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Recession of Milam Glacier, Kumaun Himalaya, Observed via Lichenometric Dating of Moraines

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ABSTRACT

Glaciers being very sensitive to climate change have been identified as one of the best indicators of climate change and evidences have proved that most of the Himalayan glaciers have receded with an increased rate during the recent past under the influence of global warming. Lichenometric study was carried out on the moraines of Milam glacier (located in Pithoragarh district of Uttarakhand) with the help of lichen species *Dimelaena oreina* having an average annual growth rate of 1.31 mm. The study revealed that Milam glacier has receded 1450 m in last 69.37 years with an average recession rate of 20.90 m/year. Since lichenometric studies are cost effective and ecofriendly in comparison to carbon dating, satellite and remote sensing based studies and also reliable, hence, it should be promoted in Himalaya which is an abode of glaciers.

INTRODUCTION

Climate change and global warming are the most urgent issues which all countries are facing presently. Among several indicators of climate change, the glaciers have emerged as important indicators of global climate change because their advancement and recession depends on the prevailing climatic conditions, and even a slight difference in climate can fluctuate them. Since glaciers have receded worldwide in recent years with an alarming rate because of climate change, but the rate of recession varies among the glaciers. The establishment of International Glacier Commission in 1984 in Zurich, Switzerland initiated worldwide glacier monitoring with an aim to monitor glacier variations and to understand the mechanisms leading to change over time (Haeberli et al., 1996). They have noticed drastic glacial retreats during the last century which are clear evidences of the ongoing process of global warming (Beniston and Fox, 1996).

The Himalaya consists of several glaciers and the glacier inventory carried out by Sangewar and Shukla (2009) revealed the presence 9040 glaciers covering an area of 18,528 sq. km in the Indian Himalayan Region (IHR). However, Raina and Srivastava (2008) reported 9575 glaciers in IHR. Another glacier inventory conducted using satellite images showed 23,308 sq. km extent of glaciers in IHR (Kulkarni and Buch, 1991). International Centre for Integrated Mountain Development (ICIMOD) carried out glacier inventory for the Hindu Kush Himalaya (HKH) region using data from Landsat and Shuttle Radar Topography Mission (SRTM) and listed 54,252 glaciers covering an area of 60,054 sq. km in the entire HKH region (Bajracharya and Shrestha, 2011). Glacier inventory of the Indus, Ganga and Brahmaputra basins made by Space Applications Centre (SAC-ISRO), using LISS-III images of the Indian Remote Sensing satellite listed 32,392 glaciers covering an area of 71,182 sq. km (SAC 2011). This variation in the number of glaciers and the area occupied by them is possibly due to different reference areas, scale of mapping and different methodologies *viz.* topographic studies, aerial photography, satellite imaging and field observations (Kulkarni and Karyakarte, 2014).

The Himalayan glaciers are also affected with the process of climate change and various studies suggest that many of them have receded in recent decades due to global warming (Bahuguna et al., 2014; Wiltshire, 2014). Kulkarni and Karyakarte (2014) reviewed the studies conducted over 11,000 sq. km glaciated area, distributed in all major climatic zones of the Himalaya and revealed the loss of almost 13% of glaciated area during the last 4-5 decades. All these studies suggested that glaciers in the Himalaya are retreating, however, the rate of retreat is different for different regions and the rate of recession remained a subject of debate.

To analyze the impact of global warming on glaciers, monitoring the fluctuations of glaciers over time is needed, which is a time taking and resource intensive process. Hence to overcome this challenge, lichenometry can play a significant role in estimating the approximate time of glacier retreat, since it is a cost-effective and time saving method. During the process of glacier retreat heaps of moraines are left, which on exposure to environment and sunlight get colonized by lichens. The peculiar morphological, anatomical and physiological characteristics of lichens enable them to have a long life span and survive in harsh high alpine climate where other plant groups cannot survive. Therefore, lichens can be effectively used for rapidly determining the impact of climate change on glaciers.

Lichenometry, which uses lichens to estimate the age of the sub-strate on which it grows, is the most frequently used technique by geologists for dating rock surface and moraine ridge on recent glacier forelands in polar and alpine regions and is based on the principle that the size of thallus forms an index of the growth of lichens and gives information about the age of the sub-strate (Armstrong 2015).

Lichenometry has been widely applied in glacier chronology in different countries (Solomina and Calkin, 2003; McCarthy, 2003; Bradwell, 2004; Winkler, 2004; Matthews, 2005; Hansen, 2008; Roberts et al., 2010; Trenbirth and Mathhews, 2010; Loso et al., 2013; Decaulne, 2016), but in India, it has been conducted recently and that too from very few areas *viz.* Jammu & Kashmir, Sikkim, Uttarakhand (Srivastava et al., 2001; Awasthi et al., 2005; Chaujar, 2009; Joshi and Upreti, 2010; Bajpai et al., 2016). As Uttarakhand comprises of 968 glaciers (Raina and Srivastava, 2008), lichenometric studies have been performed only on 5 glaciers. The first lichenometry study in Uttarakhand was carried out in Gangotri glacier (Srivastava et al., 2001; Awasthi et al., 2005). Thereafter Chaujar (2009) studied the glacier activities in Chorabari and Dokriani glacier of Garhwal Himalayas in Uttarakhand. Joshi and Upreti (2010) estimated the minimum age of exposure of the moraines near Pindari glacier. Recently Bisht et al. (2018) estimated the average recession rate of

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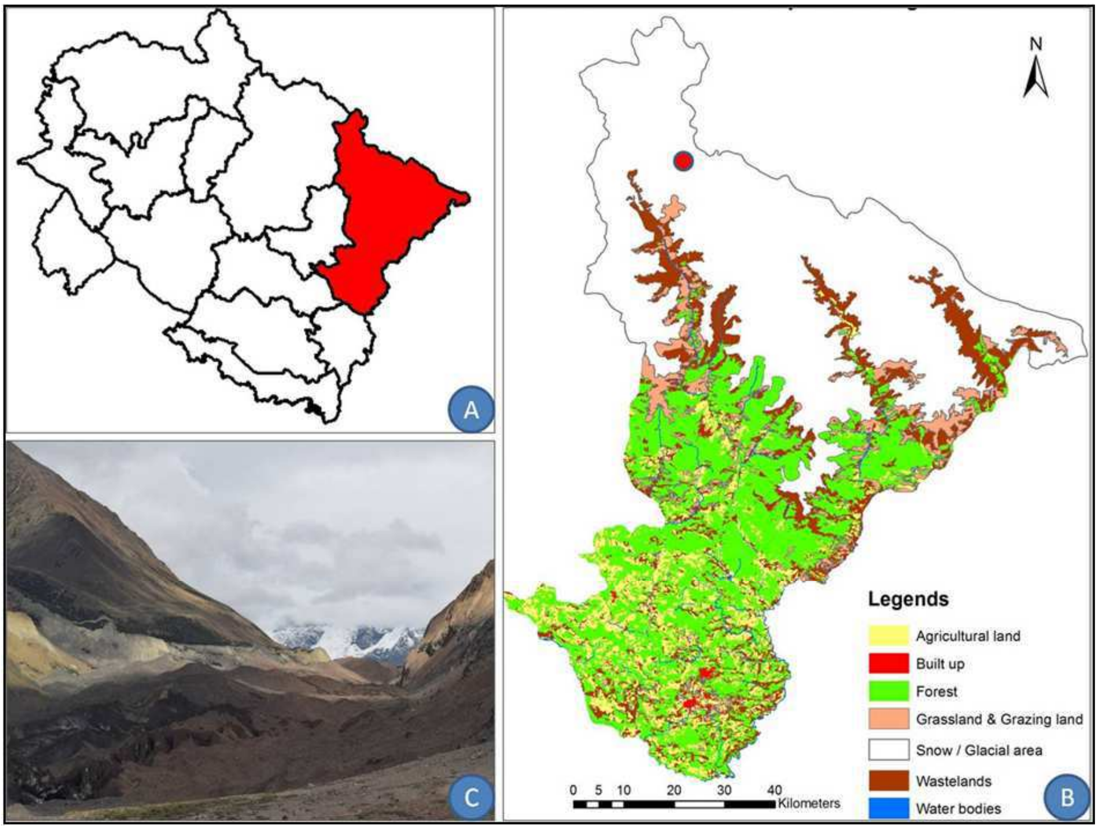

Fig.1. Location map of Milam Glacier **(A)** Uttarakhand, **(B)** Pithoragarh district, **(C)** Milam Glacier.

Adi Kailash glacier situated in Pithoragarh district by using this technique.

In the present study, Milam glacier has been chosen because it is the largest glacier in Kumaun region (16 km long and having an area of about 37 sq. km) and one of the most commonly trekked glacier of Kumaun Himalaya after Pindari and Sunderdhunga and is facing high anthropogenic pressure (K. Bisht, *pers. comm.*).

MATERIALS AND METHODS

The present study was conducted on the moraines of Milam glacier in September 2016 and 2017. Milam glacier (N30°27.952; E80°06.702 ; 3579 m asl, at snout) is located in Johar valley of Munsiyari block of Pithoragarh district in the state of Uttarakhand (Fig.1). The Johar Valley comprises of 13 villages namely Milam, Bilju, Mapa, Ganghar, Tola, Burfu, Martoli, Laspa, Rilkot, Ralam, Panchu, Khilanch and Lawn which are located on both the banks of river Gori Ganga. Gori Ganga which is a major tributary of the Kali/Sharda originates from Milam glacier and confluences with Kali at Jauljibi. The villages are inhabited by the Bhotia tribe having migratory mode of living i.e. move to lower regions during winter season and come back to Johar in summer. Before Indo-China war in 1962, Milam was the bustling trade centre with Tibet, but after the war the trade was closed and the Johar community migrated to other regions.

The sampling was done at the vicinity of glacier towards the lower side from the snout and the sampling area was divided into several transverse sections separated from each other by a distance of 50 m. On the moraines the population of lichens was meager; hence wherever the lichen thalli were encountered their diameters were measured with the help of Vernier caliper. The lichen species *Dimelaena oreina* (Ach.) Norman was chosen due to its availability on the boulders, slow growth rate and circular growth of the thallus. The annual growth rate of *D. oreina* was calculated by measuring its diameter on one year interval (Fig.2) with the help of Vernier caliper and by dividing the diameter of the lichen thalli by the annual growth rate, the age of lichen thalli was calculated. The sampling was done until the thalli having the largest diameter was found. The distances from the snout of these measurement points (where lichen diameters were measured) were measured with the help of transverse sections as per Joshi and Upreti (2010).

Polynomial regression analysis was performed using PAST software (Hammer et al., 2001) to compare diameter of lichen thallus (in year 2016 and 2017) and age of lichen with distance from the snout of glacier. Paired sample t-test was performed for comparing the diameter of lichen thallus in year 2016 and 2017 by using SPSS 16.0 version software.

RESULTS AND DISCUSSION

The first thallus of *Dimelaena oreina* was encountered 180 m away from the snout having a diameter of 8.28 mm, while the last thallus was measured at 1450 m distance with a diameter of 89.53 mm in the month of September; 2016 (Table 1, Fig.2). To calculate the annual growth rate of the lichen thalli, the same thalli were again measured in the month of September, 2017 (annual growth of the lichen thalli is

Fig.2. Diameters of different lichen specimens at different locations from the snout measured in September 2016.

Table 1. Thallus diameters of *D. oreina* at different locations, their age and recession rate of Milam Glacier over time

Location	Distance from snout	Diameter in 2016 (mm)	Diameter in 2017 (mm)	Average diameter (±SE*)	Annual Growth Rate (mm/year)	Average Growth Rate (mm/year)	Age of lichen (year)	Recession Rate (m/year)
1	180	8.28	9.56	8.92±0.64	1.28		7.30	24.67
2	350	19.94	20.96	20.45±0.51	1.02		16.00	21.88
3	470	21.92	23.12	22.52±0.60	1.20		17.65	26.63
4	580	27.45	29.66	28.56±1.11	2.21	1.31	22.64	25.62
5	620	36.20	37.26	36.73±0.53	1.06		28.44	21.80
6	980	51.41	52.49	51.95±0.54	1.08		40.07	24.46
7	1450	89.53	90.87	90.20±0.67	1.34		69.37	20.90

*SE= standard error

given in Table 1). The thalli of *D. oreina* showed variation in its annual growth (1.02-2.21 mm/year) hence an average value of 1.31 mm/year was taken as the annual growth rate of *D. oreina.* The age of lichen thalli is considered as the minimum time of exposure of the substrate. The measurements showed that the Milam glacier has receded 1450 m during the last 69.37 years with an average recession rate of 20.90 m/year.

The same lichen species (*D. oreina*) was used by Hale (1959) and Awasthi et al. (2005) for performing lichenometric studies in Litchfield (USA) and Gangotri glacier (India), respectively, and they reported its growth rate to be 0.57 mm/year and 0.3 mm/year, respectively. However, variation in the growth rate of *D. oreina* in the present study in Milam glacier (1.02 to 2.21 mm/year) justifies the work of Trenbirth (2010) who stated that the same taxon can have different growth rates in different locations because of variations in microclimatic conditions and nature of substrate.

Polynomial data fit suggests that diameter of lichen thalli in the years 2016 and 2017 have been influenced by the distance from the snout of the glacier and it was observed that lichen thalli diameter increased with increasing distance from the snout of glacier. There was a significant positive correlation between the diameter (in 2016 and 2017) and distance from the snout (r^2= 0.990, p<0.001; r^2= 0.991, p<0.001; Fig.3A & B). The lichen thalli diameter of the year 2016 and 2017 differed significantly with each other in all distances and it was confirmed by Paired sample t-test analysis (t-value= -8.411, p<0.001). In case of relationship between the age of lichen thallus and distance from snout, the polynomial regression analysis shows significant positive relationship (r^2= 0.991, p<0.001; Fig.3C).

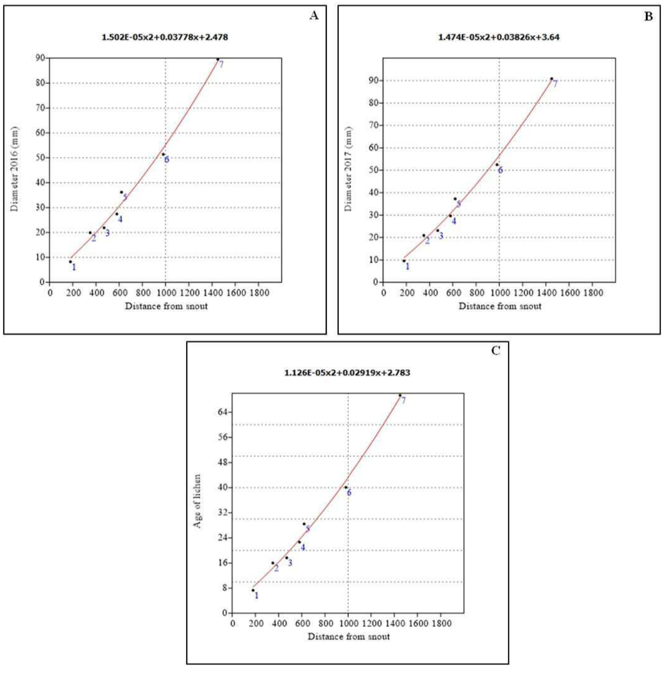

Fig.3. Polynomial regression analysis between distance from snout of glacier and, **(A)** diameter of lichen thallus in year 2016, **(B)** diameter of lichen thallus in year 2017, and **(C)** age of lichen thallus

Sangewar and Kulkarni (2011) monitored the Milam glacier from 1948-1997 for duration of about 50 years, and observed a retreat of 17 m/year. Raj (2011) monitored the same glacier from the year 1954-2006 and observed a retreat of 25 m/year. Though the results of Sangewar and Kulkarni (2011) and Raj (2011) not only differ with each other but also with the present study, but the results generated in the present study somehow corroborate with these previous studies and these variations in the results may be due to different reference areas, scale of mapping and methodologies used.

Rhizocarpon geographicum (L.) DC. which is the most commonly and widely used lichen species in lichenometry throughout the world was not found on the moraines of Milam glacier, although it was found downwards beyond the sampling area. This indicates that *R. geographicum* is not showing immediate colonization on the moraines of Milam glacier after its retreat.

In the present study annual growth of *Acarospora fuscata* (Schrad.) Th. Fr. and *Rusavskia elegans* (Link) S.Y. Kondr. & Kämefelt were also measured (Fig.4). They showed higher annual growth rates as compared to *D. oreina* but were omitted because the perquisite for a lichen to be used in lichenometric studies is that it should be slow

Fig.4. Increase in thallus diameters of different lichen species measured in September 2016 and 2017. **(A)** *Acarospora fuscata*, **(B)** *Dimelaena oreina*, **(C)** *Rusavskia elegans*

growing and have a circular shape of the thallus. The thalli of *A. fuscata* and *R. elegans* rupture after a certain period of age and were not maintaining the intact circular size of the thallus. In view of the above *D. oreina* came out as the best lichen species to be used in lichenometric studies in Milam glacier, because it maintained the circular shape of the thalli, showed a slower growth rate as compared to the other potential species to be used in lichenometry and was found to be the pioneer colonizer on the boulders after the exposure of the moraines.

As some developed European and American countries rely on this cost effective and ecofriendly technique, hence, precedence should be given to Lichenometry over satellite and GPS based observations in India too.

CONCLUSION

On the basis of present study it can be concluded that every glacier either in the Himalaya or anywhere in the globe is not receding with an equal rate. Global warming may be responsible for the overall glacier retreat across the globe, but the variations in the recession rates of the glaciers may be due to microclimatic conditions. Hence each glacier needs to be monitored separately, so that the glaciers which are receding at faster rate can be identified and steps can be taken to prevent their rapid recession. The results generated in the present study and also from the previous ones are showing that Milam is not receding with an equal rate. Its rate of recession is varying over time. As Milam is 16 km long, with the current recession rate it can survive hundreds of years, but what about the small glaciers? About 66% of the Himalayan glaciers are less than 1 sq. km in area and if the recession prevails, a large number of Himalayan glaciers may disappear during the next century and this may drastically affect the freshwater supply to the Himalayan states.

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