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Understating the Dynamics of Himalayan Glaciers . . .

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Glaciers, the storehouse of frozen water, hold nearly 77% of the world's fresh water resources and feed major rivers. In the absence of direct measurements, glaciers serve as proxy for climate as they store vital information about the past climatic perturbations and atmospheric composition assessed by different geological proxies (e.g. landforms and sediments). Himalayan glaciers, the largest glacier system outside the Polar regions, occupy highest altitudes in the world and feed the perennial rivers of north India, which sustains life and livelihood of millions of people. Himalayan glaciers form and modulate regional and global climate systems by affecting the land-ocean-atmospheric circulation patterns. Monitoring, studying and understanding glaciers is, therefore, of vital importance for managing the river flows and water resources, conserving the biodiversity, weather forecasting and sustaining the life-livelihood-systems of the Himalayan terrain and the plains below.

The Himalayan range act as a natural barrier on the earth and play an important role in maintaining and controlling the monsoon system of Asia mainly because of the interaction of polar, tropical and mediterranean influences. The major glacier-fed Himalayan rivers along with glaciated catchments have regional importance as the water from glacier melt

sustains stream flow in such rivers through dry season. These rivers have displayed significant variations in stream flow, particularly the eastern Himalaya where seasonal flows and monsoon flows showed huge changes in the recent past. It is assumed that sea-surface temperature and atmospheric circulation system cause these changes, however, the alterations in the timing and rate of snowmelt are assumed to be a result of changing temperature in the Himalayan region. In light of these changes, it is expected that water resources of the Himalayan region are likely to undergo significant alterations in future. Any change in the climatic conditions of the Himalayas has far reaching impact in the downstream areas.

Himalayan glaciers have been in a state of general retreat since 1850s and recent studies confirm that the rate of retreat of many glaciers is accelerating. The glaciers in the region are showing fluctuations in retreat rates during the last century, possibly due to the mixed influence of variable topography, temperature and snowfall regime. Surging, retreating and fast melting of glaciers in these high mountains expose terminal moraines and create glacial lakes at the terminus of end moraines. Rapid accumulation of water in glacial lakes particularly those adjacent to receding valley



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ENVIS Staff

Dinesh Giri
Vipin Chandra Sharma
Satish K. Sinha
Arvind Kumar

Guest Editor

Rajesh Joshi

Scientist

G B Pant Institute of Himalayan Environment and Development,
Kosi-Katarmal, Almora 263 643
(Uttarakhand)

dr.rajeshjoshi@gmail.com

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Editors' Note

Dear Readers,

Glaciers make an extremely important eternal source of fresh water to the mountain people as well as those live downstream. Roughly 500 million people depend on the melt water from these glaciers for various consumptive and non-consumptive uses of water that flows in the rivers originating from these glaciers. Indian Himalayan region (IHR) harbours ~ 9,575 glaciers with an estimated ice volume of ~ 2000 km³.

In the wake of Inter Governmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4), and the controversy about rapid melting of Himalayan glaciers has given rise to a renewed spurt of investigations on glaciers globally, particularly in the IHR. Further, this region has been identified as 'data deficient' by the IPCC. This can be illustrated by the fact that the Hindu Kush Himalayan region has the largest glaciated areas in the world outside the Polar Regions, but mass balance studies have only been carried out for 10 or so of the regions' > 50,000 glaciers, and most data deals with terminus position of the glaciers. Therefore, concerted efforts are required to understand the snow and ice dynamics of these glaciers, particularly under the influence of changing climate. Realizing the importance of the glaciers, Govt. of India has given special emphasis on the glaciers in the National Mission on Sustaining the Himalayan Ecosystem. We hope the selected articles presented in this NewsLetter will prove useful to the readers and invite their deep queries into this vital subject.

Editors

glaciers can lead to a sudden breaching of the unstable debris dam which shall ultimately cause glacial lake outburst floods (GLOF) and is a matter of concern for economic and life losses in the river valleys. The fast retreat of Himalayan glaciers is not only decreasing the channel discharge in long-term but may also cause flashfloods downstream and thus has direct bearing on socio-economic implications for the population living in valleys and downstream area. Therefore, proper understanding of the status and health of these glaciers is very important for long-term planning in the area.

Records from the high altitude mountain meteorological observatories over the last thirty years indicate accelerated warming and decrease in seasonal snowfall in the different ranges of North West Himalaya. There is, hence, a convergence from global, regional and sub-continental data indicating that the Indian land mass has been warming at an enhanced rate, particularly during the last three decades. In the context of the global warming, the fear is that this temperature-precipitation change would reduce the snow cover, accelerate melting of glaciers, affect the landscape and slope stability, the water cycle, sediment load in rivers, and natural hazards far beyond the historical and Holocene variability. This provides a compelling and urgent rationale to study the Himalayan glaciers in all their facets using the latest

technologies to understand their dynamics and determine answers to the many concerns that confront the scientists, policy and decision makers and above all the community that is likely to be affected most. The Himalaya is a highly complex system with linear and non-linear interactions/ feedbacks between the atmosphere, ocean, ice and biota and complex links to the tectonic processes originating deep in the earth system. To understand such a complex system, a cross disciplinary approach embracing climate sciences, glaciology, geophysics, paleo-climatology, remote sensing and modeling needs to be adopted.

This issue of the ENVIS News letter on Himalayan Ecology focuses of dynamics of glaciers of Himalayan region and provides vital information on retreat pattern of glaciers, precipitation system controlling the glacier region, mass balance and influence of climate change, winter snow albedo and its impact on cryosphere, glacial lakes and GLOFs, understating the snow and glacier melt runoff processes using isotopes and observed changes in glaciers of Sikkim Himalaya. This issue highlights insights of many facets of glaciers of Himalayan region covering northwest to northeast Himalayan region.

GUEST EDITOR

Rajesh Joshi
dr.rajeshjoshi@gmail.com



GLACIER MASS CHANGES

Subsistence in the Indian Himalaya.....

Glaciers are dynamic, self-regulating and highly sensitive to the changes in the climate. Each glacier accumulates mass during the winter when maximum solid precipitation occurs whereas releases water during the summer through melting when temperature is above 0°C. The processes of accumulation (input) and ablation (output) is called mass balance and signifies the health of the glacier. Mass balance of a glacier is an important component in understanding the processes of glacier gain and loss that links between climate and glacier health. The sum total of the input and output at the end of ablation period in a hydrological year is net annual balance and measured in cubic meter water equivalent ($\text{m}^3 \text{w.e.}$). The sum of net balance amount divided by the area of the glacier represents the specific mass balance and expressed in 'm w.e. or mm w.e.; which in turn provides a clear picture of mass balance trend at regional scale. Changes over the glacier regime that can be detected through the assessment of mass, volume, length and area with time and space are some of the key indicators of changes in the glaciers and their response to variation in climatic conditions. Across the globe the shrinking of glaciers is a clear indication of climate change. Increase in glacier recession rate and continuous negative mass balance in the last few decades have been observed.

Indian Himalayan Cryosphere, 'Third Pole', houses ~9,575 glaciers, with glacier ice cover area of ~36,000 Km^2 and ~2,000 Km^3 of ice volume (Raina and Srivastava, 2008). Most of the Himalayan glaciers are retreating (5-20 m/year) and thinning (0.15-1.0 m/year). It is estimated that the average ice thickness of the Himalayan glaciers (of area 5-10 Km^2) is between 60 to 65 m.

Mass balance studies of 15 glaciers, widely distributed in the Himalaya (Fig. 1), reveal that most of the glaciers are continuously losing mass with variable rates (mean annual specific mass balance in 1975-1980, -0.31 m w.e. a^{-1} ; 1981-90, -0.41 m w.e. a^{-1} ; 1993-2000, -0.39 m w.e. a^{-1} ; 2001-2010, -0.91 m w.e. a^{-1}). Cumulative specific mass loss observed over different regions of the Indian Himalayan glaciers shows negative mass balance trend since the first in-suit measurement conducted in 1974. In addition, on a regional level, the geodetic studies suggest that the entire western, central and eastern Himalaya experienced vast thinning during the last few decades. On the contrary, Karakoram region showed slight mass gain during the same period. In a broader sense it is a fact that Himalayan glaciers are under the process of thinning (mass loss) and reduction of length and area in the present climate conditions. However, the recession rate and the amount of mass loss of Himalayan glaciers vary with glacier to glacier depending upon the geographical location and climatic regime. The trend of recession is more or less similar and shows the susceptibility of precipitation and behaviour of Himalayan glaciers. The recent inventory of the Indian Himalayan glaciers was conducted in 2009. Large number of smaller glaciers (less than 1 Km^2) with their subsistence above 4500 m a.s.l were added to the list. These small glaciers accounts for nearly 66% of the total glaciers covering ~12% of the total glacierized area and only 4% of the total ice volume in the region. However, the larger glaciers (more than 5 Km^2) are nearly 7% of the total ice volume with 60% of glacierized area, and 77% of total ice volume. The smaller glaciers lying above 4500 m a.s.l are controlled by the microclimate of high altitude region. Whereas, the larger glacier flow downward to the valley up to 3800 m a.s.l and sustained by cold climate in the valleys. Continuous mass loss and recession rate of larger glaciers is subsequently resulting in the formation of more number of smaller tributary glaciers. It is assumed that, the trunk glacier (having large ice mass, long length and recession rate of 10-20 m a^{-1}), eventually would not disappear within near future. For example, 32 Km long Gangotri Glacier with its average retreat rate of 20 m a^{-1} (during 1962-2006) would take ~1500 years to disappear completely. However, widespread shrinkage of the glaciers in the Indian Himalaya will convert many of the present glacier-fed river systems into rain-fed ones. Furthermore, reduced melting of glaciers might affect seasonal water availability and would result in more pronounced seasonal hydrological imbalances in the downstream regions of Indian Himalaya.



Fig. 1. Location of glaciers studied for mass balance estimation for Indian Himalaya

Climate-Mass Balance Interaction:

Climate change is likely to accelerate the receding of Himalayan glaciers thereby affecting the mass balance which is a key indicator of glacier change and retreat. Although the overall mass balance for the Himalayan region was found negative, yet positive mass balance also recorded for few glaciers over the Karakoram and Kunlun mountain ranges (east of Karakoram), which are mainly fed by winter precipitation. Temperature rise is assumed to be the main driving factor behind the global mass loss of glaciers. Temperature on the glacier surface is related to radiation balance, turbulent heat exchange and precipitation ratio, playing predominant role in determining the mass and energy balance. It has been noted that, during the last few decades there has been rise in temperature and decline in the snowfall in the North Western Himalaya, thus reinforcing each other's effect on the annual mass balance through a positive feedback. This is in contrast to the global trend where a marginal increase in winter precipitation and a higher increase in summer ablation has been observed, which partially balances each other's effect.

Mass balance of glaciers is now accepted as a direct undelayed key indicator for assessing the trends of climate change. The associated parameters like the equilibrium line altitude (ELA), area accumulation ratio, mass balance gradient and mass turn over, together help characterize the response of glaciers to climatic change. Through the efforts of the World Glacial Monitoring Service (WGMS), a global system of monitoring glaciers has evolved over the years. The analyses of available global mass balance data, undertaken by many researchers, highlight the recent increase (post mid 1970s) in the amplitude of mass balance variations (mass turn over), with values increasing for both the winter and summer mass balance. Incremental ablation exceeds the additional accumulation and hence the net increase in the negative mass balance. While increase in ablation due to the rising temperature regime is expected, the rise in winter accumulation has been quite unexpected. In the Indian Himalayan region thirteen glaciers have been studied for multi-year assessment of mass balance by the conventional glaciological method with the varying time length. Though, the monitoring coverage of Himalayan glaciers is improving in recent time, but still there are some constraints (such as variable retreat rates, less glacier mass-balance data and lack of long-term in-situ measurement) in glacier mass balance studies. Therefore, there is need to further understand Himalayan glaciers vis-a-vis climate change.

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D.P. Dobhal (dpdobhal@wihg.res.in)
Centre for Glaciology
Wadia Institute of Himalayan Geology
Dehradun-248 001, India



WINTER SNOW ALBEDO

Himalayan Cryosphere.....

The Himalayan cryosphere is important source of fresh water in Indian subcontinent. Seasonal snow covers to its maximum extent during winter and minimum during summer months in Himalaya. Therefore, Himalayan snow cover has an impact on the glaciology, hydrology, climatology and environment of the entire Indian subcontinent. In the recent past several sources are raising concern about receding of glaciers in Great Himalayan and heterogeneity taking place in Karakoram glaciers. Adding further to concern the Himalayan glaciers are reported to be highly affected by the snow/ice darkening effect due to black carbon (BC) and dust layer formation, which is a significant factor for melting of snow and receding glaciers. But in the Himalayan context there is no concrete source to validate these concerns. Unfortunately, there is no systematic long term albedo data from higher elevations due to remoteness and difficult access to these mountains.

Winter snow albedo collected over NW-Himalaya using field techniques (1991/93-2010) and MODIS derived (2001-14) was analysed by Snow and Avalanche Study Establishment (SASE) for a period of approximately 24 years. Albedo data from 8 representative observatories in Lower Himalaya (LH), Greater Himalaya (GH) and Karakoram Himalaya (KH) (Fig.1) were analysed. A significant decrease in albedo of GH approximately of 0.2 was observed during 1993-2010. The rise in average winter temperature was found to be approx. 2.1°C in 18 years. The trends of seasonal cumulative and seasonal average snow thickness were found to be decreasing. Therefore, the temperature condition of GH (mean air temperature -10 to 0°C) with significant increasing trend was attributed to decreasing albedo due to thermal metamorphism. As the albedo reduction varies significantly for snow temperatures above -10°C, the metamorphic processes have profound effects on albedo.

The insignificant change (approximately stable) was observed in albedo for LH of approx. 0.02 between 1991-2010. The rise in average winter temperature was found significant but as the snowfall occurs in warmer temperature regime the moderate air temperature (average temperature more than 0°C) causes the melt-freeze metamorphism to proceed quickly and thus form clusters from snow single grains. After multiple melt-refreeze cycles, these clusters transform into single melt-freeze grain of much larger grain radius. Because of frequent melt-refreezing cycles, snow cover of LH is characterized by coarse (1.0-2.0 mm) or even very coarse (more than 2 mm) grain size distribution with moist to wet snow. Therefore, snow albedo found to be lower in LH. Such moderate winter average temperatures of LH station were found above 0°C since beginning of the study period (1991 onward). Therefore, no appreciable change was observed in snow metamorphic regime. Thus no significant change in albedo was observed as well. The trends show that seasonal cumulative and seasonal average snow thickness is decreasing significantly. Now due to rising temperature liquid precipitation has increased, whereas winter snowfall has decreased. Snow albedo is very stable at temperatures below -10°C. The persistent very low temperature of KH and more frequent occurrences of snowfall events during winter period are attributed to insignificant change in albedo.

The snow cover mapping investigations of Himalaya conducted between 1990-2001 suggest reduction in snow cover by almost 6%. Whereas, significantly less declining trend of snow cover area of Himalaya was reported for 2000-2010 (Gurung et al., 2011). The MODIS derived winter snow albedo shows overall insignificant increasing trend over NW-Himalaya during 2001 and 2014. However, between 2001 and 2010 winter snow albedo has declined. The analyses of winter average temperature from 2001 to 2010 shows that in all the three ranges, temperature is increasing. Whereas, declining winter mean temperature in recent years has slowed. This is termed as 'hiatus'

in the winter average temperature rise. As a result of this, winter average albedo was found insignificantly increasing over NW-Himalaya. The hiatus in global warming has also been reported by many researchers. Thus the present albedo study supports the findings of recently reported Himalayan snow cover in different duration.

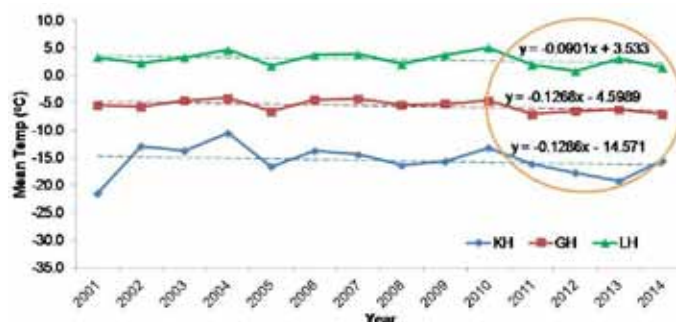


Fig. 1. Winter mean temperatures between 2001 and 2014 for different north-west Himalayan ranges. The recent 4-5 years temperature has slowed down the rise in winter mean temperature and attributed to insignificant rise in albedo after 2001

As albedo is a major contributing parameter for surface energy exchanges and hence, it is an important component for glacier mass balance. The long-term rate of retreat for approximately 40 years (1960-2000) shows the significant loss of glacial length in Himalaya. But the recent study of glacier after 2001 has reported that most of the glaciers are in a steady state compared to the results of other studies carried out for the period prior to 2001. The results of albedo study over Himalaya that the decrease in snow albedo with respect to year 1991 and increase in albedo 2001 onward supports the above findings.

The snow-albedo feedback is a contributing factor in the amplified warming over cryospheric region in Himalaya and also contributes to elevation dependent warming. Ground-based observations of snow are scarce in Himalaya mainly owing to the rugged terrain. This leads to a challenge in studying the regional variability in snow cover and albedo. Furthermore, the high elevation regions, extend across a vast geographic area, are affected by different circulation and precipitation regimes, which lead to higher spatial variability in snow cover. The loss of snowpack decreases surface albedo, and leads to an increase in surface absorption of solar radiation, which in turn leads to amplified warming. On the other hand, snow pack may itself decline as a response to large-scale warming. It is difficult to isolate the individual components of the associated feedback mechanism related to changes in snow pack and surface temperature. The presence of snow pack in high elevation regions and its interaction with the atmosphere can affect surface air temperature. It is, therefore, important to understand the reasons for such spatial variability and the potential role of the snow-albedo feedback mechanism.

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H.S. Negi (hs.negi@sase.drdo.in)

Snow & Avalanche Study Establishment,
Him Parisar, Sector-37A,
Chandigarh 160 036

GLACIAL LAKES AND OUTBURST FLOODS (GLOFs)

Indian Himalayan Region.....

Glaciers, important sources of fresh water, act as a natural frozen reservoir storing water during winters and releasing it in the summer. The Central Asian Mountains contain about 50% glaciers of the total mountain glaciers of the World. A large portion of these drains into the Indian sub-continent. Global warming induced retreat of glaciers is influencing stream run-off and eventually formation of glacial lakes. Glacier retreat and shrinking could form dangerous moraine lakes, causing sudden glacier lake outburst floods (GLOFs) damaging life and property downstream over a long distance on its way.

Glacial lakes often form between the frontal moraine and the retreating glacier or on the surface of the lower section of the glacier (Fig. 1). These kinds of lakes are held back (dammed) by unstable moraine complexes, and have potential to breach their moraine dams causing GLOF. Glacial lakes in the Himalaya region, formed mostly since last 5-6 decades, are increasing in number and size.

In order to assess the possible hazards from such lakes, it is, therefore, essential to have a systematic and temporal inventory of all such lakes formed at varying altitudes to assess the change

in their nature and aerial extent. The glacial lakes are classified into Erosion, Valley trough, Cirque, Blocked, Moraine Dammed (Lateral Moraine and End Moraine Dammed lakes), and Supraglacial lakes. Factors contributing to the hazard risk of moraine-dammed glacial lake include (a) large lake volume, (b) narrow and high moraine dam, (c) stagnant glacier ice within the dam, and (d) limited freeboard between the lake level and the crest of the moraine ridge. The risk of development of lake is highest where the glaciers have a low slope angle and a low flow velocity (Worni et al., 2012; Negi et al., 2012). The potential danger of glacial lakes largely depends on their elevation relative to the spillway over the surrounding moraine. Triggering events for an outburst can be by- earthquake induced moraine failures, decrease of permafrost, increased water pressure, or a rock snow avalanche slumping into the lake causing an overflow.

Different triggering mechanisms of GLOF events depend on the nature of the damming materials, the position of the lake, the volume of the water, the nature and position of the associated mother glacier, physical and topographical conditions, and other physical conditions of the surroundings. Interaction between the above processes may strongly increase the risk of hazards. The most significant chain reaction in this context is probably the danger from ice avalanches, debris flows, rock fall or landslides reaching a lake and thus provoking a lake outburst. Generally the ice core-dammed and moraine-dammed lakes failure occurs due to (i) ice dammed lakes drain through, over or underneath the ice (ii) initiation of opening within or under the ice dam, which occurs due to floatation of the ice dam, pressure deformation, melting of a tunnel through or under the ice, drainage associated with tectonic activity, water overflowing the ice dam generally along the lower margin, and sub-glacial melting by volcanic heat. The bursting mechanism for ice core-dammed lakes can be highly complex and involve one or more above-stated hypothesis.

Although, GLOFs have occurred in various parts of the Himalayan region in the past, known both from the living memories of local people and from sparsely documented evidence. However, precise location, frequency, and actual scale of their effects are not precisely known. Very few studies have been conducted in the Himalaya



Fig. 1. Settlement of debris and formation of glacial lakes over Gangotri glacier (Adopted from Negi et al., 2012)

regarding the impacts of climate change on GLOFs. Remote sensing with its advantages of spatial, spectral and temporal availability to cover data from large and inaccessible areas within short time has become a very handy tool in assessing and monitoring disaster prone zones in high altitude regions.

Table 1. Proportion of glacier lake counts per state in the Indian Himalaya, classified as critical, potentially critical, and uncritical. The difference to 100% corresponds to unclassifiable lakes

	J&K	H.P	Uttarakhand	Sikkim	Arunachal Pradesh
Total lakes	103	45	27	50	26
Critical	2%	4%	0%	16%	0%
Potentially critical	32%	36%	52%	60%	0%
Uncritical	41%	24%	40%	22%	96%

(Source: Worni et al., 2012)

In a study by Worni et al. (2012) a total of 251 glacial lakes (area more than 0.01 km²) were identified and mapped over the Indian Himalaya which were qualitatively classified according to outburst probability and damage potential. Based on the remote-sensing analysis, critical lakes were detected in the states of Jammu & Kashmir (2 lakes), Himachal Pradesh (2) and Sikkim (8). Although the Himalayan region shows generally less critical glacial lakes compared to other part of the Hindu Kush Himalaya, yet, many large and critical glacial lakes exist in Sikkim. Glacial lake density in Sikkim is high compared to Jammu & Kashmir, Himachal Pradesh and Uttarakhand where glacial lake distribution is more uniform. The lake distribution pattern corresponds with lake characteristics in the different regions and also classified and numbered as critical, potentially critical, and uncritical lakes per state (Table 1). A high proportion of large lakes exist in Sikkim, whereas all other states host medium to small sized lakes. Therefore, Sikkim Himalaya a hotspot of possible GLOF occurrences, require further research, monitoring and preparedness.

Global warming resulting in significant shrinkage in snow-cover area, retreating of glaciers and formation of glacier lakes thereby increasing the risks of GLOF. For assessment of GLOF, comprehensive studies on stream flow pattern a glacier retreat are needed. So far, no glacial lake inventory exist for the Indian Himalayan region. Therefore, a comprehensive inventory of glacial lakes is essentially important for the assessment of potential hazard and planning of adequate coping strategies. Despite prevailing uncertainties, a standard modeling process can be a valuable tool to assess lake-outburst probabilities and potential lake outburst magnitudes. Such study would facilitate the planning and dimensioning of accurate mitigation measures in the form of early warning systems. Further, regular monitoring of glaciers and glacial lakes and adaptation measures including early warning systems are required in areas vulnerable to GLOF.

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Sanjay K. Jain (sanjay.nih@gmail.com) and A.K Lohani

National Institute of Hydrology
Him Parisar, Sector-37A, Roorkee



RECESSION PATTERN AND PRECIPITATION REGIME

Himalayan Glaciers: An Overview....

The Himalayan range, known as water tower of Asia, consists of a number of glaciers and houses hundreds of small and large glacial lakes. The glaciers in the Indian Himalaya have been classified on the basis of two first order river basins, namely; the Indus and the Ganga which further have been sub-divided up to fifth order basins (Raina and Srivastava, 2008). As per the inventory, there are 9,575 glaciers in the Indian part of Himalaya out of which Indus Basin houses 7,997 (total area: 33,679 Km²) and the Ganga Basin (including the Brahmaputra basin) has 1,578 (total area: 3,787 Km²) glaciers (Table 1). The total area under glaciers located in five states of India (namely, Jammu and Kashmir, Himachal Pradesh, Uttarakhand, Sikkim and Arunachal Pradesh) is estimated as 37,466 Km² (Kaul, 1999; Raina and Srivastava, 2008). The highest numbers of glaciers (3,136) are in the Jammu & Kashmir state which covers approximately 13% of the state's area. Garhwal region of Uttarakhand state has 917 glaciers, Sikkim has 450 glaciers (912 Km²) and Arunachal Pradesh has 162 glaciers covering 228 Km². In the Indus basin, 68% of the glaciers have less than 1 Km² area. In Ganga and Brahmaputra basins, 42% and 68% of the glaciers, respectively, have less than 1 Km² of area. There are 60 glaciers in the Ganga basin, 191 glaciers in the Indus basin and 13 glaciers in the Brahmaputra basin having area greater than 10 Km² (Kaul, 1999; Raina and Srivastava, 2008).

Table 1. Distribution of Glaciers in Indus and Ganga Basin

Basin	No. of glaciers	Glacier coved Area (Km ²)	Ice volume (Km ³)
A. Indus Basin			
Ravi	172	193	8.04
Chenab	1,278	3,059	206.30
Jhelum	133	94	3.30
Beas	277	579	36.93
Satluj	926	635	34.95
Upper Indus	1,796	8,370	73.58
Shyok	2,454	10,810	NA
Nubra	204	1,536	NA
Gilgit	535	8,240	NA
Kishenganga	222	163	NA
Total	7,997	33,679	363.10
B. Ganga Basin			
Yamuna	52	144	12.20
Bhagirathi	238	755	67.02
Alaknanda	407	1,229	86.38
Ghaghra	271	729	43.77
Tista	449	706	39.61
Brahmputra	161	223	10.00
Total	1578	2786	258.98

(Source: Kaul, 1999; Raina and Srivastava, 2008)

Depending on the latitude, precipitation pattern and the local climatic conditions, the glaciers descend to about 3700 m in the eastern Kashmir, 4000 m in the central Himalaya and 4500 m in eastern Himalaya. Variation in Equilibrium Line Altitude (ELA), which marks the lowest elevation at which glaciers can exist, effect the combined effect of latitude, precipitation and temperature. On an average, a latitudinal difference of 1° in this area leads to 152 m change in ELA. Glaciers at higher latitudes (e.g. in Kashmir Himalaya), show lower ELAs than the glaciers at lower latitudes (e.g. in Garhwal Himalaya). Thus latitudinal position, along with precipitation and micro climatic factors like aspect, topography and hypsography appears to have more effective influence on the position of ELA.

Recession pattern of Himalayan glaciers

Himalayan glaciers, largest outside of the polar region, are showing decline in snow cover and glacial retreat with variable rates during the last century, possibly due to the mixed influence of variable topography, temperature and snowfall regime. In Uttarakhand Gangotri glacier which was earlier receding at the rate of around 26 m/year between 1935 and 1971 has shown a gradual decline in the rate of recession. (17m/year between 1971 and 2004; 12m/year during 2004-2005). The rate of recession of Pindari glacier has come down to 6.5 m/year in comparison to earlier reported rate of 26m/year between 1996 and 2007. Similarly, the rate of recession of Milam glacier has been observed as 16.5 m/year in the last 150 years. Glacier recession rates of important glaciers of western Himalaya are given in Table 2. Between 1962 and 1995, volume of ice in the Dokriani glacier has reduced by approximately 20% and the frontal area has vacated by 10%, whereas the glacier has receded by 550 m with an average rate of 16.6 m/yr. However, the yearly monitoring of trunk position of the glacier during 1991–1995 revealed an average rate of recession of 17.4 m/yr and has vacated an area of 3957 m².

In Zaskar and Great Himalayan ranges of Jammu & Kashmir, most of the glaciers are receding, and the change in glacier volume range between 3.6-97%. The Nubra valley in Jammu & Kashmir houses 114 small sized glaciers varying between less than 5 Km to 10 Km in length; these glaciers have not shown much change in their length and area during the period 1989-2001. However, variable decline in the glacial area of Siachin glacier has been observed. Recession pattern of 466 glaciers in the Chenab, Parbati and Baspa basins of Western Himalayas has resulted into reduction in the total glacial area from 2077 Km² to 1628 Km² and an overall deglaciation of 21% during 1962-2008 (INCCA Report #2). The report says that most of the glaciers in western Himalaya are receding (expect a few in J&K state, which do not show any change or are advancing). The processes controlling the rate of retreat of the glaciers are complex and vary with location and topography of the area. However, the impact of rising temperature and declining snowfall on glacier mass balance has been reflected in many studies, which require long term database for a definite climate change impact assessment.

Precipitation system over Himalayan glacier

Glaciers of the Himalayan region have been classified as summer accumulation type as collection and extraction occur almost simultaneously during the summer. Glaciers are sustained by the Indian summer monsoon system, rooted in the larger atmospheric phenomenon, the Inter-Tropical Convergence Zone (ITCZ) that arises because of the seasonal temperature and pressure difference in the Northern and Southern hemispheres (Fig.1). In particular, the temperature deviation between the Himalaya, Tibet massif and the surrounding oceans drives the summer monsoon system. The winter-spring snow cover over the Himalaya and Tibet plateau plays an important role in the depletion of this heat difference. The extreme western and the Trans-Himalaya regions receive maximum precipitation during the winter months (December-March) due to the westerly disturbances that originate in the Mediterranean, Caspian and Black seas. These varying weather systems give rise to precipitation deviation along and across the Himalaya. Their relative importance in bringing moisture to Himalaya and the Trans-Himalaya has played an important role in defining the spatial and temporal distribution of glaciers. During winter months, the mid-latitude disturbances move to their lowest latitudes and travel across the north and central parts of India in a phased manner from west to east, disturbing the normal features of circulation and results in snow fall in the higher elevations and winter rainfall in the plains of northern and central India. In the east, summer monsoon precipitation dominates, while in the west, westerly circulation and cyclonic storms contribute about two-third of the annual precipitation as high altitude snowfall

Himalayan Glaciers: An Overview....

during winter, with the remaining one-third resulting from summer precipitation mainly due to monsoon circulation.

Table 2: Recession rate of selected glaciers of Indian Himalayan region

Name of the Glacier	State	Retreat of snout (m)	Period of observation	Trend	Avg. retreat rate (m/yr)
Gangotri	Uttarakhand	954.14	1935-1971	Retreating	26.50
		564.99	1971-2004	--do--	17.15
		12.10	2004-2005	--do--	12.10
Pindari	Uttarakhand	1600	1845-1906	Retreating	26.23
		1040	1906-1958	--do--	20.0
		61	1958-1996	--do--	7.62
		262	1966-2007	--do--	6.39
Dokriani	Uttarakhand	550	1962-1995	Retreating	16.67
Durung Drung	Jammu & Kashmir	-	2004-2007	No Change	-
Kangriz	Jammu & Kashmir	-	1913-2007	No Change	-
Siachin	Jammu & Kashmir	NA	1862-1909	Advancing	15.42
		--do--	1909-1929	Retreating	2.5
		--do--	1929-1958	Retreating	14
		-	1958-1985	No Change	-
		NA	1985-2004	Retreating	3
-	2004-2005	No change	-		

NA: Data Not Available (Source: MoEF, INCCA Report; 2010)

The complex precipitation patterns and their interaction with the topographic, geological and biological systems have produced varied snow climatic zones in the Himalaya. Annual winter snowfall varies from 100 to 1600 cm with the highest snowfall occurring in the Pir Panjal range and higher ranges receive progressively lesser snowfall. Glaciers in the eastern Himalaya receive most of their precipitation during the summer, SW monsoon months (June-September), coinciding with the melting season. Under the influence of NE monsoon, some precipitation is received in the winter months and the Trans Himalaya experience semi-desert-like conditions. There is a large variation in the annual average precipitation in the Himalayas. The southern slopes of the Eastern Himalayas experience some of the highest annual rainfall of the total on Earth while other areas receive as low as 50 mm a year. Mean daily air temperature is low in January and rises during the pre-monsoon period (February to May) with maximum daily temperature in late May or early June while post-monsoon (October to January) mean daily air temperatures generally decline.

From various studies it is clear that most of the part of Himalaya has been showing irregular temperature since last 5-6 decades and snowfall precipitation during winter has reduced. The Northern Hemisphere which contains nearly 98% of the seasonal snow cover (Fig. 2) is witnessing a long-term decreasing trend. The decline in snow cover has been rapid particularly over Asia and the Himalaya-Tibet Plateau region. This implies that there has been significant decline in storage of frozen water in Himalaya which is further likely to get accentuated in the course of the time (IPCC, 2007c).

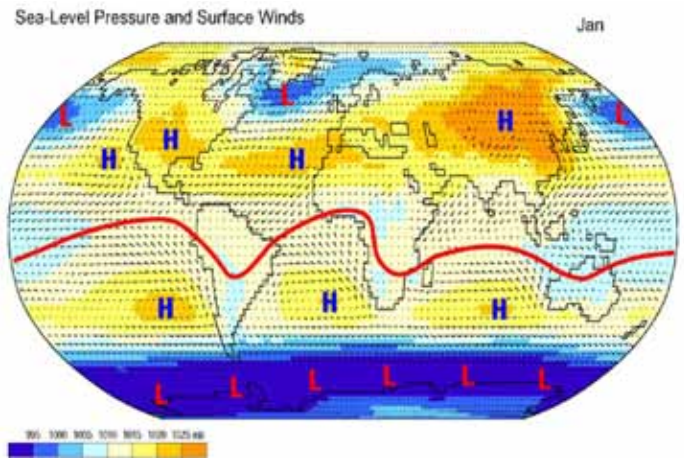


Fig 1. The ITCZ moves farther away from the equator during the Northern summer than the Southern one due to the North-heavy arrangement of the continents

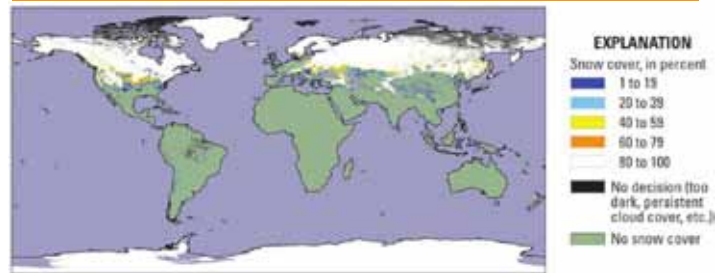


Fig. 2. Moderate Resolution Imaging Spectroradiometer (MODIS) monthly snow map with fractional snow cover for February 2004

Fig Source: MODIS Snow and Ice Project, NASA/Goddard Space Flight Center

The temperature and the precipitation regime (mainly dominated by the monsoon and westerlies) in Himalaya determine the space and terrestrial distribution of glaciers in Himalayan region. The orography and climatological set up of the region makes it vulnerable to global warming. The rise in temperature together with other forcing factors (such as feedback mechanisms, GHG emission, aerosol, etc.) are likely to impact the Himalayan cryosphere thereby adversely affecting the retreating pattern of glaciers, precipitation system of the region, seasonal river flows, and water availability in upstream and downstream regions. Therefore, understanding the interplay of the diverse regional forcings on the global climate is very essential to define the impact of climate change on the Himalayan cryosphere.

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Rajesh Joshi (dr.rajeshjoshi@gmail.com)
 GBPIHED, Kosi-Katarmal, Almora, 263 643

RUNOFF PROCESS OF SNOW AND GLACIER FED RIVER

Western Himalaya.....

Isotope technique is important and reliable method to understand the snow, glacier and river basin characteristics. Origin, age, distribution of water in a region, including the occurrence and recharge mechanism, and interconnection between groundwater bodies, can be easily studied using isotopes. In the context of snow and glaciers, scope of isotope is much wider. The problems related to snow/glacier melt runoff, ice dynamics (movement of glacier ice, accumulation rates of ice), age (residence time of snow/ice in the glacier) of glacier ice all along the glacier can be studied using the isotopes. It provide time index to study the snow, glacier, groundwater, and rainfall indices. Further, the information on the history of glacier and past climate can be obtained using isotopes. Because glaciers are very sensitive to climate change, they are considered an important source of palaeoclimatic data. Now a days, isotope techniques are used frequently in the developed countries while their use in the developing countries is emerging slowly.

In order to understand the isotopic characteristics, the Beas River located in western Himalaya is selected for the study. Two tributaries of River Beas, originating from Beas Kund and Rohtang pass at the altitudes of 3505 m and 3977 m, respectively, meet at Palchan, which is 10 km above the Manali and flows for approximate 470 kilometres to Sutlej River at place called Hari Ka Doon. There are many hydroelectric projects on the Beas River which are in operational mode and some projects are under construction.

Further to develop isotope signature of different type of water such as precipitation (rainfall and snow), glacier melt, river water and groundwater samples were collected at upstream of Manali town. These samples were analysed for $\delta^{18}\text{O}$ and δD using Dual Inlet Isotope Ratio Mass Spectrometer. The CO_2 equilibration method was used to determine $\delta^{18}\text{O}$, while the δD equilibration method with HOKKO beads was used to determine δD following the standard procedure (Kumar et al., 2010). The overall precision, based on ten points of repeated measurements of each sample, was within $\pm 0.1\text{‰}$ for $\delta^{18}\text{O}$ and $\pm 1\text{‰}$ for δD .

The precipitation samples were collected daily (on event basis) at Manali in Beas River basin. The rainfall samples were analysed by giving the special focus on seasonal variation of isotopic signature.

Fig. 1 shows the variation in isotopic composition of rainfall during the different seasons. In premonsoon season (April to June), isotopically enriched rainfall is being observed, whereas in postmonsoon and winter season, isotopic signatures are slightly depleted. The most depleted isotopic values ($\delta^{18}\text{O}$) of rainfall are observed in monsoon season, which are -14.16‰ , -15.57‰ , -15.43‰ for July, August and September, respectively. Variation in isotopic signature of precipitation becomes a unique feature and useful to understand the hydrological processes of river. The monsoonal rainfall isotopic values reveal that source of rainfall for these months is south west monsoon vapours, which further depleted due to amount and altitude effect (Rai et al., 2009). The $\delta^{18}\text{O}$ of fresh snow samples is -10.05‰ which represent the snowmelt signature of the basin.

Analysis of river water indicates that the isotopic values ($\delta^{18}\text{O}$) of river water also varies temporally. The $\delta^{18}\text{O}$ of Beas River water carries enriched signature for premonsoon season (April to June) at Manali. The abrupt depletion is being observed in Beas River water sample of monsoon season (July to September). The sudden depletion of $\delta^{18}\text{O}$ in monsoon season is caused due to rain derived runoff joining to river (Figure 1). There is an enrichment in isotopic values ($\delta^{18}\text{O}$) for postmonsoon and winter season (October to March) in comparison to premonsoon season. These values range from -11.44‰ (November) to -9.73‰ (January). During post monsoon season, rainfall amount is not significant in the basin (Fig. 1), and air temperature also falls at high altitude region. Therefore the melting of snow/glacier becomes insignificant in river flow. That is why, river is mainly sustained by the groundwater (baseflow) during postmonsoon and winter season (Ahluwalia et al., 2013).

Based on the isotopic signature developed for different component, an attempt was also made to compute the estimation of

different component (Snow/glacier melt runoff, rainfall derived runoff, groundwater) in Beas River. The computed maximum snow/glacier

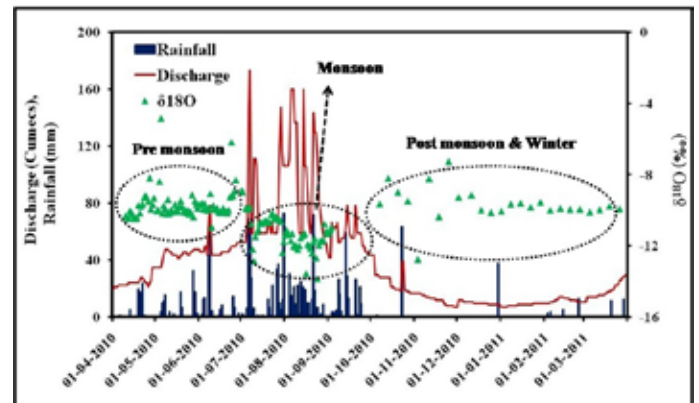


Fig. 1: Variation of stream discharge and its $\delta^{18}\text{O}$ composition with rainfall.

ice melt contribution to the river runoff was up to 83% (April) in the starting of summer season. For the monsoon season, snow/glacier ice melt was varied between 42% (September) to 62% (July). In the post monsoon and winter season, it goes from 32% in October to 55% in March. On an average, it is 50% of the total annual discharge by using isotopic technique in the river Beas at Manali site. Stable isotope composition (deuterium [δD] and oxygen 18 [$\delta^{18}\text{O}$]) of water have successfully been used as naturally occurring hydrologic tracers to constrain estimates of the contributions of different water sources to stream flow, including snowmelt, glaciers meltwater, and groundwater base flow. Glaciers store water over a range of temporal scales with important implications for downstream human and natural systems. Assessment of the contribution of glacial meltwater runoff to total watershed discharge is an essential part of climate risk assessment and sustainable water management in glacierized watersheds. Although there have been a number of important hydrological investigations across the world that have employed isotope tracers, the use of isotopic tracers in studies to identify contributions of rain, snowmelt, groundwater baseflow, and glacier meltwater to stream flow in alpine catchments has received little attention. Potential effects of climate variability, loss of alpine glaciers, and forest disturbances on stream flow are highly uncertain. Stable isotope tracers technique can play a prominent role in reducing this uncertainty.

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S.P. Rai¹ (spr@nih.ernet.in), Rajeev S. Ahluwalia² and Sanjay K. Jain¹

¹National Institute of Hydrology, Roorkee, India
²Centre of Glaciology, WIHG, Dehradun, India



CLIMATE CHANGE IMPACTS ON GLACIERS

Sikkim Himalaya.....

The Himalaya is source of fresh water supply to many river systems of Indian sub-continent including the major river systems Indus, Ganges and Brahmaputra. Various studies suggest that most of Himalayan glaciers are shrinking due to global warming. The process of recession of glacier is self-regulating mechanism controlled by the glacier's shape, geometry, bedrock topography and climate of the area. Change in snout position varies for different glaciers and processes are rather irregular in amount, rate and time of occurrence. In North-Eastern part of Indian Himalaya 610 glaciers have been inventorized those drain into Teesta and Brahmaputra basins. Teesta basin houses 449 glaciers having glacier area 706 Km² with ice volume 39.61 Km³ (Raina and Srivastava, 2008). There are five main glacier basins in Sikkim Himalaya, namely; East Rathong, Rangpo, Taung, Changme Khangpu and Zemu. Zemu glacier, the largest glacier in Eastern Himalaya with 20 Km length having a total surface area about 42 Km², originates from the eastern slope of World's third highest mountain peak Khangchendzonga. The basin covered area of Zemu glacier is 359.85 Km² with ice volume of 15.05 Km³. From 1909 to 2005, Zemu glacier has retreated approximately 863 m (Table 1). Like other glaciers, supra glacier lakes have been noticed on Zemu glacier in its ablation zone. Such lakes drain out due to climatic fluctuations and give rise to flash flood or glacial lake outburst flood (GLOF); one of such incident was reported in of August, 1965.

Table 1. Retreat pattern of Zemu glacier during last 100 years

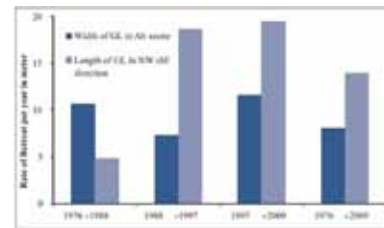
Period	Total retreat (m)	Annual retreat (m)
1903-1909	Nil	Nil
1909-1965	440	7.85
1965-1975	320	32.0
1975-1986	78	7.09
1986-2005	79	4.15

(Source: Raina and Srivastava, 2008)

East Rathong is another important glacier in West Sikkim being the source of river Rangit, the largest tributary of river Teesta. This glacier is 7.49 Km long and has 16.2 Km² area with 3.02 Km³ ice volume. During 1976-2009 this glacier was found retreating with average rate of 13.52 m/year. However, during 1997-2009 the rate of retreat was estimated as 19.5 m/year. The loss in length and width of Rathong glacier, as monitored by Department of Science and Technology, Govt. of Sikkim, is depicted in Fig. 1 which indicate possible role of climate in regulating the retreat pattern of the glacier.

Snowfall plays an important role in maintaining the climate and health of a glacier. The seasonal snowfall pattern has been monitored by scientists for two sub river basin of Sikkim Himalaya, namely Teesta and Rangit basins. Teesta sub basin has higher snow cover due to high concentration of glaciers and higher altitude in comparison to Rangit basin. In both the basins, snow accumulation starts from November and reaches to its peak in February. During summer months this region also receives snow precipitation because of the locational advantageous. This suggests different snow accumulation and ablation pattern in Teesta and Rangit basin of Sikkim.

Changes in climate leads to high melting, formation and enlargement of glacial lakes; due to this the lake increases in extent and water storage capacity. When such situation occurs it leads to possibility of sudden discharge of large volume of water and debris from moraine bound areas of lakes known as GLOF. Remote sensing based hazard assessment carried by NRSC, ISRO observed 320 glacial lakes in Sikkim Himalaya, the glacial lake hazard vulnerability study for Shako Cho lake in Sikkim Himalaya shows a high risk of potential for GLOF. Another study of ISRO confirms 1.9 km retreat of South Lhonak glacier during 1962-2008 and formation of moraine dammed glacial lake at the snout of glacier (Raj et al., 2013). The first occurrence of a lake was marked



(Adopted from Luitel et al., 2012)

Fig. 1. Rate of retreat of East Rathong glacier

in 1977 using satellite data. In that year, the lake was observed as 17.54 ha and attached to the glacier terminus. The remapping of the lake in year 1989, 2002 and 2008 showed lake area increased to 81.1 ha in 31 years (1977-2008). The depth of the lake was estimated around 20 m with a real extent 98.7 ha, and the volume of 19.7 million m³. High value of outburst probability (42%) and lake volume was estimated together with very high peak discharge (586 m³/s); with this estimated rate of discharge, a huge flash flood could occur in the downstream. Regular monitoring of potential glacial lakes with early warning system is required to mitigate the impacts of GLOF incidents in Sikkim Himalaya.

Table 2. Lake area and retreat of the South Lhonak glacier

Year	Lake Area (ha)	Period	Retreat glacier (m)
1977	17.54	1962-1977	675.3
1989	37.32	1977-1989	443.8
2002	78.95	1989-2002	511.4
2008	98.73	2002-2008	310.5
	Total retreat	1962-2008	1941

(Source: Raj et al., 2013)

Sikkim glaciers are located at low latitude and high elevation as compare to Western Himalayan glaciers. The elevation of the glaciers ranges between 4500-8000 m, therefore, the individual glacier has the different characteristics like slope, aspect, size, length, width, depth etc. Hence, while the small glaciers like East Rathong has shown retreat, but glaciers of large dimensions like Zemu Glacier have not shown any significant response to global warming. Climate change has influenced the glaciers and glacial environment in Indian Himalayan Region which has been witness with several studies across the Himalaya. Though retreat of glacier is a natural process but climate change has further enhanced this process. However, the main impact of climate change on glacier is evacuation of glacial area and melting on a fast rate, generating huge sediment load. Formation of supraglacial and glacial lake has also increased from last few decades. These lakes could be considered as potential hazardous sites for GLOF. To understand changes in glacial regime a long-term and continuous monitoring is required to establish the factual relation between climate change and glacial melt.

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Varun Joshi (varunj63@gmail.com)

Guru Gobind Singh Indraprastha University
Dwarka, New Delhi



HIMALAYAN GLACIERS

Research Programmes.....

Cryosphere Studies in Himalaya (Ministry of Earth Sciences, Govt of India)



The Cryosphere is the second largest component of the climate system, after the ocean, that stores about 75% of the world's freshwater. In terms of the ice mass and its heat capacity, therefore, it plays a significant role in the global climate. The Himalaya forms the most important concentration of snow covered region outside the polar region. The Himalayan glaciers are highly sensitive to the on-going warming. The detailed glacier inventory of Indian Himalayas (GSI, SAC) indicates presence of 9579 glaciers in the Himalaya, some of which form the perennial source of major rivers. Changes in glaciers are one of the clearest indicators of alterations in regional climate, since they are governed by changes in accumulation (from snowfall) and ablation (by melting of ice). The difference between accumulation and ablation or the mass balance is crucial to the health of a glacier.

Objectives of the Programme -

1. To study the dynamics and the rate of change in glaciers to understand its impact on hydrology, ecology and climate;
2. To assess the climate change using ice as an archive of information on past climate and its future implications.
3. To study the biogeochemical aspects of Himalayan ice and compare it with the polar environment.

More details on - <http://moes.gov.in/programmes/cryosphere-studies-himalaya>

Himalayan Glaciology (Department of Science & Technology, Govt of India)



Under "Extra Mural Research Funding (Individual Centric)" scheme of Science and Engineering Research Board, Department of Science & Technology, Govt of India, this theme has separate Project Advisory Committee. Individual centric competitive mode of funding is provided under this scheme to support potential scientists for undertaking research. Proposals can be submitted throughout the year.

More details are available at <http://serb.gov.in/emr.php>.

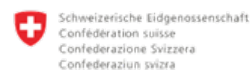


Field Observatory
Photo Credit: Dr. H.S. Negi

Indo-Swiss Capacity Building Programme on Himalayan Glaciology



The Indo-Swiss Capacity Building Programme on Himalayan Glaciology has been conceptualized under Indian Himalayas Climate Adaptation Programme (IHCAP) jointly by Swiss Agency for Development and Cooperation (SDC) and Climate Change Programme of Department of Science & Technology, Government of India. Indo-Swiss Capacity Building Programme on Himalayan Glaciology and Related Areas was designed and launched with the aim of training 25 glaciologists envisaged under NMSHE. The Capacity Building Programme as envisaged at present consists of Level I and Level II and was hosted by Jawaharlal Nehru University (JNU), New Delhi since April 2013.



Swiss Agency for Development and Cooperation SDC



Level I of the Indo-Swiss Capacity Building programme consists of class room teaching and exercises which are jointly conducted by faculties from Swiss and Indian Universities/Institutions. Based on assessment, a subset of these students is selected for the Level II training programme. Level II training programme consists of classroom teaching and field exercises at ChhotaShigri glacier in Himachal Pradesh (HP). The Capacity Building Programme contributes towards strengthening of institutional and human capacities in the field of glaciology and related areas in India.

In 2013 and 2014 programmes, 52 researchers were trained in the basics of glaciology and related areas (Level 1). Out of these, 27 researchers completed advanced teaching and field work (Level 2) during 2013 –2015.

More details on - <http://www.ihcap.in>

Innovations/Discoveries in Science April - June 2015

India

- Researchers at the Tata Institute of Fundamental Research, Mumbai and Institute for Plasma Research, Gandhi Nagar have fashioned bacteria to emit intense, hard x-ray radiation. They show that irradiating a glass slide coated with nanoparticle doped bacteria, turns the cellular material into hot, dense plasma, making this a useful table top X-ray source with several potential applications.
- Scientists at Central Institute of Medicinal and Aromatic Plants, Lucknow, Uttar Pradesh, India succeeded in whole genome sequencing of Holy basil or Tulsi.
- Ecologists found a new species of fish called *Pethia striata* in Western Ghats, Karnataka.



Pethia striata

- New Catfish Species *Glyptothorax senapatiensis* discovered in Manipur.

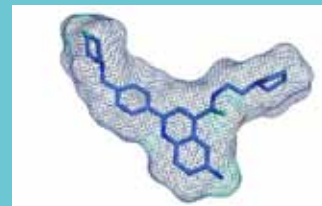


Glyptothorax senapatiensis

- Rare huntsman and jumping spiders have been discovered in the Western Ghats.
- Planet found between Mars and Jupiter has been named after India's chess legend Vishwanathan Anand as 4538 Vishyanand.
- Indian Space Research Organization successfully launched fourth navigation satellite Indian Regional Navigation Satellite System (IRNSS)-1D
- Airborne Warning and Control Systems (AWACS) has been launched by Govt. of India.
- New species of Geckos (type of lizard), discovered at the World Heritage Site of Hampi in Karnataka by herpetology researcher from Hyderabad, Aditya Srinivasulu.
- India on 9 April 2015 successfully test fired nuclear weapons-capable Dhanush missile from a ship, off the Odisha coast.

Worldwide

- Jean-Louis Magnard from The University of Lyon Saint-Etienne, France, and colleagues discovered have identified enzyme RhNUDX1 which plays a key role in producing the sweet fragrances in roses. This enzyme acts in the cytoplasm of cells located in the flowers' petals, generates the fragrant and well-known monoterpene geraniol, the primary part of rose oil.
- A novel anti-malarial compound DDD107498 that inhibits protein synthesis discovered by scientists of University of Dundee (Ian Gilbert, Head of Chemistry at the Drug Discovery Unit and his team). The compound was found to have all the attributes of an anti-malarial drug which extends to multiple lifecycle stages of the Plasmodium parasite.



DDD107498

- Tripp, curator of botany for the University of Colorado Museum of Natural History and Assistant Professor of Ecology and evolutionary biology discovered two species of lichens *Candelariella clarkii* and *Lecidea hoganii*. They are distinctive by their morphology, anatomy and DNA. One has a charismatic yellowish-green color while the other is distinctive by its conspicuously raised fruiting bodies that are tinged pink on the inside.
- Rick Overson and Brian Fisher from the California Academy of Sciences have discovered six new species of strange subterranean ants from the genus *Prionopelta* in Madagascar and Seychelles.
- Researchers from National Oceanic and Atmospheric Administration (NOAA), US discovered the world's first fully farm-blooded fish species names Opah or moonfish. It circulates heated blood throughout its body much like mammals and birds, giving it a competitive advantage in the cold ocean depths.
- Researchers at the Massachusetts General Hospital (MGH) of USA developed a smart phone-based device, called as D3 (Digital Diffraction Diagnosis) System, which performs rapid and accurate molecular diagnosis of cancerous tumors.



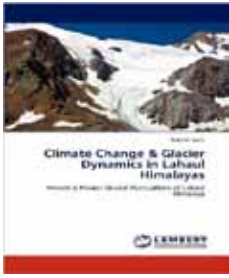
Opah or Moon fish

Vasudha Agnihotri (vasudha@gbpihed.nic.in)
Scientist-C
GBPIHED, Kosi-Katarmal Almora-263 643
Uttarakhand

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Books on Himalayan Glaciers

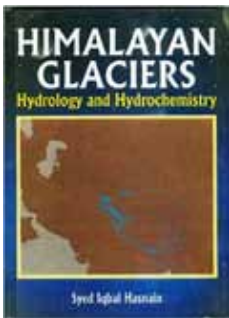


Climate Change & Glacier Dynamics in Lahaul Himalayas

The book is result of primary field work during the "Snow & Glacier Monitoring" project in Lahaul Himalaya, where complex behavior of alpine glaciers led an idea to work out this book.

Authored by: Rakesh Saini

Published by: LAP Lambert Academic Publishing| Year: 2012

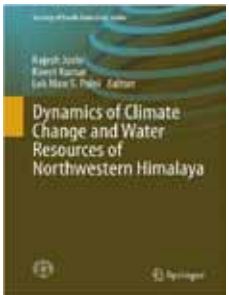


Himalayan Glaciers: Hydrology and Hydrochemistry

The glacier hydrology and hydrochemistry of the Himalayan/ Karakoram mountain ranges. The majority of glaciers, in the largest mountain ranges of the world, are debris-covered and are unique in that they depend on precipitation received both in summer and winter, making them very sensitive to temperature variations than most other glaciers.

Authored by: Syed Iqbal Haswain

Published by: Allied Publishers Pvt. Ltd | Year: 2002

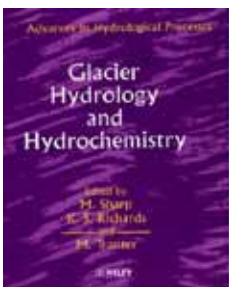


Dynamics of Climate Change and Water Resources of Northwestern Himalaya

This book is about the Himalayan ranges as a source of fresh water supply and a perennial store house of ice, snow and permafrost as well as a vast repository of rich biodiversity, in the light of climate change. This book Highlights the dynamics of snow and glaciers in the northwestern Himalayas, assessment of climate change patterns, and the consequences of changes and flow regime in order to understand the behaviour of climate change in the northwestern Himalayas.

Authored by: Rajesh Joshi, Kireet Kumar, Lok Man S Palni

Published by: Springer | Year: 2015



Glacier Hydrology and Hydrochemistry

The last decade has been a period of rapid advances in glacier hydrology and hydrochemistry. These have resulted from the application of new technologies to the direct observation of englacial and subglacial drainage systems via boreholes, from theoretical advances and from increased interactions between fieldworkers and modellers.

Authored/Edited by: M. Sharp, Keith S. Richards, M. Tranter

Published by: : Wiley-Blackwell | Year: 2002

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Forthcoming Events ...

International

2-14 JANUARY 2016

"1st Annual International Conference on BioScience and Biotechnology – 2016 (BioTech 2016)"

Venue: Colombo, Sri Lanka

6 JANUARY 2016

"RW- 4th International Conference on Civil and Environmental Engineering (I2C2E)"

Venue: Istanbul, Turkey

3 JANUARY 2016

"Academics World-14th International Conference on Environmental Science and Development (ICESD)"

Venue: Brussels, Belgium

3 JANUARY 2016

"ISERD – 16th International Conference on Environment and Natural Science (ICENS)"

Venue: : Barcelona, Spain

National

13-14 JANUARY 2016

"National Conference on E-waste Management"

Venue: Jamshedpur, Jharkhand, India

21-23 JANUARY 2016

"Biennial international conference on Power and Energy Systems: Towards Sustainable Energy (PESTSE2016)"

Venue: Bengaluru, Karnataka, India

28-31 JANUARY 2016

"International Livestock Conference and Expo 23rd Annual Convention of ISAPM "

Venue: Hyderabad, AP/Telangana, India