Glaciers and Glacial Lakes under Changing Climate in Pakistan

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Abstract

The Himalayas, Karakoram and Hindukush lofty mountain ranges meet each other in Pakistan hosting more than 5000 glaciers in Pakistani geographical limits which feed snow/ice melt water to the Indus River System together with summer monsoon. Due to global warming, frozen water resources have been losing their reserves at an unprecedented rate, not only, reducing the ice mass but increasing the number and extent of glacial lakes. Glacial Lake Outburst Floods (GLOFs) are the devastating mountain hazards which have started occurring with increased frequency during the recent years. An alarming increasing temperature trend in northern parts of Pakistan during the last decade which surpassed all the past records has enhanced the snow/ice melt rate and given rise to lake formation process some of which are potentially dangerous for outburst. Due to increase in temperature, the snowline has shifted upward causing migration of biodiversity and lower elevation glaciers have started melting faster. Snow used to occur now in late winter and disappears in early summer, hence, reducing the residency period to complete metamorphic processes for conversion into ice. Ponding of melt water underneath and around the terminal moraine need continuous monitoring to understand their supraglacial behavior and to assess the potential danger of outburst on scientific basis for development of an early warning mechanism. An initiative of The Mountain Institute (TMI) in collaboration of ICIMOD toward Global Glacial Lake Partnership is a step forward to manage such lakes to mitigate the potential losses due to their outburst.

Key Words: Glaciers, Glacial Lakes, Snowline Shift, Passu Lake, Global Glacial Lake Partnership

Introduction

Pakistan is located in South Asia between 24°-37°N latitude and 66°-77°E. It hosts the triple point (junction) of three world famous mountain rages Himalayas, Karakoram and Hindukush in its north. There are more than 5000 glaciers feeding the Indus from 10 sub-basins through different tributaries ranging from few tens of meters to more than 70 km long. According to glacier inventory developed by ICIMOD in 2005 with the help of RS/GIS techniques, over this glaciated domain, there are about 2500 glacial lakes formed due to glacier melt waters and 52 of them were declared potentially dangerous for Glacial Lake Outburst Flood (GLOF). The GLOF events are catastrophic as huge loads of debris and mud flows downstream sweeping the infrastructure, houses and crop-lands resulting in scores of life losses if it happens without any alert signal. For mountain population, GLOF is the greatest hazard which is being reinforced by climate change in terms of frequency and vulnerability. Booni Gole Glacier located near Chitral in Hindukush mountain range generated outburst flood in July 2010 triggered by monsoon downpour and caused huge erosive damage to agricultural land and human settlements along the flow channel. It used to store water under the terminus of the glacier and produce surge either by accelerated melting of snow/ice or by intense rainfall. Due to steep slope downstream, the carried loads of mud, debris including heavy boulders gain momentum and cause heavy losses to land, settlements and infrastructure. Passu lake outburst had also followed the similar mechanism in the past with the frequency of outburst at an irregular interval of 2 to 5 years. The scene of its damages is quite visible travelling from Karakoram Highway as Passu village is located along that highway. There is an increasing tendency of formation of new lakes and expansion of existing ones near the glaciers of the Himalayas and Hindukush as confirmed by the temporal comparison of satellite imagaries. Recently UNDP has taken an initiative to study two glacial lakes in Chitral and Gilgit by in-situ observations and remote sensing tools in association with local public and private organizations concerned with glacier monitoring and research. Hopefully, a warning system will be developed to save the lives of the people most likely exposed to that hazard. Experience of Bhutan may be replicated with certain modifications in accordance with organizational and social set up.

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Climate Change

Although there are both natural and anthropogenic reasons of climate change but latter is the most dominant with an ever increasing trend since the industrial revolution of 1940s. Population growth in developing countries, which makes about 70% of the comity of nations, has been too high putting an increased pressure on fixed natural resources and the compensation of increased demand for food and shelter through better socio-economic conditions. Increasing population and changing life style under economic transformation raised the level of anthropogenic contribution to climate change many folds as compared to always existing natural ones. Economic development at the cost of environmental degradation played very important role in producing drastic rise in global warming and hence changing the climate over the global and regional scales. Glaciers and icy surfaces are the most sensitive indicators of global warming which have shown their immediate response in terms of mass balance and contribution of melt water to the sea level rise. Accelerated melting of glaciers generates voluminous water accumulating in deeper pans giving rise to the formation of glacial lakes which continue to increase their size and hence water content. When the water accumulated in such lakes exceeds certain limit and develops enormous pressure on the retaining walls of the lakes, the weakest bank surrenders to outburst and whole of the volume of water rush down slope carrying debris and boulders. Such outburst floods are sudden in nature therefore inflict huge losses to downstream population, land and infrastructure. The reasons of climate change can be categorized as natural and anthropogenic while latter is dominating the former one.

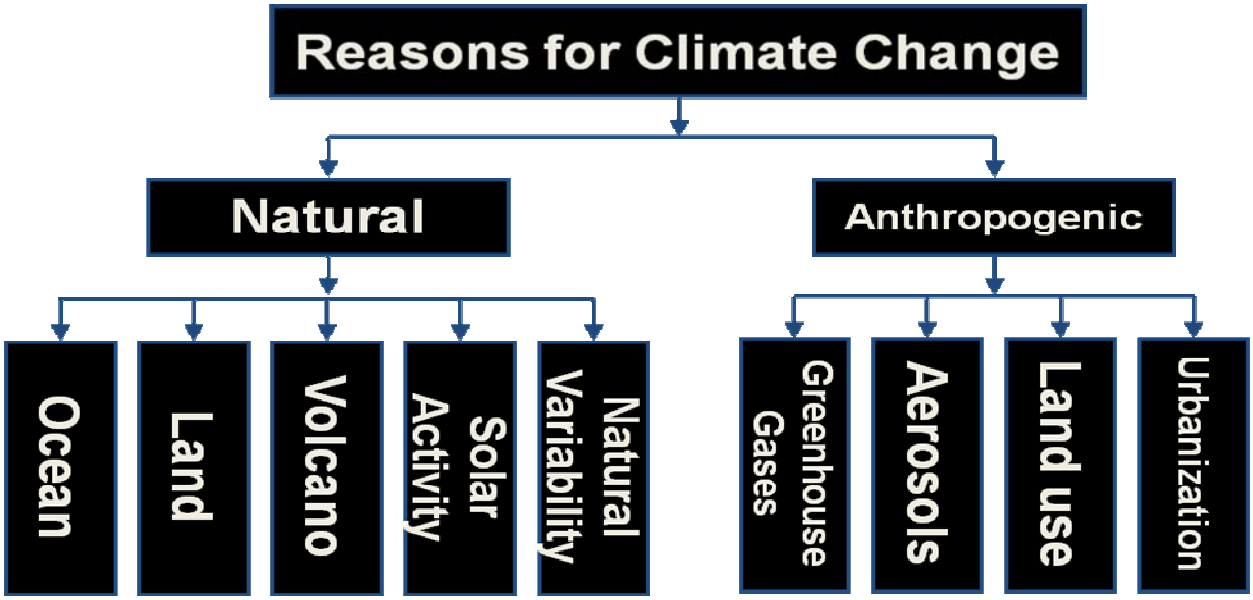

Figure 1: Organogram showing reasons of climate change both due to natural and anthropogenic (human) activities. After industrial revolution, anthropogenic reasons are predominantly held responsible for global warming and climate change.

Global warming due to human activities has been affecting all aspects of life posing serious challenges to the availability and utilization of natural resources. Rise in temperature registered during the first decade of 21st century has been two times higher than it was anticipated. According to World Meteorological Organization (WMO, 2011) statement on status of climate, the first decade (2001-2010) is the warmest decade recorded over the globe and 2010 ranked as the warmest year (+0.53°C) followed by 2005 (+0.52°C) and 1998 (0.52°C). Sixteen warmest years of the globe occurred during the last two decades.

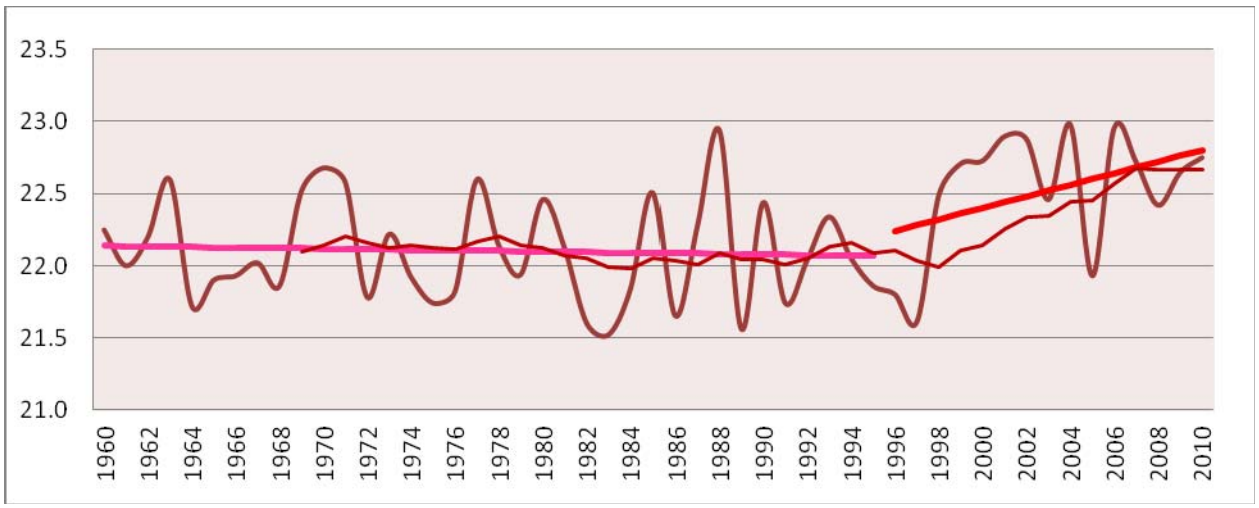

Figure 2: Graph showing temperature records of meteorological observatories (1500-2900 masl) located in northern mountains of Pakistan from 1961 to 2010. Last decade has shown a sharp rise. (Source: PMD)

Pakistan has no exception and warming trend in northern mountains is double as compared to the lower elevations. Sharp increase in temperature during last decade can be seen in Figure.1. A study conducted by Chaudhry et al., 2009 indicated that Pakistan experienced 0.76°C rise in temperature during last 40 years. However, the increase in temperature in the mountain environment hosting thousands of glaciers was recorded as 1.5°C during the same time period. Occurrence of precipitation in the form of rainfall upto 4000m above mean sea level is common feature in mountainous terrain where it was rare in the past and now snowfall seldom occur at these elevations. Due to changing climate, the precipitation pattern has erratic as there is general tendency of snow occurrence in the end of winter. During November to January, there was hardly any snowfall, but two consecutive spells of snow during last decade of February completed the total of the whole season. Such accumulation of snow at the end of the winter season does not stay longer and melt immediately when warming starts in March-April. Reduced residency period of snow does not allow the metamorphic processes to complete for conversion of snow into ice. They further pointed out that the frequency and persistence of heat waves in glacierized mountains has been increased drastically causing rapid melting and sudden discharge of bulk of water to terminal lakes of glaciers increasing the risk of outburst. Last decade has been the warmest over the globe and same is true for Pakistan. Warming trend was much higher than the projections made by GCMs and RCMs. For Pakistan 0.6°C rise in temperature was projected during 2001-2010 but it ended up with 0.93°C and northern mountain climate heated up to the level of 1.3°C which hosts the glaciers of Himalayas-Karakoram-Hindukush mountain ranges. Such signatures leave alarming signals of glacial lakes formation, their expansion and outburst flooding.

Snowline Shift

Snowline is the extent of down slope elevations upto which snow used to occur during the winter season. They are the regions where air temperatures drop below zero for an extended time period. A research study conducted by Rasul, et al., 2006 pointed out that snowline has risen up slope by about a 1 km during the last 25 years. They have also stated that the frequency, intensity as well duration of heat waves (High temperatures persisting for 10 consecutive days) have increased considerably in early summer season which triggered snow/ice melt floods downstream. They carried out isothermic analysis on pentad basis considering the march of 30C isotherm. Its upward movement with the passage of time marked the warming of low elevation thermal regime along the northern mountains. To confirm the research results, a survey was conducted interviewing the elders of the region who confirmed that in the past they used to receive heavy snowfalls in winter and doors of their houses used to remain shut for several days but they

experience generally rainfall in winter and seldom get light snow. This upward shift of snowline has caused massive migration of animal and plant species. Increasing trend of temperatures from lower elevation to higher one has not only resulted into shift in biodiversity but also started melting lower elevation glaciers at a much faster rate. Accelerated melting process has been giving rise to formation of visible, sub-glacial and superaglacial lakes in Himalayas, Karakoram and Hindukush glaciers.

Glacier Melting

Most of the world glaciers are subjected to depletion with a few exceptions (IPCC 2007) posing serious challenges to water security. Schroder et al., 2007 found that the loss of significant glaciers in Afghanistan and Pakistan may become more serious progressively unless warming generates greater marine evaporation that augments precipitation. The global retreat of glaciers is striking and interaction of atmosphere-cryosphere approach is appropriate to study the dynamic behaviour of glacial fluctuations (Kaser, 2001; Wagnon et al., 2001). Temperature analysis revealed that snowline has shifted about one kilometer higher than its location 25 years before resulting into upward migration of animals and plants species (Rasul, 2006). The effects of global warming in mountain areas are visibly manifested by shrinking of mountain glaciers and reduced snow cover duration (Barry, 2002). However, Hewitt (1998) reported the widespread expansion of large glaciers in the central Karakoram, accompanied by an exceptional number of glacier surges. Rasul et al., 2008 reported that the frequency and intensity of heat waves have significantly increased over the southern slopes of HKH along with an unprecedented increasing trend of annual mean temperatures over this heavily glacierized region. There are contrasting results from scientists about this region. The main reasons of this controversy include insufficient in-situ measurements, lack of data sharing and projection of small scale study over the entire region. However, all the scientists agree upon that low elevation glaciers are losing their ice mass at a faster rate and high elevation glaciers are comparatively stable or melting at a slow rate.

Most of the glaciers in Pakistan's geographic limits are debris covered and melting rate differs according to the thickness and type of debris in addition to the other factors such as their aspect, elevation etc. Pakistan Meteorological Department in collaboration with several international research groups have been recording in-situ meteorological data and glacier characteristics by high altitude Automatic Weather Stations (3000-5000amsl) installed over the glaciers and through field measurements since 2006. At present 10 large glaciers are being studied in Karakoram and 2 in Hindukush Range. However, the extensive research is focused on two major glaciers Baltoro (heavily debris covered) and Passu (relatively clear). There are 3 AWS installed over the Baltoro Glacier and two at Passu Glacier at an elevation ranging from 3000 to 5000 masl. The results of ablation experiments conducted on Baltoro Glacier are shown in Figure.2.

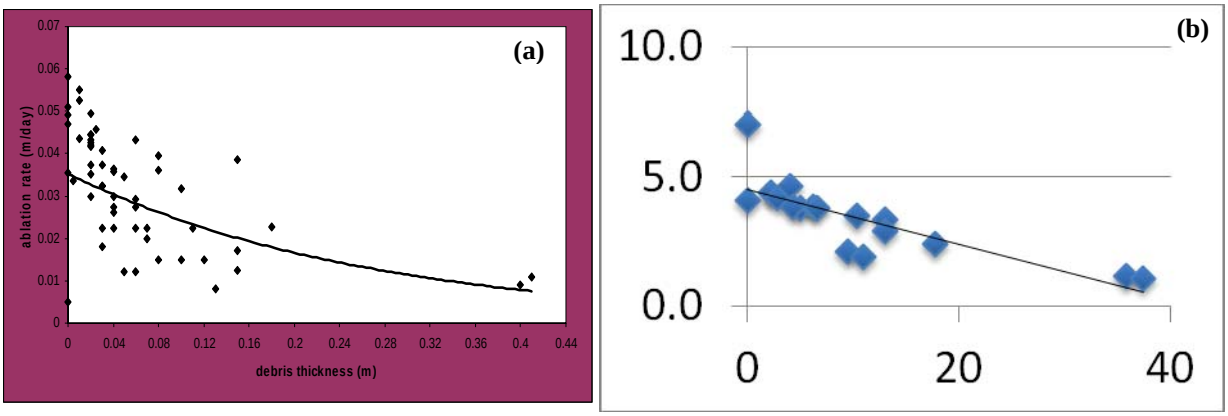

Figure 3: Ablation experiments conducted over the surface of Baltoro Glacier by installation of stakes form to study the melt rate per day against thickness of debris cover during summer (a) 2008 and (b) 2011.

During the field visits, it was noticed that huge amount of water was held under the ice bulk near the terminus (tongue) of many glaciers especially in case of Booni and Passu glaciers which used to cause mysterious outbursts in the past. As such large volume of water ever increasing was not visible, therefore caused serious damages downstream to human lives, settlements as well as infrastructure.

Recently a lake on Hinarchi Glacier grew rapidly in surface area as well as depth as shown in Figure 4 below. Field teams of PMD snapped the likely formation of lake in 2008 along the moraine. It was surprising that a small pond (about 100 m2) of water expanded into a big lake (1100 m2) when snapped the same site after three years in 2011. The samples collected from the terminal region of the Hinarchi Glacier in 2009 were analysed and results show a significant deposit of black carbon along with other contents of debris. Source of carbon may be the burning of wood in villages which deposit on icy surface due to low level inversion in the valley.

Figure 4: Growth of glacial lake along Hinarchi Glacier over a period of 3 years. Chemical analysis of samples taken from dirty ice surface showed significant proportion of black carbon in addition to moraine debris which might have caused accelerated melting of

Candidate Pilot Project in Pakistan at Passu Lake

According to ICIMOD glacier inventory published in 2005, there were 52 potentially dangerous lakes identified in Pakistani Himalayas-Karakoram-Hindukush mountain ranges. This assessment was made on the basis of satellite imageries using remote sensing and GIS techniques but none of them was studies on ground. Most of the identified lakes are located in an un-accessible terrain where logistics and frequent visits are not possible by normal means.

Introduction

Passu lake is a glacial lake located at the terminus of 38km long east-west oriented Passu Glacier which suffered at least two outbursts in last two decades destroying a bridge on Karakoram Highway (KKH) and several houses of Passu village settled on the right bank of the Hunza River (a tributary of the Indus which is partially blocked due to landslide dam January, 2010 called Ata Abad Lake).

Outburst Mechanism

Although the Passu Lake has natural drainage and apparently there is the least probability of its outburst but it happened mysteriously causing huge losses. On investigation, it was disclosed that under the fragmented tongue of the glacier, a large volume of water used to store which continues to discharge to the nearby lake under normal conditions. The generation of massive flow in last two events was associated with a 37mm rainfall event in 2 hours and due to accelerated snow/ice melt from a 14 days long heat wave (day highs > 33° C). During the past outburst events, very heavy loads

of mud as well as debris (mixed with huge boulders) flowed downstream under the action of gravity flow destroying the structures on the way.

Existing Monitoring

Pakistan Meteorological Department (PMD) has installed two AWS with the financial assistance of ICIMOD in the accumulation and ablation zones of the glacier to monitor the gradient flow and drift velocity along with the ablation rate assessment under different conditions. Hydrometeorological monitoring equipment has also been operational on the lake site since 2010 measuring lake discharge. There are two meteorological observatories located in the radius of 15 km around the Passu Lake at elevations 2815m and 2975m respectively above the mean sea level.

A Non-Governmental Organization known as FOCUS Humanitarian Assistance of the Agha Khan Foundation has been very active in the mountainous region and an effective connect for community involvement may become an active partner in GLOF monitoring and warning activity. The local community is also well organized on the individual village level as well as at the regional level. There are numerous young educated and well trained volunteers who are always willing to undertake any challenging task in proper supervision.

Data Sharing Policy

The Mountain Institute (TMI) and International Center for Integrated Mountain Area Development (ICIMOD) are planning an initiative on Global Glacial Lake Partnership which would serve as a common platform for data, knowledge and experience sharing. They may establish a pilot project with further installations for GLOF early warning system in Pakistan. Data sharing for modeling and operational activities may not be restricted rather the WMO mechanism may be followed among global community.

Conclusion and Recommendations

Following results can be drawn from the above discussion.

a. Pakistan has followed the similar warming trend as the global average during the past 100 years rather northern mountains housing the Himalayan-Karakoram-Hindukush glaciers have retained more heat that the low elevation plains.

b. Last decade was the warmest one in Pakistan with 0.93C rise in temperature as compared to 1971-2000 long term average. High mountain climate was even warmer than the national average by additional 0.4C. This rise was 75% more than that was projected for Pakistan during the decade 2001-2010.

c. Snowline has been shifting rapidly uphill causing the biodiversity to migrate and precipitation in the form of rainfall instead of snowfall. Such up-rise of thermal regime has started melting the low elevation glaciers at a faster rate. As a result the formation of new glacial lakes and expansion of existing lakes to the danger of outburst flood has increased.

d. Supra- and sub glacial lakes have been showing the greater potential of outburst due to the addition of glacier melt water and rainfall. Their monitoring is more serious concern as they continue discharging and accumulating water in an irregular and invisible manner. The monitoring of terminal lakes is comparatively easy.

e. In general, low elevation glaciers up to 4500 masl have been losing their ice mass at a much faster rate above that elevation either the melt rate is slow or glaciers or stable. There are a few examples of advancing glaciers but only satellite imageries will not prove it until mass balance shows positive signs.

f. Most of the Pakistani glaciers are debris covered and thickness of debris layer is inversely related to the ice melt rate. Lower elevation glaciers have large coverage of debris that higher ones.

Debris cover poses several challenges to remote sensing assessment and on field measurements to study different characteristics of glacial dynamics.

g. Signs of black carbon have been traced on lower terminus of the valley glaciers adding the acceleration to the melting process. Source of that carbon may be wood burning in the nearby villages for cooking and heating. Valley temperature inversion, which commonly prevails, helps smoke to deposit on terminal ice.

h. Increased danger of Glacial Lake Outburst Floods (GLOFs) and extreme water cycle variability demand an organized approach on global and regional scales replicating knowledge, experience and success stories of one place to another. Concerned organizations should build their capacity to increase the density of glacier/lake monitoring network, refine monitoring techniques, follow innovative research methodology and construct resilient infrastructure as well as developing early warning system.

i. Global community must mobilize the resources for initiatives to address the GLOF issues and other water related disasters for holistic disaster risk reduction. An integrated approach would not only help to prevent disasters but also ensure sustainable Green Growth with combination of White and Blue.

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