Climate Change and Mountaineering in Nepal: Issues and Challenges

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Abstract

Mountaineering is an adventure tourism that has a significant economic contribution to Nepal. The mountain environment, especially the high altitude (>3000m) *areas where major mountaineering activities happen, is considered to be highly impacted by current and emerging issues of climate change through different types of natural hazards. Climate change has direct and indirect impacts on the mountain environment. The glaciers are shrinking (nearly by* 15% *in the last half a century), and the glacial lakes are increasing* (25% *from* 1970s-2017). *The number of snow and rock avalanches are also increasing with the increase in intensities of the one-day rainfalls and increasing temperature. The rock falls, avalanches, GLOFs, and permafrost degradations are the potential threats for the mountaineering activities that can destroy the infrastructures, trekking trails, and resulting the demise of mountain climbers. The unpredictability of weather has cost a lot of lives of tourists. We underline a need of effective planning and perspectives for upscaling the mountaineering business with consideration of climate change.*

Keywords: Avalanche, glacial lakes, periglacial environment, mountaineering

Introduction

Mountains have been a major attraction of tourists in the world. In 2016, 8,176 climbers were given permission by the Department of Tourism and Nepal Mountaineering Association (MoCTCA, 2018) in Nepal. The mountains, however, have been extremely vulnerable to a changing climate and extreme events in recent decades. Recently, Ballesteros Cánovas et al. (2018) have presented evidences that the warming observed in recent decades has been accompanied by increased snow avalanche frequencies in the Western Indian

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Himalaya. They observed a very high activity from 1970 to 1977 and 1989 to 2003 (with occurrence rates >0.875 yr-1). Accelerated melting of snow and glaciers in the Himalaya reduce the number of trekkers and mountaineers. Considering the average vertical lapse rate of 6.0 °C km-1, the present glaciarized area above 5,000 m is likely to be free of snow with an increase in temperature of 1 °C in the next few decades. Similarly, an increase in temperature of 3-4 °C could result in the loss of 60-70% of snow-cover from the Himalaya (Alam & Regmi, 2004). This will make the major cause of mountain landscapes losing their beauty that will adversely impact the tourism industry.

Tourism sector along with the environmental resources in which tourism directly depends on is most likely be impacted by the climate change (Scott, 2003). Mountaineering is a popular form of adventure tourism, which basically includes ascending a mountain. It further includes activities like skiing, trekking, hiking, and climbing (Apollo, 2017). Climate has the major influence in any kind of tourism, especially mountaineering and trekking expeditions (Scott et al., 2008).

The high altitude areas (>3000 m), especially the glaciers and periglacial environment, where major mountaineering activities happen, are a very important part of Nepal Himalaya. These areas are providing an attraction for the tourism, particularly for mountaineering. Periglacial environment includes a perennially frozen ground with freeze-thaw oscillation. Every year, thousands of people try to summit a peak, and trek along the snowcapped Himalaya. Studies have suggested that the high mountain regions are adversely impacted by climate change, though the concern on the ecosystem services along with some economic and livelihood impacts seem to be disorganized in the literatures (Nepal, 2011; Palomo, 2017). Especially climate change can cause disastrous impacts on the countries, which depends mainly on natural resources for the economy and livelihoods (Shrestha & Aryal, 2011).

In the greater Himalaya, the prominent impacts are seen in glaciers and runoff response due to precipitation and temperature changes (Xu et al., 2009). Further, elevation dependent warming has a prominent effect on the mass balance of the cryosphere, associated runoff and other ecological changes making mountain

Figure 1: Tourists visit to see the greatest mountains of the Himalaya (Photos by S. Thakuri)

regions more sensitive towards climate change (MRI, 2015). Nepal is highly dependent on agriculture and tourism sectors, which are very sensitive to climatic variability (World Bank, 2002). Mountain tourism plays an important role in tourism development (Figure 1). Nepal Himalaya has pleased a significant number of tourists every year since 1951 (Nepal, 2003).

Since 2000, a huge growth in trekking and mountaineerings have been observed in Nepal (Nepal, 2010). According to MoCTCA (Ministry of Culture, Tourism & Civil Aviation), out of 2,277 persons 1,225 succeeded summit to various peaks composed by 692 foreigners and 533 Nepalese in 2017 (MoCTCA, 2017). Climate change disasters in high mountains are very specific and most likely to trigger the rates and intensity of natural hazards like snow avalanches, rock falls, GLOFs which severely impact the mountaineering sites (Bhandari, 2014). We need to explore how glacial and snow cover changes, and climate-induced disasters impacts the mountaineering in direct and indirect ways. In this paper, we present the potential and realized impacts of climate change on the mountaineering and challenges of mountaineering in future with examples from Nepal Himalaya based on the review of the existing scientific publications.

Glaciers, glacial lakes, and snow cover

The Himalayan region has the largest number of glaciers (Bolch et al., 2012), glacial lakes (Gardelle et al., 2011; ICIMOD, 2011) and snow cover besides the polar region. Changes in snow cover and snow cover duration can visibly be seen in comparison to today's climatic condition (Laternser & Schneebeli, 2003). Alam and Regmi (2004) estimated that increase of 3-4 °C temperature, about 60-70% of snow cover will be lost forming a large number of glacial lakes. A recent remote sensing-based analysis of the glaciers in Nepal Himalaya, by the author of this article, suggests about 15% glaciers shrinkage in the last fifty years. Thakuri et al. (2014) showed that the glaciers in the Southern part of Everest region are shrinking by 13% in last 50 years and the debris-covered area has increased due to the increasing temperature as well as the weakening Asian monsoon in the last decades. Changes in the snow cover due to climate change results in socio-economic and environmental implications (Harrison et al., 2001).

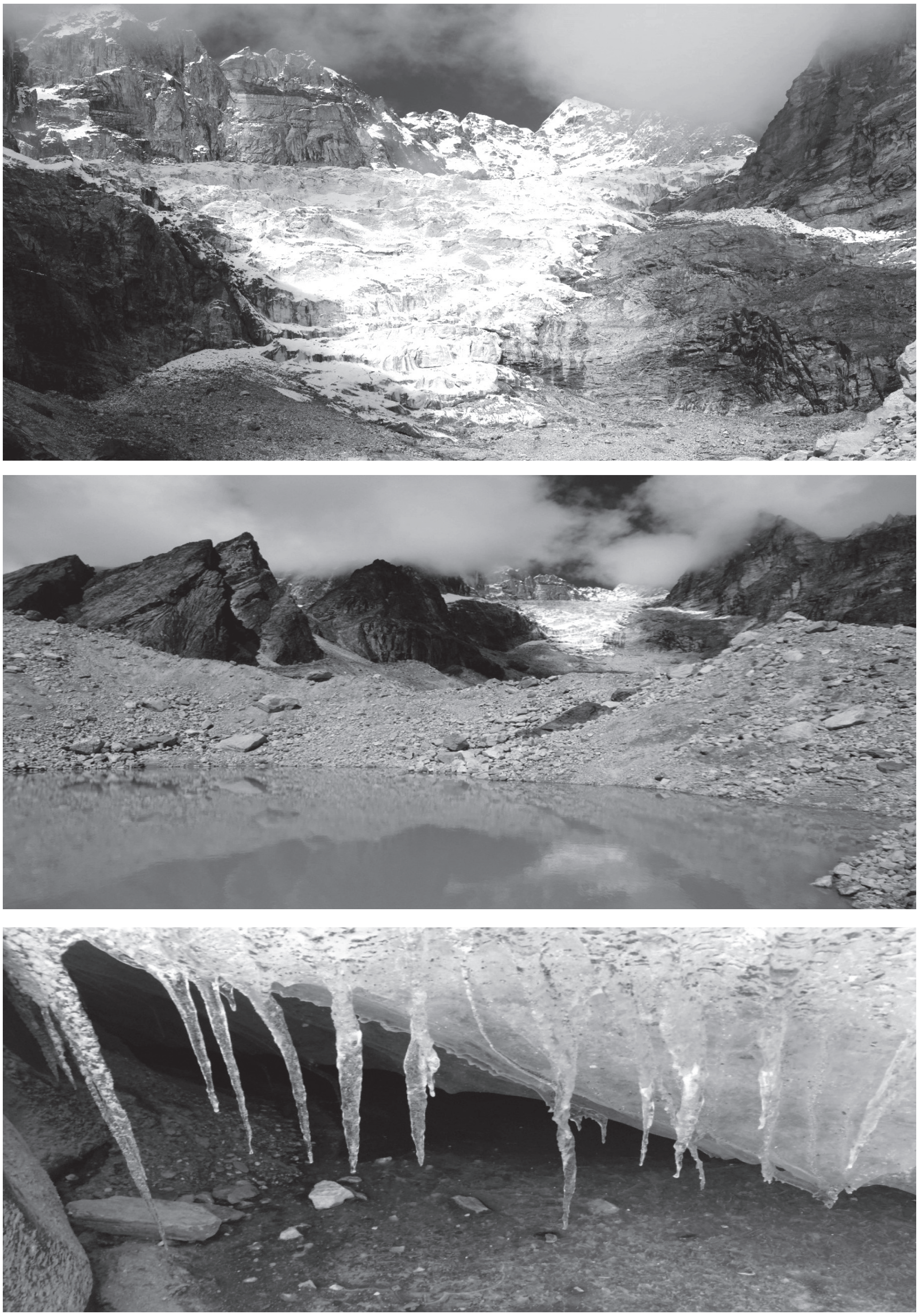

Figure 2: *Upper part of Lobuche Glacier (a) Lobuche Glacial Lake, located on the Khumbu valley, near Everest Base Camp, (b). Glacial ice melt, (c) are producing and enlarging the glacial lakes- (Photos by S. Thakuri)*

Moreover, glacial lake has shown more than 25% of expansion in their surface areas from 1987 to 2017 (Khadka et al., 2018). The glacial lakes on the surface of glaciers are resulting accelerated mass loss of glacier ices. In Everest region, the reduction in glacial mass due to climate change has caused the thinning of the glaciers and induced the formation of large supraglacial lakes (Figure 2; Salerno et al., 2012; Thakuri et al., 2014). It has prohibited the mountaineers to access the trekking routes and mountaineering activities (Watson & King, 2018). The local communities and tourists are likely to be impacted by the lack of accessibility of mountaineers to trekking routes.

Unpredictable weather and climate extremes

Climate extremes are found to be increasing with climate change, causing disruption in weather pattern, landslides, floods and drought. Nepal is very much vulnerable to such climate extremes. Precipitation extremes lead to many natural disasters especially in Himalayan region, causing impacts to the mountaineering business (Karki et al., 2017). Mountain region depends mainly on orographic precipitation. These kinds of extremes result in an unpredictable weather. Weather forecast sensitivity is a big issue for mountaineering business, so detailed and accurate climate information is required to minimize the associated risks of unpredictable weather and extremes (Scott & Lemieux, 2010). The snow characteristics of the Himalaya are complex and require a denser network and assessment of snow conditions for effective forecasting. There are only a few stations in upper Himalaya for weather forecasting that sometimes can result in poor forecasting. However, avalanche forecasting in the Himalayan region is biased towards a conventional knowledge-based approach. The Pyramid lab (5500m) was established in 1990 in the middle of the Lobuche and Khumbu glaciers just a few kilometers away from the Mount Everest. This station provides the meteorological data like air temperature, wind speed and direction, relative humidity, precipitation, and barometric pressure at 2-hour intervals. Such weather stations are very important in predicting the approaching storms and avalanches (Huey et al., 2001).

Extreme one-day rainfall has been found to be increasing from 1871-2007 in the Himalaya resulting in cloudbursts, landslides, and erosion (Nandargi & Dhar, 2011). The risk of slumps, landslides, and debris flow occur if the daily rainfalls exceed more than 144 mm in a day in the Himalaya (Dahal & Hasegawa, 2008). In the southern Himalaya including Nepal, the deaths due to extreme events were more in pre-and - post monsoon when good climate and weather was expected. So, the uncertainties in weather in good climatic condition can result in more casualties of mountaineers (McClung, 2016).

Avalanches (snow and ice)

Figure 3: *Sagarmatha Base Camp and the Khumbu icefall region (a). The Himalayan mountains are turning into snow and ice free rock that can increase the frequency of rockfall, (b). (Photos by S. Thakuri)*

The northern part of the country, particularly the higher-Himalaya is prone to avalanches because of the thick snow cover on the steep slopes (Figure 3). The avalanche of November 1995 killed 43 people, including some foreign trekkers at Khumbu and Kanchanjungha areas. On 2nd January 1999, 5 people were swept away by the avalanche that occurred in Chunchet Village Development Committee- 8 of Gorkha district (MoHA & DPNet, 2015).

Mountaineering is considered an adventure sport, but the risks of death while climbing the summit is very high. Snow avalanche has caused a lot of deaths in the Himalaya as well as have destroyed many infrastructures. The avalanche causes the rapid flow of snow down the mountain or hillside. On 18 April 2014, an incidence of a snow-ice avalanche in the Khumbu Icefall area of Mt. Everest region draws an attention of the world. The event brought a tragic death of 16 climbing staff heading to the Everest summit. That was the largest disaster in the history, resulting huge numbers of human casualties. It is expected that the climate change may lead to disasters, but it is not fair to link every single event to the climate change. Avalanche is generally triggered by the increasing temperature and slope. In colder temperature, the snow sticks to the surface and does not fall, but when the temperature increases the snow sluffs and takes a form of avalanche. So, the gradual increase of temperature due to climate change causes disastrous avalanches.

Nepal Himalaya is characterized by having rugged terrain and the slope instability and failures on the rugged terrain gives rise to rock avalanches (Figure 3). The freeze-thaw mechanism in mountain areas gives rise to instability of the rock materials. The expedition of mountaineering more than 7000m has caused 4% of death rate only by avalanches. With the increasing elevation the risk of avalanche also increases. Annapurna, Dhaulagiri and Manaslu, which are the peaks of Nepal Himalaya, exhibit very high avalanche risk to climbers (McClung, 2016). Changes in solar radiation are an attribute that is brought about by the climate change. Solar activity is presented at higher levels in comparison to the historical record of the past 8,000 years (Gil et al., 2018). The increase in solar radiation tends to trigger the avalanche on the Himalaya on clear weather. Also, the increasing temperature and precipitation changes on the mountain region disrupt the mass balance of the glaciers. In 1995, 28 people died in tourists locations due to avalanches in the Gokyo valley (Nepal, 2011).

In 2014, Nepal experienced worst series of avalanche causing death of more than 43 people in the Annapurna circuit (BBC, 2014). Manaslu Avalanche in 2012 killed 9 mountaineers due to the snow avalanche at 7,300m (Horrell, 2013). In Khumbu, 23 deaths caused from 13 accidents on the northern side since 1992 and 7 deaths seem to be avalanche prone. The Annapurna massif has experienced 54 avalanche deaths and the area south of the Annapurna massif has higher precipitation rate. The avalanche death rate is more concentrated in the Central Himalaya range rather than other part of the world (McClung, 2016).

Climate change is foreseen to increase the frequency of avalanches in such high elevations. Studies indicate that an increase in temperature, changes in the precipitation form (solid or liquid), and precipitation quantity may increase the likelihood of avalanches. Unfortunately, no recorded data exist on the frequency of occurrence (increased or decreased) of such events in this region to attribute scientifically to the climate change, but continuously increasing debris coverage on the glacier surface has been recorded since the 1960s (Thakuri et al., 2014). This indirectly provides hints on such avalanches could have increased in the region because avalanches and rock falls deliver the debris to the glaciers.

Landslide and rockfalls

In high altitude, the mountain slopes are very steep (Figure 4). Mass movement (e.g., landslide and rock fall) downward under the influence of gravity is very common. Everyday small and large mass fall occurs hundreds of times. In most instances, such phenomenon is not noticed as they do not have economic and livelihood impacts. The geographic location with distinct characteristics of the very steep sloped mountain even more favors for the movement of mass downward under the influence of gravity. Earth, itself is a dynamic and changing continuously.

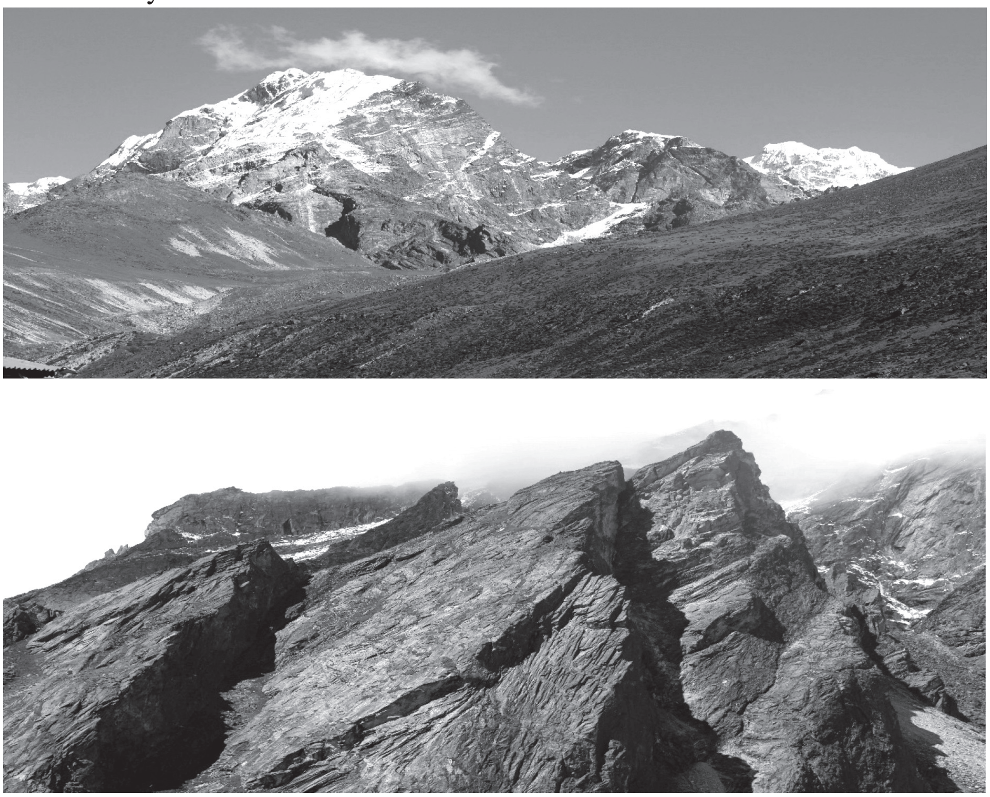

Figure 4: *Rocky mountain peaks are increasing in the Himalaya (Photos by S. Thakuri)*

Glacial Lake Outburst Floods (GLOFs)

On April 20, 2017, a GLOF hit the Barun River valley, a tributary of the Arun River, due to blockage by debris, forming a lake up to 3 km long and 500 m wide. The flood source was small Langmale Glacial Lake that had undergone a rapid change. It resulted a great concern and required emergency response (Byers et al., 2018). On May 25, 2015, an outburst flood was resulted from a lake in Lhotse Glacier, adjacent to the Imja Glacier and Glacial Lake (Thakuri et al., 2016). The outburst flood appeared from the same glacier again on 12 June 2016 through the drainage of glacier water through englacial conduits ((Rounce et al., 2017). Both events have resulted turmoil in this region of the high tourists destination. On September 03, 1998, a GLOF of Tam Pokhari (lake) in the Hinku valley of the

MBNP toll death of several human lives and loss of more than NRs 156 million properties (ICIMOD, 2011). These are some of the recent cases of the GLOFs in the region. Several GLOF events have already been experienced in the Nepal Himalaya (Osti & Egashira, 2009; ICIMOD, 2011) with a loss of lives and properties and affecting the tourism. Several lakes in the region are emerging as a Potentially Dangerous Glacial Lakes (Bolch et al., 2008).

In Nepal, climate change is considered to have triggered many high mountain avalanches and GLOFs (Nepal, 2011). The GLOF events are common in the High-mountain areas, as there are large numbers of glacial lakes. Among the glacial lakes existing in Nepal, 32 are considered to be potentially dangerous. The historical GLOF events in Nepal reportedly occurred about 450 years ago. A total of 24 GLOFs event has been reported in Nepal, originating 14 GLOFs in Nepal Himalaya itself and another 10 GLOFs originating in the Tibetan part of China (ICIMOD, 2011). Moraine collapse has been the major reason of GLOFs in Nepal (Mool, 1995). On the basis of probability index, the Tsho Rolpa and Imja Tsho were identified for continuous and intensive study (ICIMOD, 2011).

Table 3.17: GLOF events recorded in Nepal

S.N.	Date	River basin	Lake
1	450 years ago	Seti Khola	Machhapuchhre
2	3 Sep, 1977	Dudh Koshi	Nare
3	23 Jun, 1980	Tamor	Nagma Pokhari
4	4 Aug, 1985	Dudh Koshi	Dig Tsho
5	12 Jul, 1991	Tama Koshi	Chubung
6	3 Sept, 1998	Dudh Koshi	Tam Pokhari
7	15 Aug, 2003	Madi River	Kabache Lake
8	8 Aug, 2004	Madi River	Kabache Lake
9	NA	Arun	Barun Khola
10	NA	Arun	Barun Khola
11	NA	Dudh Koshi	Chokarma Cho
12	NA	Kali Gandaki	Unnamed (Mustang)
13	NA	Kali Gandaki	Unnamed (Mustang)
14	NA	Mugu Karnali	Unnamed (Mugu Karnali)

Source: *ICIMOD (2011); NA= Not Available*

Glacial lakes formed when the waters hemmed in by rock, ice, or any debris barriers when snow and ice melts in high altitude. The meltwater is accumulated in loosely consolidated end moraine dams. A large glacial lake gets enlarged through coalesce of the small water ponds. With the presence of a large number of increasing glacial lakes the Himalaya of Nepal is very prone to outburst of lakes and the glacial lakes being very much sensitive to the increase in temperature.

Basically, two types of GLOFs exist in the Nepal Himalaya i.e., overtopping or collapsing of the morraine or ice dams on the glacier itself and another one is the one which occurs when there is fast draining of or from lakes formed on the lower surface of glaciers (supra-glacial lake) or between the end moraine and the terminus of a retreating glacier (moraine dammed glacial lake), however ice dammed lakes are also present in very small numbers in Nepal (ICIMOD, 2011).

Dig Tsho Lake is situated on the Langmoche Valley sub-basin of the Nangpo-Tsangpo area in the Bhote Koshi valley at an altitude of 4365 m and is fed by Langmoche lake situated at an altitude of 5400m. The snout of the glacier is exposed to solar radiation, which has contributed to the rapid retreating. Before the burst the 1985, the Dig Tsho lake had a depth of 20 m and 60m high moraine. The GLOF of Dig Tsho was triggered by ice avalanche on Langmoche lake, causing the ice mass of 100 to 200,000 m3 dislodged itself from the overhanging glacier tongue and plunged into the lake. The outburst of Dig Tsho (Moraine-dammed lake) in 1985 in the Everest region damaged the infrastructures and killed 5 people (Vuichard & Zimmermann, 1987). The oubrust of the Dig Tsho had not only affected the people socially, but also impacted the tourism industry very badly. The destruction of trails and bridges affected the reach of the mountaineers as well as the sudden bursts of the glacial lake increased the risk of fatalities among mountaineers.

Imja Tsho, a moraine-dammed lake, is another potentially dangerous glacial lake of Nepal, which is one of the six dangerous glacial lakes (Thulagi, Tsho Rolpa, Lumding, Imja Tsho, Lower Barun, and West Chamjang) of Nepal (ICIMOD, 2011). The Lake is situated in the northeastern part of the Dudh Koshi basin and lies on the South of the Mount Everest (8,848m). It lies at the terminus of Imja glacier. This lake showed very rapid growth 0.03 km2 in 1962 to 1.35 km2 in 2013 (Thakuri et al., 2016). Water draining from the lake through its natural outlet runs over the end moraine called as the Imja Khola. Since this, the lake is growing at an alarming rate, it can possibly cause a huge damage to the infrastructures and 87,782 people living downstream with a loss $11 billion, and the trekkers and mountaineers are also at a huge risk as it threatens to destroy the trekking trails, settlements and tourist destinations (Bajracharya et al., 2007; Mool, 1995; ICIMOD, 2011). Hence the increase in number of glacial lakes due to climate change and the resulting GLOFS will immensely impact the mountaineers and the tourism sector of Nepal.

Permafrost thaw

Permafrost is a frozen rock and snow, which is at a temperature of below 0 °C for a period of more than two years. Ground ice may or may not be presented and the permafrost is generally found in higher altitude. The surface layer that thaws in warm season is called an active layer. The thawing of permafrost is directly affected by changing climate and being a consequence of climate change, it will have social, biological and economic impacts on the fragile ecosystems of mountain regions (ICIMOD, 2016). Mountain permafrost degradation is an important indicator of the climate change, however, not distinct studies on the permafrost and periglacial environment of Nepal are available (Chahuhan & Thakuri, 2017). Permafrost is not visible at the surface so it makes the mapping and inventory of the permafrost region more difficult. Permafrost influences a wide range of systems, including the hydrology, landscape and vegetation. Permafrost stabilizes the rock slopes, moraines and debris-covered slopes through cohesion and decreasing the hydrostatic pressure. So the permafrost thawing has its own consequences.

The glacial lakes or hydropower dams near the permafrost can trigger rock falls and flood hazards. The permafrost holds the sediments due to cohesion. With increasing temperature, the sediments might be lost in sediment loads in torrents and rivers, debris flows and rock falls. It can destroy bridges and trekking trails of the tourists carrying out mountaineering activities (ICIMOD, 2017). Two studies done so far show the impact of climate change on permafrost (Chahuhan & Thakuri, 2017). Fukui et al. (2007) studied the Lower Limit of Permafrost (LLP) of Khumbu Himal between 1973-2004. The study was done by measuring the ground temperature lapse rate at 50 cm depth. The LLP of 5200–5300m a.s.l in 1973 increased by 100–300m between 1973 and 1991 followed by a stable limit of 5400–550 m a.s.l. over the last decade. The study explains that the climate change impact on Khumbu region is more severe than Tibetan plateau. Another study done by Mayer et al. (2012) in a permafrost change in the Gokyo valley by applying the temperature rise based on the IPCC (Intergovernmental Panel on Climate Change) scenarios in the Perma-map model showed that the LLP would rise by 188 m between 2009 and 2039. These two studies prove that there are some changes going on the permafrost of periglacial environment due to climate change and it will surely cause negative impact on the mountaineering as the instability of permafrost is associated with some natural hazards.

Conclusions and future perspectives

The unique mountain features with rugged terrain make the Himalaya a seamless tourist destination for the mountaineering activities. Mountaineering is a nature-based tourism and has contributed significantly to the economy of Nepal since after it opened its door to climbers from late 1940s; however, the mountaineering activities are potentially impacted by the climate change and threats to the future of this business. The studies have indicated that the Himalaya and its environments are more severely affected by climate change than any other parts of the world. Climate change has given rise to many natural hazards, like snow cover change, permafrost degradation, glacial lake outburst floods, avalanches, and rock falls. These natural happenings have caused huge impact on the fatalities of the mountaineers, and biological, societal and economic impacts. Though, the technical parts of the mountaineering has advanced, but unpredictable weather have huge number of fatalities among mountaineers. The increase in intensity of one-day rainfall on mountain regions cause slope failures and results in dangerous rock falls and avalanches. Nepal Himalaya is experiencing an increase in the number of glacial lakes and lately snow cover are rapidly decreasing. The glacier lakes are increasing at an alarming rate forming potentially dangerous glacial lakes, which can cause GLOF in the coming years. The Dig Tsho GLOF can be considered as an example how disastrous it can be to the people and the environment. The increase in the LLP of the permafrost in the periglacial environment will trigger rock falls, debris flow, and sediment load will destroy bridges, trails and aesthetics of the mountains. The snow avalanche is also one of the main reasons for the fatalities among mountaineers and cause the loss of trekking trails. The increasing temperature has caused the decrease in the cohesion of the snow and the mass load is discharged in a huge amount destroying everything that comes along the way. So, the climate change will bring about direct and indirect impacts on mountaineering business. The control of climate change hazard is a must for mountaineering. The general approaches can be adapted to address the climate change impacts and ensure the secure mountaineering activities more effectively are summarized here.

- Dry snow can be expected on the route of the climbing and near the summit of peaks. An increasing temperature can decrease the snow cohesion that can trigger the snow avalanches and increase the risk to any human movements during the mountaineering activities. So careful considerations should be applied while summiting those peaks;
- Avalanche prone zones in the high mountain slopes must be avoided to be used as a trail;
- Snow avalanches are likely to get on release on slopes between 25° and 55° and large avalanches begin to deposit on slopes around 10°, so the camping on the peaks should be planned accordingly to avoid hazards (McClung, 2016);
- Temporal pattern of avalanche deaths is dictated by weather and climate patterns. The proper time of the pre-monsoon and post-monsoon seasons that is more favorable for mountain climbing should be selected in Nepal Himalaya;
- Climbing on the high peaks requires harsh winter climbing experience and avalanche-forecasting ability, training and basic avalanche equipment

(shovel, probe, and transceiver) to ensure a basic level of safety;

- Sensitive weather and avalanche forecasting is required for the safest mountaineering and more meteorological stations should be kept at higher altitudes;
- Mitigation programs are required for the GLOFs for reducing the potential risks;
- Early warning system should be installed in the high hazard areas;
- Hazards and risk assessment of different hazard types require in the trekking trails, tourist destinations of the high mountain areas to avoid the potential hazards and risks;
- More scientific studies on the high mountain processes, glaciers and periglacial regions are required to better understand the climatic impacts.

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