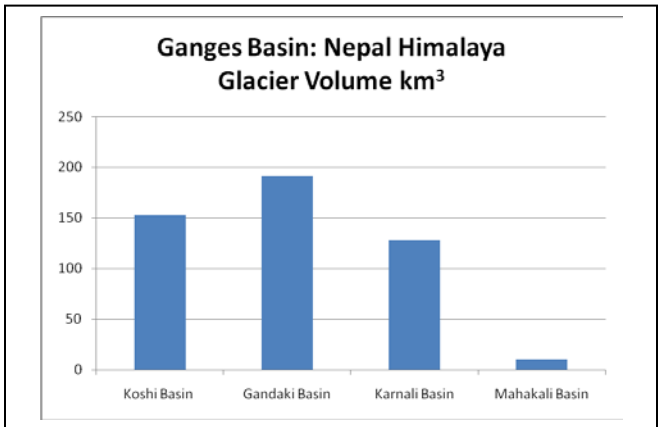

Fig. 7. Ganges Basin: Nepal Himalaya Volume km^3 [9]

Accordingly, Nepal Himalaya has 77 percent of the total number of glaciers in the Ganga basin, 65 percent of glaciated area and 69 percent of total ice volume contributing to River Ganga.

4.1 Gangotri Glacier

Gangotri glacier is the largest glacier of Ganga basin covering 5percent of the total glaciated area and 13 percent of total ice volume in the Indian Himalayan part of the basin. Furthermore, as many as 40 glaciers have a significant ice volume of more than 1km^3, but concentrated mostly in 5 of the 18 sub basins of Indian Himalayas. Out of the 40 glaciers, only 6 have an ice volume of more than 5 km^3 but they account for 26.82 percent of the ice volume.

However when compared with contributions from Nepal Himalayas, Gangotri glacier occupies 2 percent of the total glaciated area of the basin. Gangotri glacier has an estimated ice volume of 28.72 km^3 accounting for 4 percent of the total ice reserves in the Ganges River Basin.

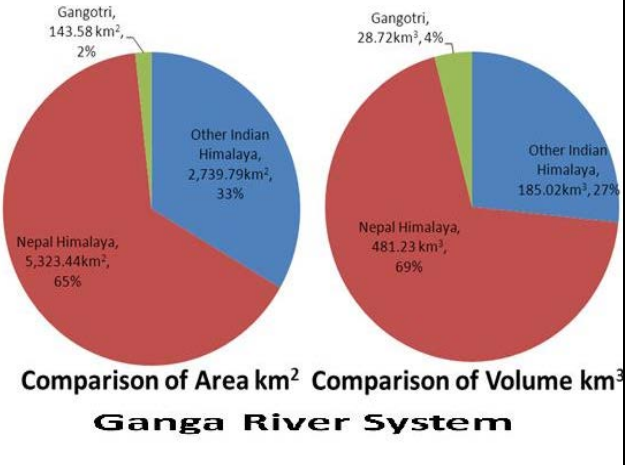

Fig. 8. Ganges River System: Comparison of Area and Volume [8], [9]

5 CONCLUSION

Majority of glaciers in Indian Himalayas, and Ganges Basin are smaller in size. Furthermore, smaller glaciers are more susceptible to melting, and hence vulnerable to global warming. Additionally, the bulk of ice volume contributing to the Ganges river system is located in Nepal Himalayas. Therefore, there is an urgent need for cross-border co-operation to develop a shared understanding of melting response of glaciers contributing to Ganges basin.

The identification of mutual benefits is vital and it is a prerequisite for successful regional cooperation. There is a need to share hydro-meteorological knowledge between India and Nepal and for collaborative efforts towards cryosphere preservation, flood forecasting and warning, and research studies on the effects of climate change in the Himalayan region. Joint field expeditions and research programmes on Indian and Nepal Himalayan glaciers should be developed with the collaborative efforts of researchers from the two sides.

Few studies have been done on glaciers other than the Gangotri glacier. Therefore it is also necessary to study the impacts on smaller glaciers which have larger representation, and face the maximum possible risks due to climate change effects.

Long term studies on glacier dynamics and mass balance are needed to understand the behavior of the Himalayan glaciers and climate change impacts.

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