

# Periglacial environment in Nepal Himalaya: Present contexts and future prospects

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## Abstract

Periglacial environment in the Nepal Himalaya (80°04' to 88°12' E longitude and 26°22' to 30°27' N latitude) is a research field that has received a little scientific attention although the first reported periglacial research was in 1958. After the first periglacial research, only 22 studies are reported in Nepal (area: 147,181 km<sup>2</sup>), most of which is carried out by researchers outside the country. Studies mainly focus on periglacial landforms and determining the lower limit of the mountain permafrost. The mean lower limit of permafrost (LLP) and the size of rock glaciers indicate a decreasing trend of the permafrost limit from the eastern (5239 m a.s.l.) to the western part of Nepal (4513 m a.s.l.). The rate of change in the LLP in response to climate change in Nepal Himalaya is 1.3–2.6 m/yr. Model on the scenario of permafrost change based on the IPCC climate scenarios shows that the LLP would rise by 188 m between 2009 and 2039 with the rise in temperature. The periglacial landforms, like vegetated patterned ground (earth hummocks, turf banked terraces), sorted polygons, sorted stripes, solifluction lobes, striated ground, and rock glaciers are reported from the Nepal Himalaya. The spatial and temporal coverage of periglacial research in Nepal Himalaya is very low. The arena of periglacial researches, like permafrost distribution modelling, periglacial hazards, periglacial ecology, relationships between permafrost and rangeland, and implication on mountain livelihood, global warming and periglacial change are the potential areas of research in the coming days.

**Key words:** Mountain, permafrost, rock glacier, high altitude, Himalaya

## Introduction

The term “Periglacial” was first used by Polish geologist W.V. Lozinski to describe the climatic and geomorphic conditions such as cold (ice marginal), mountainous, sparsely vegetated and peripheral to the late Pleistocene ice sheets in the mid latitude (Lozinski, 1912), however this condition doesn't represent the vast majority of present day periglacial environment (French, 2000). In modern day, the term is used in synonymous with the cold non-glacial environments in which frost related process dominates (French, 1996). According to Tricart (1968), periglacial environment are those areas where the influence of freeze-thaw oscillation is dominant and there is a presence of perennially frozen ground or permafrost. The permafrost is ground (soil or rock, and included ice and organic material) that remains at or below 0 °C for at least two consecutive years (Van Everdingen, 1998) and is present in the periglacial environment (Péwé, 1975). Global permafrost extent is estimated in percent area as continuous (90-100%), discontinuous (50-90%), sporadic (10-50%) and isolated patches (<10%) (Brown et al., 1997) covering an area of 16-21 x 10<sup>6</sup> km<sup>2</sup> including the Antarctic and sub-sea permafrost (Gruber, 2012). Frost (1976) identified four types of periglacial environments which include i) high arctic climates with large seasonal, but small diurnal

temperature fluctuations (e.g., the Canadian arctic), ii) continental subarctic climates with large seasonal, but small diurnal temperature fluctuations (e.g. interior Alaska including the upper Copper River watershed), iii) alpine climates in the middle latitudes with large seasonal and diurnal temperature fluctuations (e.g., the summits of the European Alps) and iv) other climates widely distributed with small seasonal and diurnal temperature fluctuations (e.g., some sub-arctic islands and some summits of the South American Andes and the Hawaiian Seamounts).

In the context of mountains, the concept of periglacial environment fits into the concept of Lozinski (1912) according to which the periglacial zone is the areas between timberline and snowline. However, the presence of this kind of environment has been reported even below the timberline (Hustich, 1966). Several aspects of research studies can be expected under the periglacial environment. Despite a significantly high number of studies on the glaciers, only little knowledge is available in the periglacial environment in the Hindu-Kush Himalaya (HKH) region. This study aims to uncover the previous studies (until the end of 2015) on the periglacial environment in Nepal Himalaya, including scope of study, type of methodology used, temporal and spatial coverage of the studies.

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This paper is based on the review of the published literatures that deals with research areas of Periglacial environment in Nepal Himalaya. Literatures were searched by using some key words like “periglacial”, “permafrost”, “rock glacier”, “ground temperature”, and “periglacial landforms” in Nepal. In this study, literatures published (journal articles, conference proceeding, abstract, unpublished thesis, project reports) up to the December 2015 are incorporated.

### **Historical research development**

A systematic research on the periglacial environment began globally in early 1910s after the conceptualization of the term by Lozinski (1912). In Nepal Himalaya, Müller (1958) conducted a glacier and soil research in the Everest region and observed a seasonal freeze-thaw process of ground at Gorakshap (5150 m a.s.l.) in the Khumbu region. The study reported patterned ground and two ice-wedge casts, but he denied the existence of permafrost. So, Müller (1958) can be considered as the first work to report on the periglacial environment in Nepal. In the early 1970s, Geological Expedition to Nepal (GEN) began the study of high altitude geomorphology in Nepal. Although the main objective of GEN was to derive information on the glaciers, climate and their relationship, it also considered periglacial morphology in their study. The results of these initial works were published in special issues of the Journal of the Japanese Society of Snow and Ice (SEPPYO) in 1976 (Fujii & Higuchi, 1976; Fujii, 1976; Iwata et al., 1976; Iwata, 1976). These initial works focused on the detection of permafrost and its relationship with ground temperature, and the study of periglacial landform features in Khumbu region in eastern Nepal and in the hidden valley, Mukut Himal in the western Nepal. The initial steps of the periglacial research in Nepal seem impressive; however, it couldn't receive similar attention in later decades. A comprehensive study was carried out by Regmi (1980) to study the distribution and lower limit of discontinuous permafrost in Nepal Himalaya. This study covered five different study areas in Kangchenjunga, Khumbu, Langtang, Annapurna and Sise from east to west in the Nepal Himalaya and made field observation and aerial photo interpretation. Watanabe et al. (1989) also described the various periglacial landforms in Langtang valley and divided the landforms into four belts. Seismic refraction study was carried out by Jakob (1992) on the active rock glacier to determine the lower limit of discontinuous alpine permafrost in Khumbu region. Using freezing and thawing indices and ground temperature measurement in Langtang valley, Shiraiwa (1993) studied the glacier fluctuation and cryogenic environment which also focused on the periglacial landforms. The work of Barsch and Jakob (1998) was first to study the periglacial erosion in Nepal Himalaya. Ishikawa et al. (2001), using Direct Current (DC) resistivity, tried to clarify the internal structure of glacier derived rock glacier and talus derived rock glacier and also determined the discontinuous permafrost zone in Kanchanjunga Himal, Nepal. Regmi and Watanabe (2005) determined the solifluction rate in the Kanchenjunga area using glass fibre tubes and strain poles. Later in the same site, the same

team (Regmi & Watanabe, 2009) studied the rock-fall activity. Considering, the significant climate warming in the higher altitude regions of Nepal, Fukui et al. (2007) studied the changes in the lower limit of mountain permafrost as a response to climate change between 1973 and 2004 in Khumbu Himal. A study on Gokyo valley assessed the scenario of permafrost change and also modeled the distribution using Perma-Map. In Nepal Himalaya, studies of periglacial environment are focused in determining the lower limit of permafrost (LLP; Fujii, 1980; Fujii & Higuchi, 1976; Fukui et al., 2007; Ishikawa et al., 2001; Jakob, 1992; Mayer, Glade, Merz, & Sharma, 2012; Regmi, 2008) recording the periglacial landforms (Fujii, 1976; Iwata et al., 1976; Iwata, 1976; Shiraiwa, 1993; Watanabe et al., 1989), quantification of periglacial mass movement and erosion (Barsch & Jakob, 1998; Heimsath & Mcglynn, 2008; Regmi & Watanabe, 2005, 2009) and very few studies on the biological aspect of the periglacial environment like Mieke (1989) which studied the periglacial environment associated with plant communities. Study of periglacial environment in Nepal Himalaya is getting very little attention in recent decades and a wide aspect of this environment is yet to be embraced.

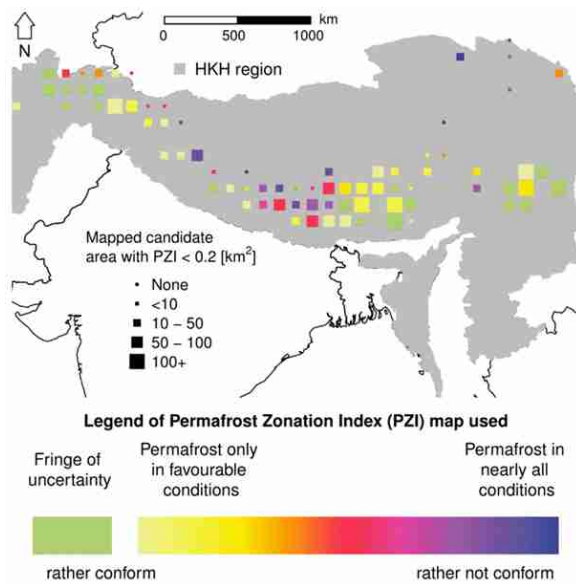
### **Occurrence and Distribution**

Globally, two maps are available regarding the distribution and extent of permafrost. The Circum-Arctic Map of Permafrost and Ground Ice Conditions (Brown et al., 1997) published by the International Permafrost Association (IPA) and the global model of permafrost extent (Gruber, 2012) based on the permafrost zonation index (PZI). Schmid et al. (2015) assessed both maps for the HKH region by mapping rock glacier in the randomly distributed square plots over the HKH region. While comparing the mapped rock glacier with IPA map, the permafrost was predominantly discontinuous and sporadic in the HKH region with very few isolated and no continuous permafrost. The Gruber's PZI was in better agreement with the study than with the IPA map (Fig. 1). In HKH region, the lowest elevation of permafrost was recorded in Northern Afghanistan at 3554 m a.s.l. and the highest elevation of 5735 m a.s.l. on the Tibetan Plateau (Schmid et al., 2015). Nepal ranks 17<sup>th</sup> position in terms of global permafrost regions. About  $15.7 \times 10^3 \text{ km}^2$  is occupied by the permafrost (permafrost region) in Nepal (Gruber, 2012).

Various attempts have been made to determine the LLP in Nepal Himalaya. In the Kanchanjunga Himal, eastern Nepal, the mean LLP is determined to be 5239 m a.s.l. (Regmi, 2008). Similar value (5300 m a.s.l.) on the south to east-facing slopes and 4800 m a.s.l. on the north-facing slopes have been suggested by DC resistivity imaging on the rock glacier by Ishikawa et al. (2001). Around Khumbu Himal, ground temperature measurement in 1973 showed the occurrence of permafrost above 4900-5000 m (Fujii & Higuchi, 1976; Fujii, 1980; Regmi, 2008) but seismic refraction study on active rock glacier in 1992 gives the LLP to be on average 5000-5300 m (Jakob, 1992). This LLP is in agreement with the calculated mean LLP of 5150 m a.s.l. using rock glacier in Gokyo valley, but

the results from the Perma-map model indicated a much lower altitude of permafrost (Mayer et al., 2012). In the western Nepal, the LLP occurrence is 5000 m in the hidden valley, Mukut Himal (Fujii, 1980; Fujii & Higuchi, 1976), 4450-5120 m in Annapurna Himal (Regmi, 2008). Similarly, LLP occurs at 4600-4920 m in Langtang Himal, Central Nepal and 4200-4800 m in the Sisne Himal, Mid-western Nepal (Fig. 2).

The mean LLP as well as the size of rock glacier shows a decreasing trend from eastern to western Nepal (Fig. 2) and the southern aspect is common for the occurrence of permafrost (Regmi, 2008).

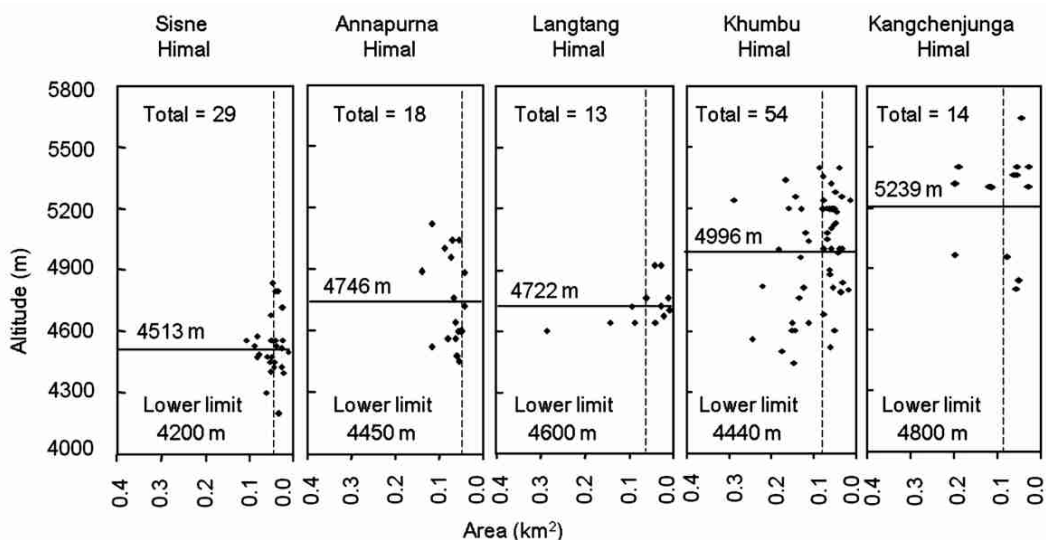


**Figure 1** Permafrost distribution in HKH: Spatial patterns of agreement between mapped rock glaciers and PZI (Schmid et al., 2015)

Studies, like Fukui et al. (2007) and Mayer et al. (2012), suggest the change in the lower limit of discontinuous mountain permafrost in Nepal Himalaya attributed to climate change.

**Permafrost and climate change**

The Intergovernmental Panel on Climate Change (IPCC) marks Nepal Himalaya as the data deficient region (IPCC, 2013). Limitation of data has been a major obstacle since weather recording began only in 1921 AD in Nepal. Moreover, the weather stations are not evenly and adequately distributed to give a clear picture. Recent studies on climate trends from the Himalayan range are limited, and even completely absent at higher elevations (> 5000 m) (Salerno et al., 2015). Therefore, mountain permafrost degradation serves as an important indicator of climate warming (Fukui et al., 2007). In Nepal Himalaya, two permafrost studies attribute to climate change. Fukui et al. (2007) measured ground temperature lapse rate at 50 cm depth (BT50) to study the change in the mountain LLP between 1973 and 2004 in Khumbu Himal. The LLP of 5200–5300 m a.s.l in 1973 was raised by 100–300 m between 1973 and 1991 followed by a stable limit of 5400–5500 m a.s.l. over the last decade. The study suggests that climate warming in the Khumbu Himal has been more severe than that in the Tibetan Plateau since the LLP raised 40–80 m a.s.l. at the Tibetan Plateau as estimated by an increase in mean annual air temperature of approximately 0.2–0.4 °C from 1970s to 1990s. Mayer et al. (2012) studied the scenario of permafrost change in the Gokyo valley by applying the temperature rise based on the IPCC scenarios in the Perma-map model which showed that the LLP would rise by 188 m between 2009 and 2039. From both the studies, it can be concluded that the Nepal Himalaya might experience a significant environmental change in near future.



**Figure 2** Comparison of size and altitude of the periglacial rock glaciers for the five study sites in the Nepal Himalaya (Regmi, 2008)

### Periglacial landforms

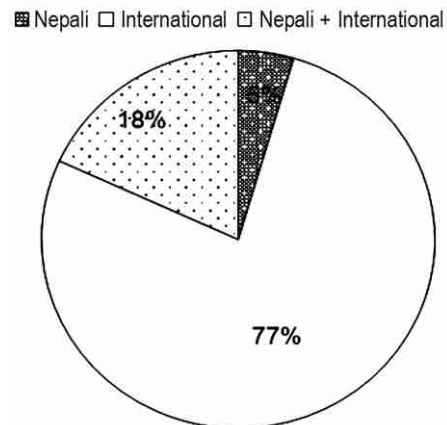
Most of the study carried out in the Nepal Himalaya are subjected to studying the periglacial landforms (Fujii, 1976; Iwata, 1976; Iwata et al., 1976; Shiraiwa, 1993; Watanabe et al., 1989). Periglacial landforms (Fig. 3) such as vegetated patterned ground (earth hummocks, turf banked terraces), sorted polygons, sorted stripes, solifluction lobes, striated ground and rock glaciers were observed in the Khumbu and hidden valley (Fujii, 1976; Iwata, 1976; Iwata et al., 1976). Similarly, active periglacial landforms like earth hummocks, turf banked terraces, talus slope, solifluction lobe, striated ground and inactive landforms like rock glacier, block stream and protalus ramparts were reported in the Langtang valley (Shiraiwa, 1993; Watanabe et al., 1989). Watanabe et al. (1989) also divided periglacial landform distribution into four belts as Belt-I (3600–3920 m) for the lowermost periglacial belt of the patchy distribution of earth hummocks and vegetated solifluction lobes, Belt-II (3920–4700 m) for a lower periglacial belt with a more continuous distribution of hummocks and vegetated solifluction lobes, Belt-III (4700–5000 m) for the middle periglacial belt of vegetated solifluction lobes, turf-banked terraces and sorted polygons and Belt IV (5000–5200 m) for the upper periglacial belt of sorted polygons.

### Research interventions

On analyzing the literature on the basis of the Nepalese or international researchers, about 77% of the studies were carried out by the international researchers, about 18% by the collaboration of both Nepalese and international researchers, and only 5% studies have been carried out by Nepalese researchers (Fig. 4). Among the international researchers, contribution of Japanese researchers to foster periglacial research in Nepal is high. Very limited Nepalese researchers are working for periglacial environment in the Nepal Himalaya (Regmi, 2008; Regmi & Watanabe, 2005, 2009).



**Figure 3** (a) Hummocky patterned ground, an alpine periglacial feature caused by ice in the ground; (b) A talus or scree slopes frequently occur in the periglacial zone. (Photo: S. Thakuri, 2015)



**Figure 4** Research carried out (by Nepalese and/or international researchers) on the periglacial environment in Nepal Himalaya

### Further issues and prospective

Nepal Himalaya is the highest mountain in the world. However, little is explored from the periglacial perspective. Knowledge on the distribution of mountain permafrost is important for evaluating the consequences of climate warming on infrastructure, water resources and mass wasting in mountain regions (Bockheim, 2015); but even the distribution of permafrost in Nepal is yet to be clarified (Regmi, 2010). The spatial coverage of the periglacial studies in Nepal Himalaya is very low. Similarly, the arenas like periglacial hazard, periglacial ecology, the relation between rangeland, permafrost and mountain livelihood are neglected in the Nepal Himalaya. Some of the key areas of importance for the future research activities in Nepal Himalaya are:

- i. Interaction of glacial and periglacial environment
- ii. Ground thermal regime and periglacial landform in the light of Himalayan landscape
- iii. Assessment of higher magnitude hazards linked to rock wall destabilization from permafrost thaw



- iv. Relationship between global warming and rock glacier acceleration and destabilization
- v. Solifluction and gelifluction processes
- vi. Dynamics and characteristics of periglacial landforms
- vii. Thermokarst features
- viii. Ground ice content and the associated implications regarding trace gas emissions
- ix. Periglacial ecology in Nepal Himalaya
- x. Relationship between permafrost and rangeland and their implication in mountain livelihood.

## Conclusion

Although, studies on periglacial environment in Nepal Himalaya began in 1958, yet it has received a very little scientific attention. So far, little is known about the periglacial environment of Nepal Himalaya. A total of 22 studies were reported from Nepal Himalaya, most of which were carried out by the international researchers and the number is slowly increasing. The studies were mainly focused on periglacial landforms and determining the mountain LLP and very few on ecological aspects of periglacial environment. Both the spatial and temporal coverage of periglacial research in Nepal is low. Rapid research progress in various avenues of periglacial environment in Nepal Himalaya is vital.

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