HUMAN RESPONSE TO HOLOCENE CLIMATIC & ENVIRONMENTAL CHANGES IN THE MIYAR BASIN, LAHAUL HIMALAYA

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July 20, 2018

DECLARATION

I, **RAKESH SAINI,** do hereby declare that the thesis entitled "**HUMAN RESPONSE TO HOLOCENE CLIMATIC & ENVIRONMENTAL CHANGES IN THE MIYAR BASIN, LAHAUL HIMALAYA**" submitted to the School of Social Sciences, Jawaharlal Nehru University, New Delhi, for the degree of **DOCTOR OF PHILOSOPHY,** embodies the result of bona fide research work carried out by me. No part of the thesis has been submitted to any other university/institution in part or full for the award of any other degree or diploma.

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ABSTRACT

The style and timing of past glacier fluctuations in the Himalayas is widely contested. The late Quaternary maximum glacier expansion in the Himalaya has been asynchronous with the global Last Glacial Maximum and the timing and extent of the Holocene glacial fluctuations in the Himalaya differ notably from northern latitudes. Little is known about the recent glacial fluctuations that occurred in the last millennium. In the absence of glacial chronology for the last millennium in the region, the relative size and extent of the Himalayan moraines were compared with that of the LIA glaciers in Europe. Although the recent studies have attempted to generate the glacial chronological of the last two millennium but careful observation of the available 1k glacial chronology suggest variation in timing and extent of glacial advance, and are mostly based on relative rather than absolute chronologies. Wherever the numerical dating technique has been applied, a limited number of dates are given ($\leq$ 2) Areas which have been historically accessible such as Khumbu (Everest) and Garhwal have provided the most dates. Such uncertainties often persist because of the absence of the suitable organic material for constraining the timing of the glacial expansions. It is a matter of concern that the last millennial was the most explorative time period of the human generations. But little is known why people move away from their indigenous locations. Such scenario recommends more studies from the inner parts of the Himalaya for the robust glacial chronology of the period in the region

Topographically, the study area is sandwiched between the lofty Pir Panjal on the south and the High Himalayan Range to the north. The Pir Panjal acts as a barrier for northward approaching Indian Summer Monsoon (ISM), resulting in a strong moisture gradient of increasing aridity towards north. The area above 4000m a.s.l. is

dominated by glacial and periglacial processes, whereas altitudes between 3200 m and 4000 m asl are dominated by paraglacial processes. The contemporary Equilibrium Line Altitude (ELA) lies between 4900 and 5200 m a.s.l. The trunk valley (main Miyar Valley) above 3200m asl displays an open U shaped cross profile, with a valley floor filled with late Quaternary glacial sediments, providing abundant scope for dating and understanding the glacial dynamics of the region. Moreover, the Holocene moraines complex between Khanjar (the last sedentary village in the main trunk valley at 3500m a.s.l.) and Gumba (where Miyar stream confluence with Gumba stream with most assemblage of moraines and broadest U shaped main trunk valley in upper the Miyar basin) encompasses several sites of completely dilapidated settlements now in ruins; the prominent are Tharang, Phundang and Patam within Tharang moraine complex. These remains hold much significance, given that under the modern climatic conditions, permanent habitation and agriculture are confined in areas below ~3500 m a.s.l. The presence of large number of ruins at an elevation of ~3710 m a.s.l., along with organized irrigation system and demarcated fields suggest that during the time of human habitation, climatic conditions may have been conducive for such activities.

Moreover, the basin had little anthropogenic modification of landforms or settlements, and the bounded fields, an important parameter to reconstruct the past archeological activities as little is known about the LIA glacio-archaeological history of this region.

This thesis addresses the issues and techniques to reconstruct the late Holocene glacio-archeological history of the Miyar basin, Lahaul Himalaya, focusing on geomorphological, archaeological and mineralogical signatures. Assessment has been made as to how the glacio-archaeological chronology of this region concurs with other climatic and glacial proxy records from the North West Himalaya. Thus the study contributes to the greater understanding of spatial character of the climatic variability, glacial fluctuations and human occupation and migration in the North-West Himalaya on a millennial scale. It presents the first account of human migration in the high altitude villages (<3700m asl) of Tharang glacier end moraine complex and provides a relative framework for both the glacial history and human migration in the Lahaul Himalaya during the last 1000 years.

Based on the proxies, map records and Radiocarbon (^{14}C) chronology of the ruins the study reports that due to increased temperature between 980- 1840AD people survived within the Tharang moraines and abandoned the site due to decreased temperature and increased snowfall between the late 18th and early 19th centuries. Existence of three abandoned sites (Tharang, Phundang and Patam), indicate exclusively towards prolonged period of settled agriculture that coincide with relatively warm temperature and limited snowfall in this region. The timing of abandonment of these villages and increased snowfall with low temperatures for the region is well supported by the available historical maps, and limited glacial fluctuation after late 18th & early 19th Century expansion. The basin experienced no glacier advance during the peak of LIA however glaciers advance during the late 18th to early 19th Century. As a consequence of increased snowfall and decreasing temperature the cropping probably failed for many years, creating inhospitable conditions by shortening cropping season. It would have been rather impossible to sustain and support large population and therefore, migration was the only alternative. We present direct and indirect evidences of limited glacier during the LIA peak. However, further investigations are required, both in the basin and in the surrounding region of the Lahaul Himalaya, to validate and refine the period of human colonization and limited glacial expansions.

In order to generate the palaeo-glacial fluctuations in the basin the study analyses the palaeo- Equilibrium Line Altitudes (ELA), landforms, historical maps and other proxy material. Keeping in view the absolute and relative geochronology of the glaciations in the basin, this basin experience two major glacier stage (Miyar Stage and Khanjar Stage) and one recent glacier advance (late 18th and early 19th Century) , well preserved in the landforms throughout the basin.

The Miyar glacial stage was associated to local Last Glacial Maximum (Plate 4.2) when Miyar, the largest glacier in the basin, coalesced with the tributary glaciers, expanding down-valley by ~35 km to reach Karpat, with an ELA depression of ~530 m relative to contemporary ELA at 5000 m. This most extensive glacial advance in the basin is recorded as a large U-shaped trunk as well as tributary valleys, scoured shoulders and bedrock walls, along with truncated spurs. This stage still remains to be dated however, considering the size and extent of the glacial landforms and features, the stage is proposed to be contemporaneous with the Chandra Stage.

The Khanjar stage is constrained within 10-8 ka (OSL), sharply crested lateral moraines of tributary glaciers descend from ~4600 m a.s.l. to ~3000 m a.s.l. within a short distance of 3.7 to 5.4 km, controlled strongly by slope characteristics in the lower part of the study area. During this stage, ELA fluctuated between 4405-4949m with a basin average of 4652m, with ΔELA of 423 m asl from present to Holocene. During this expansion the tributary glaciers chocked main trunk valley at many places. This resulted into a considerable length of blockade of the main trunk river, thus filling the space available with large and thick lacustrine fills prominently at Gumba and Than Pattan. During this stage, Tharang glacier descended to ~3595 m in comparison to its present terminus position at ~4471m a.s.la vertical drop of ~880 m in a distance of ~4.96 km and produced the highest existing lateral moraine of the Tharang complex on the either flank of the rivulet

Following the Holocene glacial advance, recent glacier advance (late 18th and early 19th Century) were identified based on fresh sediments and landforms assemblage within 2 kilometres from the present glacier terminus and similar glacier extent marked on available historical GTS map. The available plaeoclimatic proxies of the region are in consistent to the timing. There is no denying that each successive expansion was many degrees smaller than the previous, that helped preserve large number of landforms which otherwise would have obliterated the record, had there been Ice Age of higher magnitude. Landforms in the form of trimlines and shoulders are indicative of the antiquity of the event in the basin and region, which need future attention.

In order to understand the hydrological history of the study area the study investigated the changes in the major and trace elements in alpine lacustrine deposits at Par Got. Based on the oxides and carbonates distribution in the Par lacustrine deposit and available precipitation records of the region it is suggested that the area remain dry and warm throughout the last 1000 years, except with one episode of increased wet conditions in between the sample 5 to 7 (80-112 cm from the top surface). The timing based on the precipitation records of the region is in between to the late 17th to early 19th century. However, we need more detail work on the part of the chronology of the layers so that the exact possible time can be determined as the chronology of the Par lacustrine deposit depend upon 1 OSL sample only and only describe the lower limit of the deposit, the beginning of the deposition.

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Dated

2oth July, 2018 **Rakesh Saini**

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LIST OF ACRONYMS AND ABBREVIATIONS

Abbreviations	Meaning/ Explanation
LIA	Little Ice Age
1ka	1000 years
≤	is less than or equal to
TL	Thermoluminescence dating
OSL	Optically-Stimulated Luminescence Dating
CRN	Cosmogenic Radio-Nuclide Dating
^{14}C	Radiocarbon Dating
ISM	Indian Summer Monsoon
a.s.l.	Average Sea Level
NW	North-West
ELA	Equilibrium Line Altitude
GTS	Great Trigonometric Survey
LGM	Last Glacial Maximum
LLGM	Local Last Glacial Maximum
MCA	Medieval Climate Anomaly
MWP	Medieval Warm Period
~	Approximately
HHCZ	High Himalayan Crystalline Zone
Ma	mega-annum is a million years
U-Pb	Uranium–lead dating
MCT	Main Central Thrust
IUCCC	Inter University Consortium on Climate Change
TRMM	Tropical Rainfall Measurement Mission
SD	Standard Deviations
CV	Coefficient of Variation
USGS	United States Geological Survey
TM	Thematic Mapper
ETM	Enhanced Thematic Mapper
OLI	Operational Land Imager
IRS	Indian Remote Sensing
GPS	Global Positioning System
DGPS	Differential Global Positioning System
LISS	Linear Imaging Self-Scanning Sensor
2σ	Two Standard Deviations
THAR	Toe to Headwall Area Ratio
TSAM	Toe to Summit Altitude Method

Chapter I

SIGNIFICANCE OF THE STUDY, RESEARCH QUESTIONS & OBJECTIVES

1.1 Introduction:

The Himalayan glaciers exist in a climatically and topographically dynamic environment. Multiple climatic systems (North Western Disturbance and Indian Summer Monsoon and Polar Jets) prevail in different degrees in the periphery of this region, almost at a sub-continental extent. Instrumental analysis of recent climate (Bookhagen and Burbank, 2006; Bhutiyani et al., 2007) and plaeoclimatic observation, based on high resolution climate records from caves (Kotlia, et al., 1997; Sinha et al., 2011; Sanwal et al., 2013; Liang et al., 2015), tree rings (Singh and Yadav, 2002; 2005; Yadav, et al., 2009; Yadav, 2011a; 2011b; Yadav and Bhutiyani, 2013; Yadava et al., 2016; Yadav et al., 2017), lake deposits (Pant et al., 2005; Juyal et al., 2009; Wunnemann, et al., 2010; Mishra, et al., 2014; Rawat et al., 2015; Bali et al., 2017), ice cores (Thompson et al., 1997; 2000) and glacial landforms (Owen et al., 1996; 2000; 2001; 2002b; 2002a; 2005; 2008; 2009; Sharma and Owen, 1996; Derbyshire and Owen, 1997; Lehmkuhl et al., 1998; Owen and England, 1998; Benn and Owen, 1998; Owen and Derbyshire, 1998; Hewitt, 1999; 2005; Mitchell et al., 1999; Puri et al., 1999; Steig, 1999; Benn and Lehmkuhl, 2000; Richards et al., 2000a; Taylor and Mitchell, 2000; König, 2001; 2004; Finkel et al., 2003; Barnard et al., 2004b; 2004a; Fort, 2004; Mayewski et al., 2004; Lehmkuhl and Owen, 2005; Pant et al., 2005; Benn et al., 2005; Wagner, 2005; Smith et al., 2006; Seong et al., 2007; Owen, 2009; Dortch et al., 2010; Scherler et al., 2010; Mehta et al., 2012; Cogley, 2012; Deswal, 2012; Murari et al., 2014; Xu and Yi, 2014; Hochreuther et al., 2015; Solomina et al., 2015; 2016; Bisht et al., 2015; Saini et al., 2016; Orr et al., 2017; Deswal et al., 2017; Sharma et al., 2018; Shukla et al., 2018) suggest large variability in precipitation and temperature across the Himalayas on a millennial scale.

Yet the region is poorly studied because of inaccessibility and non-availability of meteorological and hydrological data (Bhutiyani et al., 2007). Proper understanding of climate of this region is most wanted as it contains the large cluster of glaciers, a source of water for the 800 million population in the forefield (Bolch et al., 2012). Any significant climate change in the region in future can have large glacier fluctuations, and subsequent glacier related hazards down the valley in minutes to decades scale (Richardson, et al. 2000). Despite such an importance, large gaps exist in our understanding of the climatic variability that exists in the region at variety of scales. It is obvious that more information is needed to understand this complex issue.

In the present thesis, an attempt has been made to address the issues and techniques to reconstruct the late Holocene glacio-archeological history of the Miyar basin, Lahaul Himalaya, focusing on geomorphological, archaeological and mineralogical signatures. Assessment has been made as to how the glacio-archaeological chronology of this region concur with other climatic and glacial proxy records from the North West Himalaya. Thus the study will contribute to the greater understanding of spatial character of the climatic variability, glacial fluctuations and human occupation and migration in the North-West Himalaya on a millennial scale.

1.2 Significance of the Research

1.2.1 Glacial Chronology

The style and timing of past glacier fluctuations in the Himalayas is widely contested. However, the late Quaternary maximum glacier expansion in the Himalaya has been asynchronous with the global Last Glacial Maximum (Goudie, 1984; Owen et al., 1996; Sharma and Owen, 1996; Derbishyre and Owen, 1997; Owen, 2001; Barnard et al., 2004a; Lehmkuhl and Owen, 2005; Owen, 2009; Heyman, 2014; Murari et al., 2014; Sharma et al., 2016; Deswal et al., 2017; Orr et al., 2017; 2018). Likewise, it is widely believed that the timing and extent of the Holocene climatic variability and associated glacial fluctuations in the Himalaya differ notably from northern latitudes (Mayewski et al., 2004; Wanner et al., 2008; Srivastava et al., 2013; Xu and Yi, 2014; Murari et al., 2014; Solomina et al., 2015; 2016; Rowan, 2016; Deswal et al., 2017; Orr et al., 2017; 2018), and also longitudinally, from East to the West.

Little is known about the recent glacial fluctuations that occurred in the last millennium (Xu and Yi 2014; Rowan 2016; Solomina et al. 2016), the most explorative time period of the human generations, associated with voyages, explorations of new habitats, markets and space for human migration and settlements in the remotest areas of the world. It is a matter of concern that why people move away from their indigenous locations. Was it just the curiosity or there were other regions such as climatic and environmental changes which actually led people to hunt for the new destinations? Climatically, the period 1300 to 1850 (with a peak between 1300-1600) in Europe, is considered as the period of Little Ice Age (LIA), where a notable glacier expansion occurred along with the lower temperatures in the northern hemisphere (Bradley and Jones 1993; Mann 2002). However, in the Himalayas the LIA is an axiom. As in the absence of glacial chronology for the last millennium in the region, the relative size and extent of the Himalayan moraines were compared with that of the LIA glaciers in Europe (Mayewski and Jeschke 1979).In comparison, to have the glacier expansion in the Europe, the Himalayan glaciers are reported retreating since 1850s (Mayewski and Jeschke, 1979b). The LIA climatic regressions and associated glacial activities during this period has been the topic of debate at the global and regional scale. Researchers believe that during the LIA, glaciers throughout the world expanded (Porter, 1981; Grove and Switsur, 1994; Grove, 2001), while, others reported that glacier expansion occurred only in areas north of 20°N (Mann, 2002; Matthews and Briffa, 2005). In addition to such debates, researchers sometimes have differing opinions as to what caused the LIA glacial expansion. They suggest that the LIA glacial expansions were a consequence of increased precipitation (Bradley and Jones, 1993), whereas, others believe that this was driven by a significant fall in temperature (Hughes and Diaz, 1994; Grove, 2001; Mann, 2002; Nesje and Dahl, 2003). Such uncertainties often persist because of absence of the LIA records from different parts of the world, limiting one's ability to assess regional and global patterns of climate and glacier behavior during this period.

Recent review studies have attempted to generate the glacial chronological of the last two millennium (Xu and Yi, 2014; Rowan, 2016). Xu and Yi, (2014) reviewed available dates of the LIA moraines in and across the Himalaya and Tibet plateau, whereas, Rowan (2016) has provided a review of the geo-chronological evidence for the LIA glacial advances in the Himalaya. Figure 1.1 presents a combined synthesis of dated chronologies for the last 2000 years available for the Himalaya and Trans Himalayas (Xu and Yi, 2014; Rowan, 2016). These researches suggest two stages of glacier advance i.e. Neoglaciation (between 300 and 900 AD) and Little Ice Age (1300-1900) in this region. Neoglacial is proposed to be a common phenomenon for the Eastern and Central Himalaya, along with few records for the Western Himalaya and Karakoram, whereas it was absent beyond Karakoram (Tian Shan, Qilan Shan, Hengduan Shan, Nyainqentanglha Shan, Pamir). Such spatial pattern indicates towards different climatic mechanisms that dominated the Western and Eastern Himalaya during the Neoglaciation. Chronological records for the last millennium suggest that the LIA peaked between 1300 and 1900 rather than 1300-1600 in the region (Rowan, 2016). However, duration of the LIA was shorter (between 1300 and 1600) in the Eastern Himalaya (up to Everest) than the Middle and Western Himalaya and beyond (1300 and 1900 AD) (fig.1.1). Contrary to extended Neoglacial fluctuations in the Eastern and Central Himalaya, the LIA extent is found to be relatively more active in the North Western and the Trans Himalaya regions (fig. 1.1). Noticeably, the frequency of obtained ages for the LIA is mainly from the Trans Himalaya (beyond Pamir), Garhwal and Everest Himalaya that enforce the dominance on chronology for the entire region until now (fig.1.1). The figure also indicates elevation gradient (from NW to South East) in the 2k glacial chronology of the region. The Trans Himalayan (beyond Karakoram) glaciers recorded advance at 4000-5000m asl whereas it was relatively lower in the south East Himalayas.

Further observation of the available 1k glacial chronology in the Himalaya reveals variation in timing and extent of glacial advance, and are mostly based on relative rather than absolute chronologies (Derbyshire and Owen, 1997; Mayewski and Jeschke, 1979a; Mayewski et al., 1980; Mehta et al., 2014; Owen et al., 1996; Sharma and Owen, 1996; Taylor and Mitchell, 2000), wherever the numerical dating technique has been applied, a limited number of dates are given (≤ 2) (Iwata, 1976; Richards et al., 2000b; Owen et al., 2001)). Areas which have been historically accessible such as Khumbu (Bendict, 1976; Iwata, 1976; Fushimi, 1978; Muller, 1980; Rothlisberger and Geyh, 1986; Richards et al., 2000), Garhwal (Sharma and Owen, 1996; Barnard et al., 2004b; Murari et al., 2014); Milam (Barnard et al., 2004a), Gonga Shan (Owen et al., 2005) have provided the most dates.

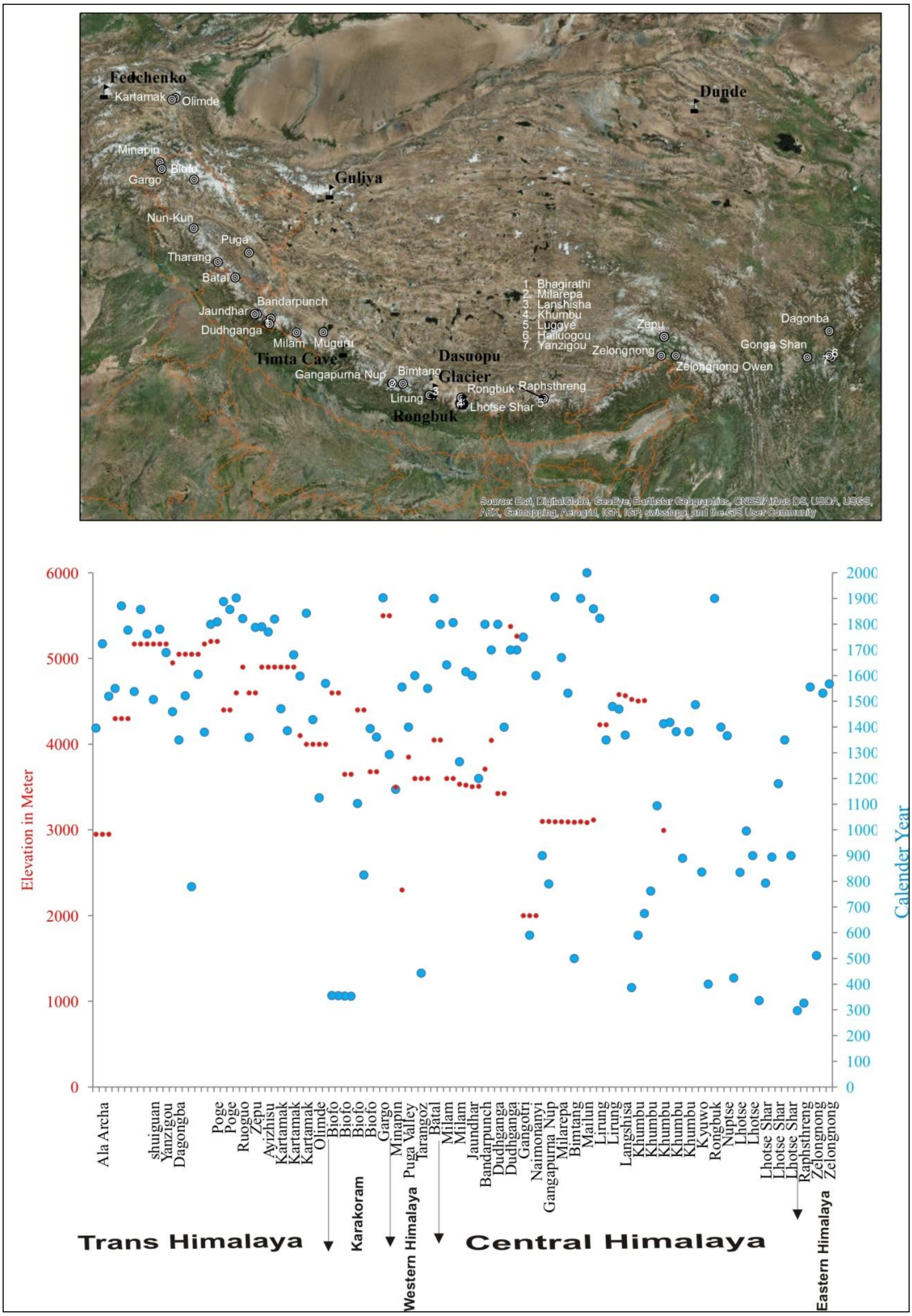

Figure 1.1 Glacial chronologies of the Himalayas for the last 2 millennium with spatial and temporal characters. Data combined from the compiled works of Rowan, 2016; Xu and Yi, 2014.

The glacial chronology of the last two millennium is dominated by the Central Himalaya (Khumbu and Garhwal Himalaya, fig. 1.1). Therefore, it is necessitated to have more studies from the inner parts of the Himalaya for the robust glacial chronology of the period; and also to understand human activities in the backdrop of prevailing climate, ecology and availability of water. The studies on the glacial chronology also suggest that the Himalayan glacial fields are devoid of suitable organic material. Most of the chronologies are based non standard radiocarbon methods and other techniques (including thermo-luminescence, TL; optically-stimulated luminescence, OSL; and cosmogenic radionuclide, CRN dating). Although these methods have been widely applied globally, yet these have associated limitations in the high energy Himalayan environment in determining ages within millennial scale (Jensen et al., 2000; Wallinga, 2002; Spencer and Owen, 2004; Blair et al., 2005; Bailiff et al., 2014).

Given the limited availability of organic material in recently de-glaciated environments in the Himalayas, radiocarbon (^{14}C) dating has been used less frequently. However, where datable organic materials are found, ^{14}C technique provides a means of establishing more robust chronology for recent glacial and climatic fluctuations. This study primarily addresses the glacial chronology of the Miyar basin, Lahaul Himalaya based on radiocarbon ^{14}C dating of archaeological relict, full of potentially datable organic material.

1.2.2 Geomorphic Significance

The Miyar basin is a major sub-basin of the lower Chandrabhaga valley within the Great Himalayan Tract of the Lahaul and Spiti district of Himachal Pradesh, India.

The area is accessible through Rohtang Pass (3970m a.s.l.) in south, Baralacha (4840m) in east and Killar in west, only during summer months (between May to September). Topographically, it is sandwiched between the lofty Pir Panjal on the south and the High Himalayan Range to the north. The Pir Panjal acts as a barrier for northward approaching Indian Summer Monsoon (ISM) (fig. 1.2), resulting in a strong moisture gradient of increasing aridity towards north (Owen et al., 1996; Hijmans et al., 2005; Bookhagen and Burbank, 2006; Bhutiyani et al., 2007).

The area above 4000m a.s.l. is dominated by glacial and periglacial processes, such as plucking, abrasion-ploughing, freeze-thaw shattering, solifluction etc; whereas altitudes between 3200 m and 4000 m asl are dominated by paraglacial processes. The contemporary Equilibrium Line Altitude (ELA) lies between 4900 and 5200 m a.s.l (Saini, 2012; Deswal et al., 2017). The trunk valley (main Miyar Valley) above 3200m asl displays an open U shaped cross profile, with a valley floor filled with late Quaternary glacial sediments (Deswal et al., 2017), providing abundant scope for dating and understanding the glacial dynamics of the region.

Moreover, the Holocene moraines complex between Khanjar (the last sedentary village in the main trunk valley at 3500m a.s.l.) and Gumba (where Miyar stream confluence with Gumba stream with most assemblage of moraines and broadest U shaped main trunk valley in upper the Miyar basin) encompasses several sites of completely dilapidated settlements now in ruins; the prominent are Tharang, Phundang and Patam within Tharang moraine complex. In spite of such huge plaeoclimatic repositories, the basin has been rarely studied, and little is known of the glacio-archaeological history.

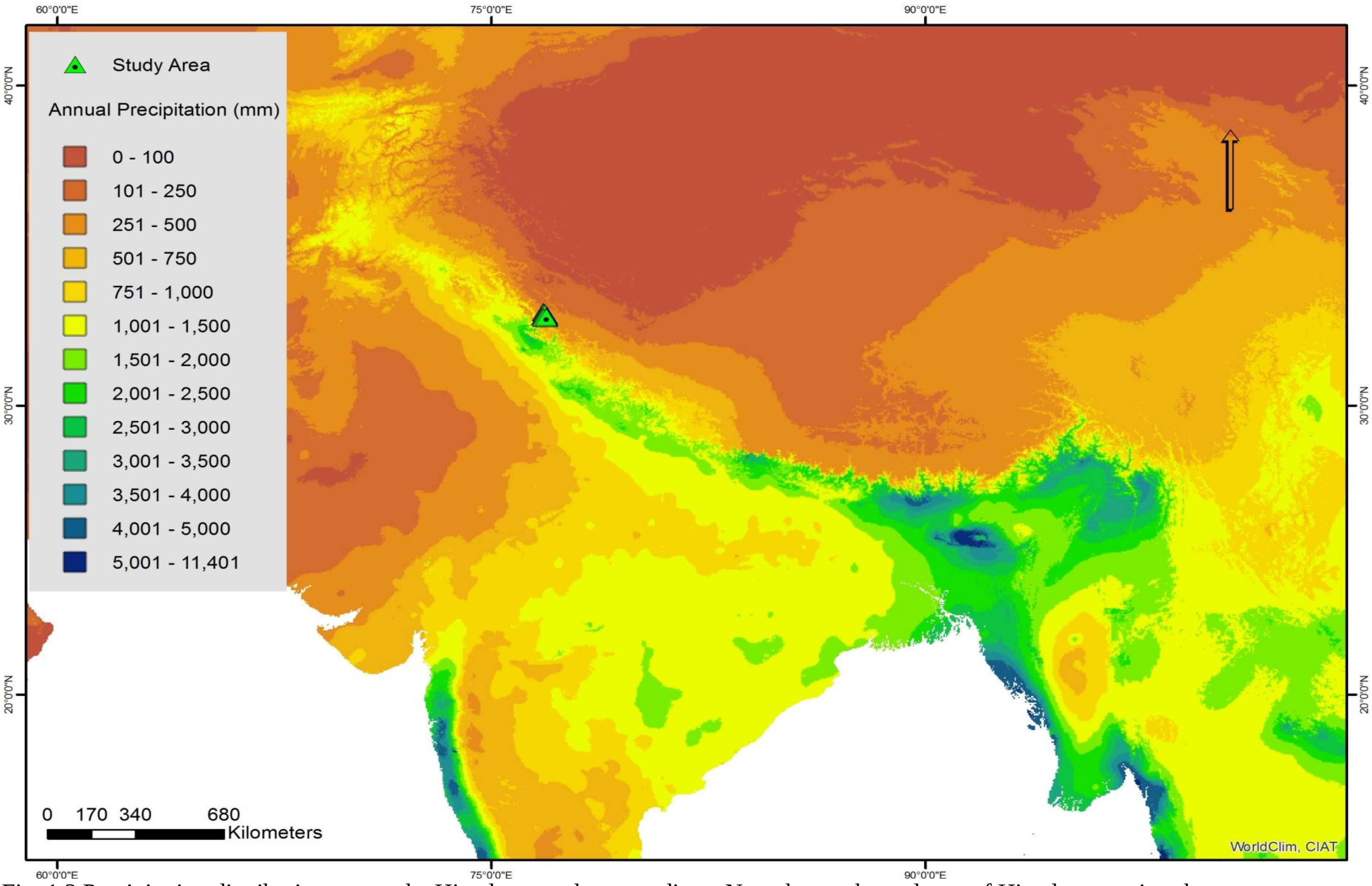

Fig. 1.2 Precipitation distribution across the Himalayas and surroundings. Note the southern slopes of Himalaya receives heavy Monsoon rainfall (1000- 5000 mm) whereas the northern slopes of Pir Panjal range in the NW Himalaya (along the study area) receives scanty rainfall, (annual precipitation after Hijmans et al. 2005).

1.2.3 Glacio-archeological Significance

The Tharang glacier end moraine complex (at 3710m a.s.l.) in the Miyar basin, Lahaul Himalaya contains a record of glacio-archaeological features. Existence of number of dilapidated settlements within these moraine ridges still have considerable information in the form of organic remains, be it bones or wood or charcoal. These remains hold much significance, given that under the modern climatic conditions, permanent habitation and agriculture are confined in areas below ~3500 m a.s.l. The presence of large number of ruins at an elevation of ~3710 m a.s.l., along with organized irrigation system and demarcated fields suggest that during the time of human habitation, climatic conditions may have been conducive for such activities.

Therefore, Tharang glacier might have been restricted, within the contemporary limits as the end moraine complex thrived with human activity. The significance of these archaeologically important ruins magnify manifold, given that the proximity of Tharang glacier terminus and ruins are marked properly on the historical maps (Harcourt, 1871 and Secretary of State for India, Great Trigonometric Survey, 1874). The assessment based on the glacio-archaeological, geomorphological and historical evidence using accurate radiocarbon dates presented in this study is the first glacio-archaeological history of the Miyar basin, Lahual Himalaya for the last millennium. This study is confined to one millennium only based on organic content constrained using ^{14}C technique.

The envisaged research questions and objectives that this study addresses are:

1.3 Research Questions:

1. How has the climate varied in the North Western Himalaya over the last millennial?
2. How did the human settlement survived in the Tharang End Moraine complex at 3700m asl?
3. Does the climate correlate with the glacial fluctuations and human activity in the Miyar basin?

1.4 Objectives:

1. To reconstruct the Late Holocene climatic history of the Miyar basin through proxy material.
2. To reconstruct the history of human habitation at Tharang end moraine complex within the Miyar basin.
3. To evaluate the history of glacial fluctuations in the Miyar basin using landforms and historical records.
4. To present a synthesis between the history of climate, settlements and glacial fluctuation in the Miyar basin, Lahaul Himalaya.

1.5 Previous studies on similar theme

Palaeo-climatic studies based on multi-proxies in the North West Himalayas suggest variability of climate across the region over millennial scale. Dendro-chronological studies in the north west Himalaya (Uttarakhand) indicate low precipitation during 15^{th} and 16^{th} Centuries AD, with 1410–1510 being the driest period in past 600-years (Singh and Yadav, 2005; Yadav, 2011a). Similar study in Lahaul & Spiti revealed high magnitude droughts during the 14th and 15th centuries and increasing wet conditions thereafter ((Yadav, 2011b). However, Yadava et al., (2016) revealed decreased precipitation between 12th to early 16th century and then progressive increase between 16th to 19th century with a peak around 1840.

Based on speleotherm, Sinha et al., (2011) have suggested a break in the Indian Summer Monsoon during AD 1400 to ~1700 and an increase (active) during AD ~1700 to 2007 whereas, Sanwal et al., (2013) reported two distinct phases of reduced precipitation towards the end of Medieval Warm Period, MWP (~1080-1160AD) and after its termination from ~1210 to 1440AD. The LIA (~1440-1880AD) is represented by sub-tropical climate similar to modern conditions. However, Liang et al., (2015) reported warmer and drier conditions during the Medieval Climate Anomaly (MCA) and also in the post-LIA periods, but cooler and slightly wetter conditions during the Little Ice Age (LIA), which lasted from ~AD 1489-1889, and AD 1450-1820.

Table 1 reveals the comparative timings of dated LIA glacier advance across the Himalayas by various studies. Chronologically, Mayewski and Jeschke, (1979) and Mayewski et al., (1980) for the first time reported the LIA glacier advance in parts of the Himalayas. These studies reported the LIA glacier advance based on the relative size and proximity of moraines to the contemporary glacier terminus that of European glaciers and mentioned 1850s as the end of LIA in parts of the Himalayas. Later on Derbyshire and Owen, (1984) constrained such moraines to Pasu I advance (800 years old) by radiocarbon (^{14}C) dating and reported the timing of these moraine even before the LIA in Europe. In 1996 two new studies from Garhwal (Sharma and Owen, 1996) and Lahul (Owen et al., 1996) reported LIA advance in these parts of the Himalaya, however the timings were based on relative rather than on absolute dating. In the year

1997, Owen et al., (1997) revised the glacial chronology of the Lahul region. The study based on OSL dating reported the timing of Batal I and II stage between 43 400 ± 10 300 and 36900 ± 8400 and Kulti stage around 9160 ± 70 ^{14}C but could not confine the timing of the LIA advances (Sonapani I, II). Later on Taylor and Mitchell, (2000) in parts of the Zanskar Himalayas reported LIA advance as Sonapani I and II, similar to the Lahul Himalaya (Owen et al., 1996; Derbishyre and Owen, 1997).

In the year 2001, Owen et al., (2001) based on the Cosmogenic radionuclide dating referred the dates (0.1±0.04) of Sonapani II advance and chronologically confined these moraines to be historical. In the year 2004, (Barnard et al., 2004b) revisited the Garhwal region and confined the timing of LIA glacier advance by 200-300 years old. In the same year (Barnard et al., 2004a) visited the Gori Ganga basin and constrained the Milam glacier LIA advance by 400-300years old. Contrary to these recent dates of LIA advance, Richards et al., (2000b) in the Khumbu Himalaya dated these Moraines to the Lobuche Stage (ca. 1–2 ka OSL). However, Seong et al., (2007) based on ^{10}Be terrestrial cosmogenic nuclide surface exposure dating of LIA moraines in the Karakoram Himalaya referred them of Askole glacial stage (7dates covering entire span of LIA). Recent two studies in lower Lahaul Himalaya (Saini et al., 2016b; Deswal et al., 2017) prescribed limited glacier in the Miyar basin during the LIA peak (1300-1600) and reported a glacier advance between the late 18th and early 19th centuries. Similarly, Orr et al., (2017; 2018) in Zanskar valley referred the LIA advance (200 years back) defined using cosmogenic10Be surface exposure dating.

Table 1.1 Comparative timings of dated LIA glacier advance across the Himalayas.

Region	Advance 0-200 Back	Advance 200-800Back	Study	Resolution	Remarks
Miyar	Historical		This study	9 dates	Radiocarbon dates
Lahul	Sonapani II	Sonapani I (800)	Owen et al. (1996, 1997, 2001)	1 Date	Based on CRN
Zanskar	Sonapani	Sonapani I (800)	Taylor & Mitchell (2000)		Based on Relative dating
Gangotri		Bhujbhas Advance (200-300)	Sharma & Owen (1996) Barnard et al. (2004)	1 date	Based on OSL
Alknanda		LIA	Bali et al. (2013)		Based on Relative dating
Nanda Devi		LIA	Barnard et al. (2004)	5	CRN four dates belongs to historical and One for LIA
Central Karakoram	Askole	Askole	Seong et al. (2007)	7 dates	Based on CRN Covering entire span of LIA
Middle Hunza	Pasu II	Pasu I	Derbyshire et al. (1984)	2 dates	Radiocarbon dates for Pasu I
Gilgit	Historical	LIA	Shroder et al. (1993)		
Hunza	Historical	LIA	Zhang & Shi (1980)		
Upper Indus	Historical	LIA	Cronin (1982)		
Swat		Drang -Drung	Porter (1970) Richardson (2000)		
Khumbu			Ben et al. (2000)		

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1.5.1 Glaciers as Indicators of Climate Change:

Glaciers are very sensitive to environmental changes. Any increase in temperature and rainfall are directly reflected in the mass balance of the glacier on annual basis (Embelton and King, 1975). The oscillation in climatic parameters such as temperature and precipitation results into fluctuation in glacier size and mass. Glaciers retreat in response to decreasing snowfall and increasing dry air temperature and advance with vice versa conditions (Benn and Lehmkuhl, 2000). When a glacier advances, it brings huge debris along with the ice, and deposits the same in the form of various glacial landforms such as terminal moraines, recessional moraines, medial moraines, hummocks, drumlins, kame terrarces, etc. (Embelton and King, 1975; Barr and Clark, 2012). These landforms have been used as the mean to reconstruct the palaeo-glacial extents by the glaciologist (Mayewski and Jeschke, 1979a; Owen et al., 1996; 2001; Sharma and Owen, 1996; Wagner, 2005; Barr and Clark, 2012; Mehta et al., 2012; Saini et al., 2016b; Deswal et al., 2017). Equilibrium Line Altitude (ELA), the line of zero mass balance of a glacier for the annual budget is also used as mean to reconstruct the palaeo-climate (Embelton and King, 1975). ELA rises in response to decreasing snowfall and increasing dry air temperature (Sharma and Owen, 1996; Benn and Lehmkuhl, 2000; Benn et al., 2005; Osmaston, 2005; Dortch et al., 2010). Comparisons between former and present day ELAs yield valuable information on the magnitude and extent of climate change in an area (Lowe and Walker, 1984; Bradley, 1985; Porter, 1977). In another sense, regional variation in ELAs helps to reconstruct the palaeo-climate as they indicate the precipitation and temperature gradient, which allows to rebuilt the moisture sources and atmospheric circulations patterns of the past (Benn and Owen, 1998; Benn and Lehmkuhl, 2000; Scherler et al., 2010; Heyman, 2014).

Therefore, the glacial proxies can be utilized as mean to reconstruct the palaeo-climatic conditions of an area. Reconstruction based on such proxies are important at two scales; firstly at global scale for environment monitoring with prediction of past and future climate conditions and secondly, for the impact of the glacial fluctuations upon the local habitats in the form of glacial lake outburst, lahars, alluvion, and avalanche and loss of property and pasture land (Reynolds, 2000). As high latitude and alpine environments are vulnerable to such events

1.5.2 Quaternary Glacial Studies in the Himalayas:

Recent studies have focused on the Quaternary history of the Himalayas and Trans-Himalayas. Table 1.2 presents the brief overview of the quaternary glacial history across the Himalayas and includes Karakoram Mountain (Derbyshire et al.,1989; Shroder et al., 1993); the Nanga Prabat Himalaya (Shroder et al., 1989; Shroder et al., 1993; Scott, 1992); the Swat Himalaya (Porter,1970; Owen et al., 1992); the Kashmir Himalaya (Holmes and Perrot, 1989); the Ladakh Himalaya (Burbank and Fort,1985; Osmaston,1994); the Nepal Himalaya (Fushimi,1977; Iwata,1984; Iwata et al., 1982; Fort,1987,1993,1995; Shiraiwa and Watanbe, 1991; Zech et al., 2002); the Lahaul Himalaya (Owen et al., 1996; 1997; 2001; Saini et al., 2016b; Deswal et al., 2017); the Garhwal Himalayas (Sharma and Owen, 1996; Barnard et al., 2004b); the Kanchanjunga Himalaya (Asahi, 2000); the North Pakistan Himalaya (Richards et al., 2000); the Khumba Himalaya (Richards et al.,2006); the Zanskar range (Taylor and Mitchell, 2000). Findings on Quaternary history of the Himalaya indicates that this part of world has experienced variations in timing and stages of glaciations and has no association with Glacial Maximum of Europe and America, at the same time the number of glacial advance and their timing also varies within the region from one valley to valley.

1.5.3 Studies on the Himalayan Glacier Monitoring

Monitoring of the Himalayan glaciers began with Madden (1847) (Bandyopadhyay, 1998), but more serious observation were recorded by Blanfordin (1873, 1877, 1891) and Theobold in 1874; followed by Bose (1891); Oldham,(1904); Geological Society of India (GSI, 1907; Cotter & Brown, 1907; Pascoe and Walker, 1907; Hayden, 1910; Grinlinton, 1911, 1914); and International Geophysical Year team in 1957-58 and

Table: 1.2 ELA fluctuations in the Himalayas.

Region	ELA last time	ELA Contemporary	Reference	Number of Glacial Stages or Advance
Lahul	*the timing of the Batal and Kulti Stages to 12–15.5 and 10–11.4 ka, the ELAs ranged from _3960 to 4270m a.s.l. and 4266 to 4726m a.s.l., respectively.*	*4800 to 5500m a.s.l*	(Owen et al., 1996; 1997; 2001; Saini, 2012; Deswal et al., 2017)	*Evidence for five glacial advances, which they called the Chandra, Batal, Kulti and Sonapani I and II*
Ladakh	*ELAs for a late Pleistocene maximum advance were ~ 4300 and 4700m a.s.l. in the Ladakh Range and Zanskar Range, respectively.*	*5200 and 5400m a.s.l*	(Dortch et al., 2010)	*Pleistocene maximum moraines in the Ladakh Range are 100 ka old ''Kar Stage have CRN ages of _70 ka*
Zanskar	*ELA during Pleistocene glacial maximum was ~ 600 m ∆ELA for their ''Batal'' and ''Kulti'' glaciations were _500 and 300 m, respectively.*	*5500 to 5800m a.s.l.*	(Owen et al., 1996; Taylor and Mitchell, 2000; Orr et al., 2017; 2018)	*''Batal Stage'' moraines of between 4079.3 and 78712.3 ka ''Kulti Glacial Stage*
Hunza valley	*1000 m.*	*DELA of 1100–1250m,a.s.l.*	(Owen et al., 2002c)	*Ghulkin I Glacial Stage is equivalent to the global LGM.Borit Jheel and Yunz glacial stages that are dated to MIS 3*
Nanga Parbat middle Indus valley	*∆ELA of between 720 and 800m for the local LGM using toe-to-headwall altitude ratio (THAR) of 0.4. Holocene (9.0–5.5 ka)*		(Owen et al., 2000)	*1*
Chitral	*∆ELA of _1200 m. Marine Isotope Stage 3 (MIS 3: 40.973.5, 40.673.7, 52.074.6, 36.673.0 ka and 27.0–55.2 ka)*		(Owen et al., 2002b)	*4 Drosh Glacial Pret Glacial two minor glacial advances, the Shandur and Barum Glacial stages,*
Swat Himalaya	*Pleistocene ∆ELA for these glaciations of between _900 and 1100m for the Laikot, Gabral and Early and Middle Kalam glaciations, and _300m for the Late Kalam glaciation*	*4000 and 4250m a.s.l.*	(Richards et al., 2000a)	*3 Laikot (oldest), Gabral and Kalam*
Garhwal	*former ∆ELA for the local LGM (_63 ka), Bhagirathi Glacial Advance at _640 m, the mid Holocene Shivling Glacial Advance at 40–100m and the Bhujbas Glacial Advance (LIA) at 20–60 m.*	*4510 to 5390m a.s.l.*	(Sharma and Owen, 1996; Barnard et al., 2004a)	*Bhagirthi Stage 63 ka-5 ka Shivling Advance < 5ka BP Bhujbas Advance 300 -200 BP*
Kashmir	*ELAs in Kashmir rise in a broadly south-west to north-east direction, from about 3900 to 4700m a.s.l.*	*the magnitude of past ELA depressions (700–800 m)*	(Owen et al., 1998)	
Langtang	*Fort (1995) estimated a ∆ELA of 510m for the Gora Tabela Stage*		*Shiraiwa (1993)*	*Six glacial stages Lama Stage; the Gora Tabela Stage (equivalent of the global LGM); the Langtang Stage Holocene Maximum); the Lirung Stage (late Holocene); and the Yala I and II Stages (Little Ice Ages).*
Mount Everest	*Neoglacial and Late Pleistocene ∆ELA to be ~ 50–100 and 350–450 m, respectively*	*ELAs average between 5800 and 5900m a.s.l*	(Richards et al., 2000b; Owen et al., 2009)	*Three Pleistocene glaciations*
Kanchenjunga	*ELA for the LGM across the Kanchenjunga Himalaya and showed that they rose from ~ 4200–4500m a.s.l. to ~ 5200m a.s.l*	*~ 5000m a.s.l. ~ 6000m a.s.l.*	(Tsukamoto et al., 2002)	*Three glacial advances to 5–6, 8–10 and 20–21 ka. The oldest advance, and coincident with the Global LGM*

the International Hydrological Programme team in 1965.The detailed work of Mayewski and Jeschke (1979) are among the initial records of the Himalayan glaciers. Recent studies on the retreat of glaciers by Space Application Centre (ISRO) in collaboration with many central institutes and universities in India have produced a detail preview of the glacial monitoring in the Indian Himalayas (Ajai, et al. 2011; Rajawat, 2016). Some of the studies have suggested alarming rate of retreat in the Himalayan glaciers since the last Little Ice Age in India.

1.6 Chapterisation Scheme

- Chapter I serves as an introduction to the study.
- In Chapter II, the study area is detailed along with its environmental, geological and climatic settings in addition; the population statistic of the Miyar basin has also been addressed.
- In chapter III, the Tharang glacier end moraine complex settlement history has been reconstructed based on the mapping of remains using irrigation system (Kuhls), agriculture fields; chronologically constrained by radiocarbon ^{14}C dating.
- Chapter IV documents the Little Ice Age (LIA) glacier advance, extent and equilibrium line altitude (ELA) change based on temperature and precipitation variability during the last 1000 years and available historical maps.
- Chapter V reconstructs the hydrological history of the Miyar basin based on mineralogical variation in a lacustrine deposit at Par Got, Thanpatan, chronologically constrained, based on optical stimulated luminescence (OSL) dating.

- Chapter VI puts together the discussion and results; summarising the findings of the work and to put them into broader context.

1.7 Limitation of the Study

The findings of the study are confined to the resolution of data and methods used. The broader glacio-archaeological mapping is conducted at 1:10000 scales however inset maps have been produced with a scale of 1:1000. The chronologies of the organic material from the ruins is based on the 14 numbers of radiocarbon samples. However, the LIA glacial chronology is based on the relative chronology of settlement in the Tharang end moraine complex, and other plaeoclimatic proxies such as snowfall (Yadav and Bhutiyani, 2013) and temperature (Yadav, Ram; Braeuning, Achim; Singh, 2009) available for the region. Moreover, the palaeo-hydrological history of the last 1k years for the basin is generated based on the 1.6 meter lacustrine deposits and its mineralogical profile, chronologically defined by OSL technique. Chronology of the lacustrine deposit is based on one OSL date.

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Chapter II

INTRODUCTION TO THE STUDY AREA AND ITS ENVIRONMENTAL SETTINGS

2.1 Introduction

The Miyar Valley contains a large repository of both physical and anthropogenic processes. The basin has large glacial as well as anthropogenic history in the form of scoured valley wall, terminal, lateral moraines, drumlins, strath, and contemporary human records. The well defined archeological settlements now in ruins at >3700m a.s.l. with well defined agricultural within the Tharang end moraine complex indicates towards past sedentary villages that properly thrived on the glacier margins for many centuries. The existence of sedentary villages in the glacier end moraine complex at such altitude provides a platform on which the climatic history of the area can be reconstructed. The basin certainly had experienced different climatic conditions than the present.

Contemporary sedentary villages are inhabited down valley at Khanjar (3500m a.s.l.) almost 200m less than the Tharang Complex. In comparison to pastoral activity of present times; with supplies coming from road-head and villages down valley, it is hypothesized that continued agriculture activity with large houses/ structures indicate towards well settled economy. Given the size of agriculture area and permanent settlement, it is obvious that the growing seasons were conducive with long warmer summers. Currently, such environment exists only below 3500m asl. Moreover, the basin had little anthropogenic modification of landforms or settlements, and the bounded fields, an important parameter to reconstruct the past archeological activities. Thirdly, little is known about the LIA glacio-archaeological history of this region. However, studies conducted in the upper parts of the Chandrabhaga valley (Kulti valley) suggest a relative age of the LIA for the region with two glacial advances called Sonapani I and II (Owen et al. 1996; L.a. Owen et al. 1997; L. A. Owen et al. 2001). The Kulti valley is right opposite the Rohtang Pass (3970m asl) where ingression of the Mosoon rainfall is frequent. On the other hand, the Monsoon rains in the Miyar basin are restricted by >5000m Pir Panjal Range to the south. The climatic parameters change rapidly with altitude and change in aspect and therefore, any generalization of palaeo-climate based on the observations made in the upper catchment may turn erroneous and need a specific study to reconstruct the climatic character at such locations.

2.2 Location of the study area

The Miyar basin is a major sub-basin of the lower Chandrabhaga valley. Administratively, it falls under the jurisdiction of the Udaipur sub tehsil of the Lahaul and Spiti district of Himachal Pradesh. The basin shares its northern boundary with the Zanskar region of Leh (Ladakh) district of Jammu and Kashmir while the southern is bounded by Chamba district of the Himachal Pradesh. The beautiful Pangi valley and Neelkanth valley shares its western and eastern boundaries respectively (fig.2.1). The National Highway number 21 (NH 21 from Chandigarh to Manali) connects the basin to the rest of the world. One can travel the basin by road through the Rohtang Pass but only during summer months (May to October). During winter months, the Rohtang Pass is heavily snow covered and blocks the mobility of the people. Each village in the basin has a provision of helipad which is used as a mode transport during winter months for emergency services. The basin extends from 32˚42′36″N to 33˚15′24″N and 76˚40′12″E to 77˚1′15″E, with an area of ~963.85 km^2, out of which ~21.6% (208.2 km^2) is covered by the contemporary glaciers (Saini, 2012; Deswal et al., 2017).

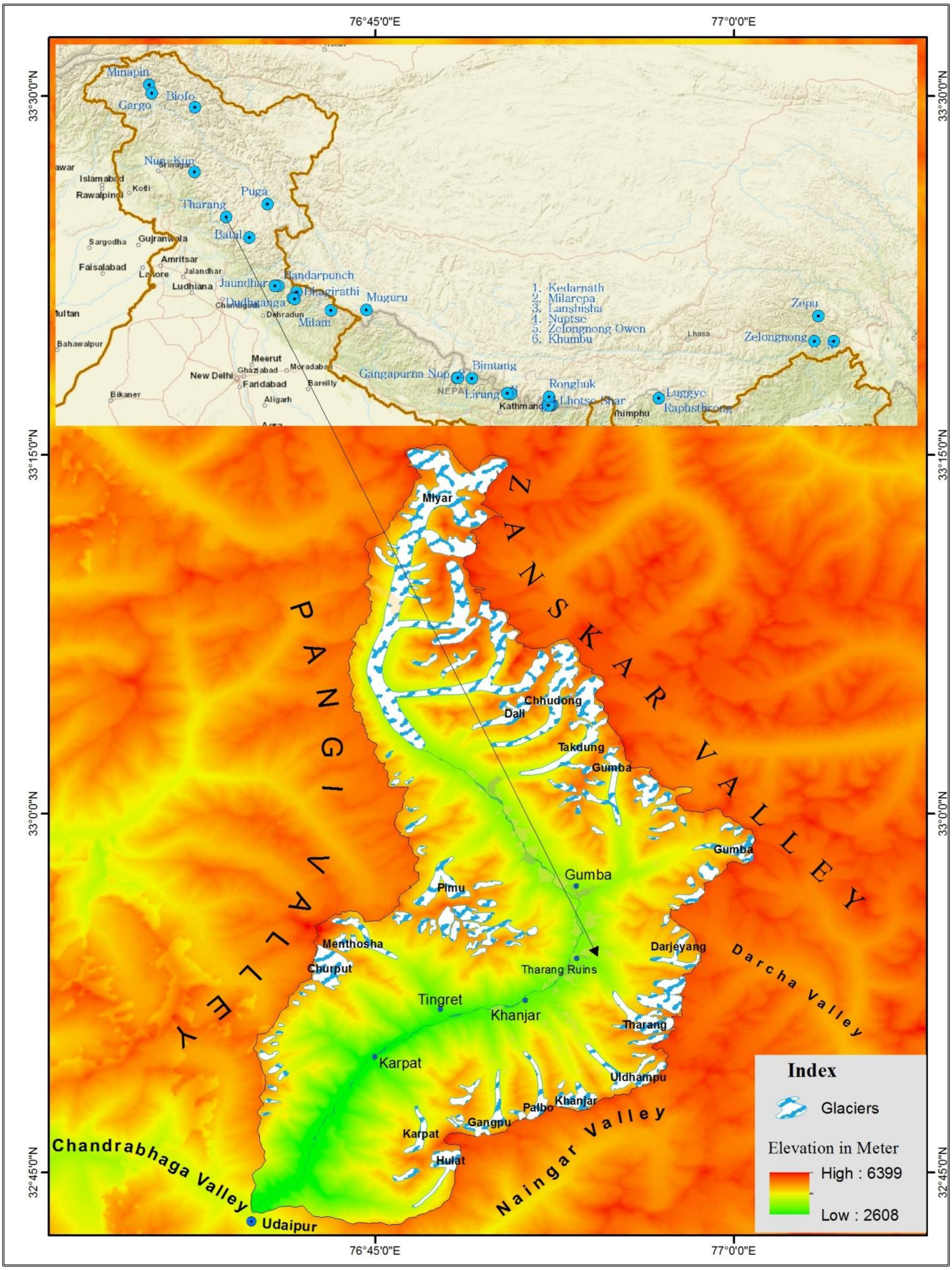

Fig. 2.1 Location map of the study area.

.The basin contains a cluster of 92 glaciers of varied dimensions and types, out of which Miyar glacier is the longest (~27 km) (Saini, 2012; Deswal et al., 2017). The Miyar glacier originates at the top of the basin at the height of 6038 m at Kangla Pass flowing south west direction initially and then turning to south east. Other glaciers are less than 10 km in length and represent many forms of alpine glaciers, ranging from valley glaciers to cirque and hanging glaciers. The Miyar stream (Miyar Nala) emanates from the Miyar glacier terminus at 4046m asl and flows through Miyar Shear Zone with south west dip (Robyr et al., 2002) upto Udaipur where it confluences with the Chandrabhaga river (2600m asl). The other important glaciers are Chhudong, Takdung, Gumba, Darjeyang, Tharang, Uldhampu, Khanjar, Palbo, Karpat, Hulat, Pimu, Menthosa and Churput which forms the origin of the tributaries of the Miyar stream. The streams that join the Miyar stream from the right bank are Pimu, Menthosa and Churput whereas rest all joins from the left bank. In terms of its location, the basin is one of the most vulnerable region of the world (Harcourt 1871; Owen et al. 1996; Deswal et al. 2017).

Topographically, the basin is sandwiched between the lofty Pir Panjal on the south and High Himalayan Range on the north. The Pir Panjal acts as a barrier for northward approaching Indian Summer Monsoon (ISM), resulting in a strong moisture gradient of increasing aridity towards north (Owen et al. 1996; Bhutiyani, et al. 2007). Observational records suggest that precipitation and temperature varies according to aspect, altitude, and dominance of wind system (Saini, 2012). The basin is dominated by severe and long winters that last from September to May. During winter months, temperatures fall to -15˚C. However, during summer months (May-September), day temperature rises to 35˚C but can fall as low as -2˚C during night time or on any cloudy day (Saini, 2012). The annual precipitation is dominated by snowfall. The contemporary Equilibrium Line Altitude (ELA) lies between 4900 and 5200m a.s.l (Saini 2012; Deswal et al. 2017). The highest sedentary village Khanjar is situated at 3500m a.s.l. However, during summer months (June-August), the alpine pastures (area above 3500m a.s.l.) are used for seasonal grazing by the transhumance Gaddis. During 2 months growing season live in hutment which are no bigger than 4×6 feet in dimension. The main valley (Miyar valley) above 3200m a.s.l. displays an open U shaped cross profile, and is broadest (about 2km) at Gumba (3800m a.s.l.) with a valley floor infilled with Quaternary and recent glacial, paraglacial sediments providing large potential for building the style and chronology of glaciers in the basin over space and time. The Holocene moraines complex between Khanjar to Gumba encompasses several sites of ruins; the prominent are Tharang, Phundang and Patam. Structurally, the ruins are in dilapidated conditions with lichen growing on the stones once used for the houses.

2.3 Geological setting

The Miyar Valley, in the upper Lahual (Lahul) represents a natural cross section through the southern border of High Himalayan Crystalline Zone (HHCZ) (fig. 2.2). Lithologically, this valley mainly consists amphibolite facies to migmatitic paragenesis. In the northern part of the basin, the continuous HHCZ is cross cut by numerous leucogranitic dykes and small plutons. These intrusions are most likely related to the early Miocene Gumburanjun Lecogranite (22.2 +/- 0.2 Ma, U-Pb Monazite, Dezes et al., 1999). The Miyar

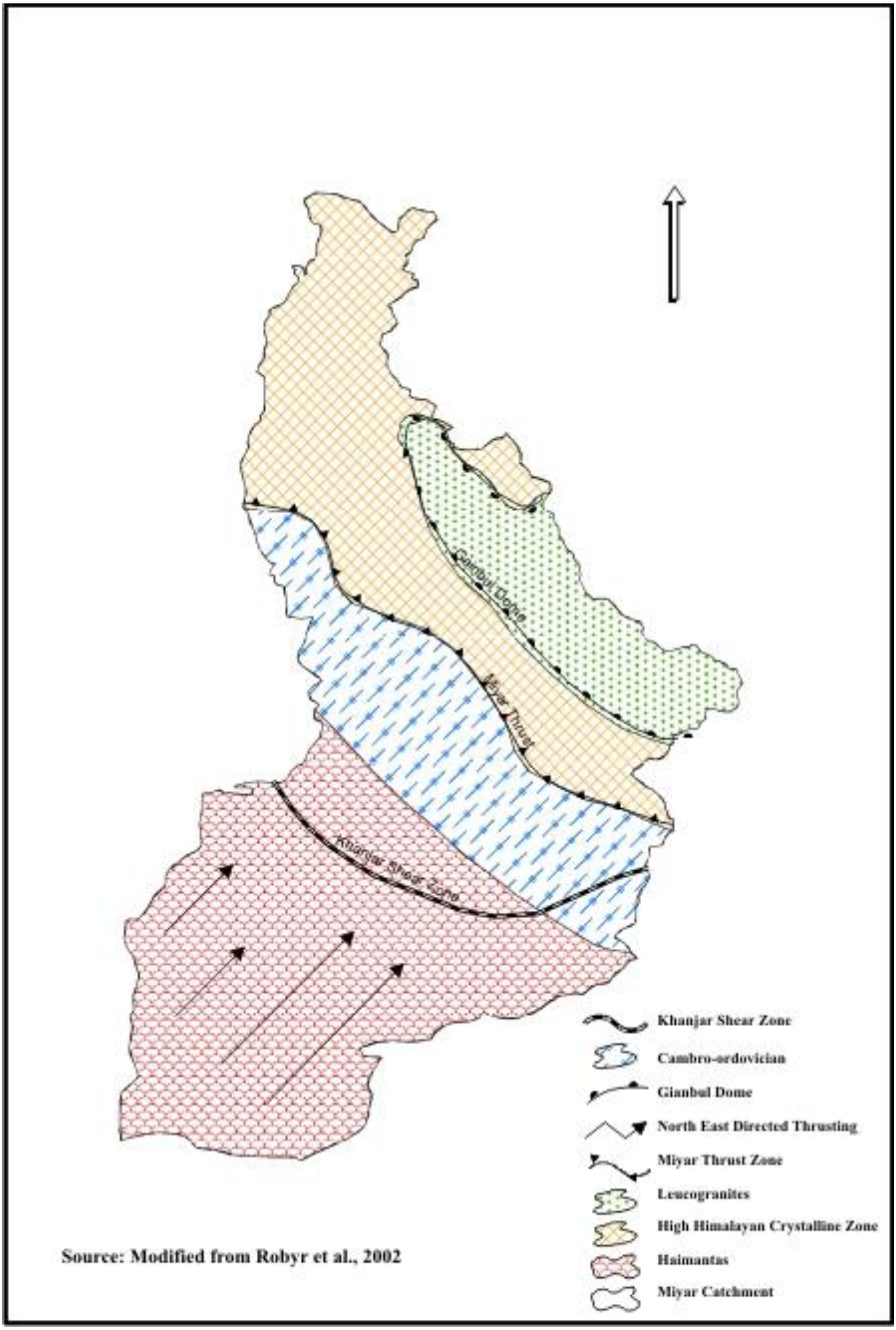

Fig. 2.2 Geological map of the Miyar basin (after Robyr et al. 2002).

valley correspondce to the SW-dipping known as Miyar Thrust Zone, which is a thick mylonitic zone affecting the orthogenesis-parageneiss contact near the pasture ground called ‘yuling’(Chhaling) (Steck et al.1999),which denotes to a thrust zone at this structural level. The tectonic evolution of the the Miyar valley section can be divided in to two major events. The earliest tectonic phase is related to thrusting along Miyar Thrust Zone, which contrast with SW directed contractional Himalayan structure with its NE directed thrust (e.g. MCT).The second major tectonic event in the Miyar valley corresponds to a large scale doming of the HHCZ.

2.4 Physiographic Settings*:*

The basin lies in the north of the Pir Panjal Range and south of Zansker Range as a sandwitch. Altitude varies from 2600 meter a.s.l. to 6448 meter a.s.l, covering 963 km^2 area with a maximum width and length of 25 and 60 kilometers respectively. Perimeter of the basin is 96318 hectares bound by snow peaks to confined valleys. The area is dominated by frost shattering and, subsequently paraglacial processes filling the valley with abundant debris in the form of debris cones, rock avalanche fans and alluvial fans. Figure 2.3 and Table 2.1 shows that the basin has a very limited area below 3500m asl, about 60 km^2; less than 7% of the total area of the basin. Physiographically, this area is confined in the form of narrow valley (fig. 2.4). This is the area within which most of the cultural activities are observed including intense agriculture, permanent settlements (villages) along with protected forestry etc. All the permanent villages (12 inhabited) including Khanjar which is the highest sedentary village in the basin is located below 3500m asl. The figure and table further shows that the area between 3500-4000m asl accounts almost 9% of the total basin area (89 km^2). Saini et al. (2016) suggested that such altitudinal zones are dominated by paraglacial and periglacial processes including, debris fan, rock avalanche, solifluction and pattern ground etc. Plate 2.1 shows sample paraglacial landforms present between Zardung and Miyar base camp, with altitudinal extent of 3800-4000m.

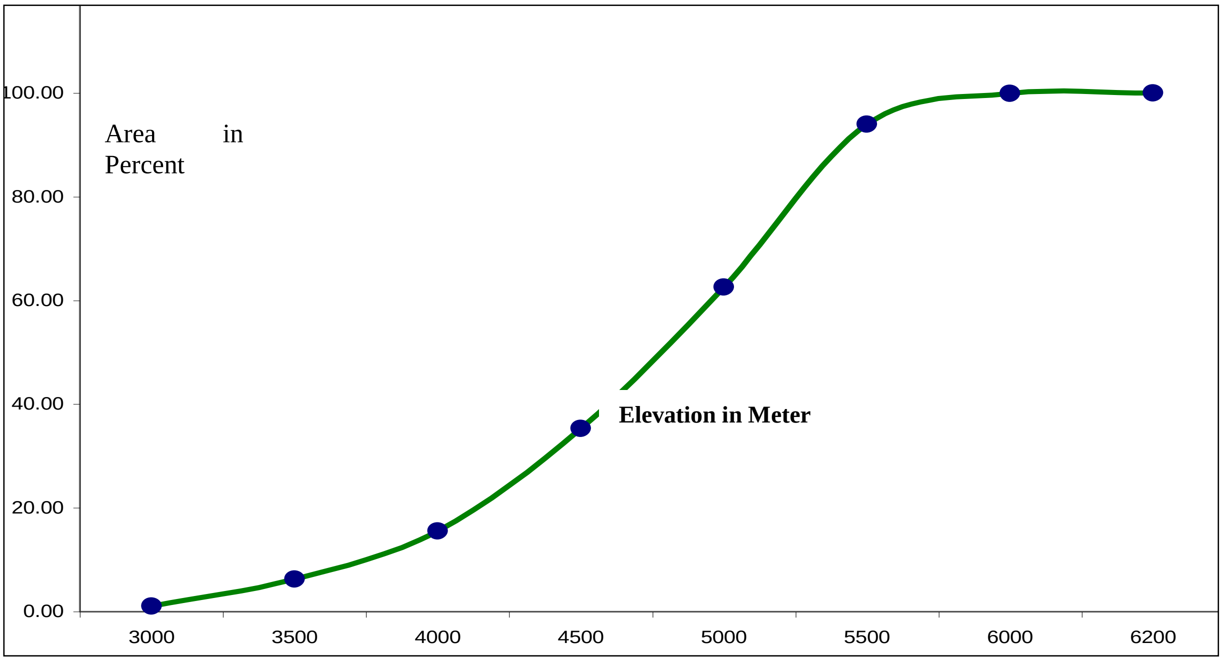

Fig. 2.3 Hypsometric curve of the Miyar basin.

Table: 2.1 Distribution of area by altitude in the Miyar basin.

Elevation	Area In km^2	Area in %	Cumulative Percentage
2800	1.75	0.18	0.18
3000	8.68	0.90	1.08
3500	49.96	5.19	6.27
4000	89.12	9.25	15.53
4500	190.24	19.75	35.28
5000	262.54	27.26	62.54
5500	302.43	31.41	93.95
6000	57.65	5.99	99.93
6200	0.64	0.07	100.00

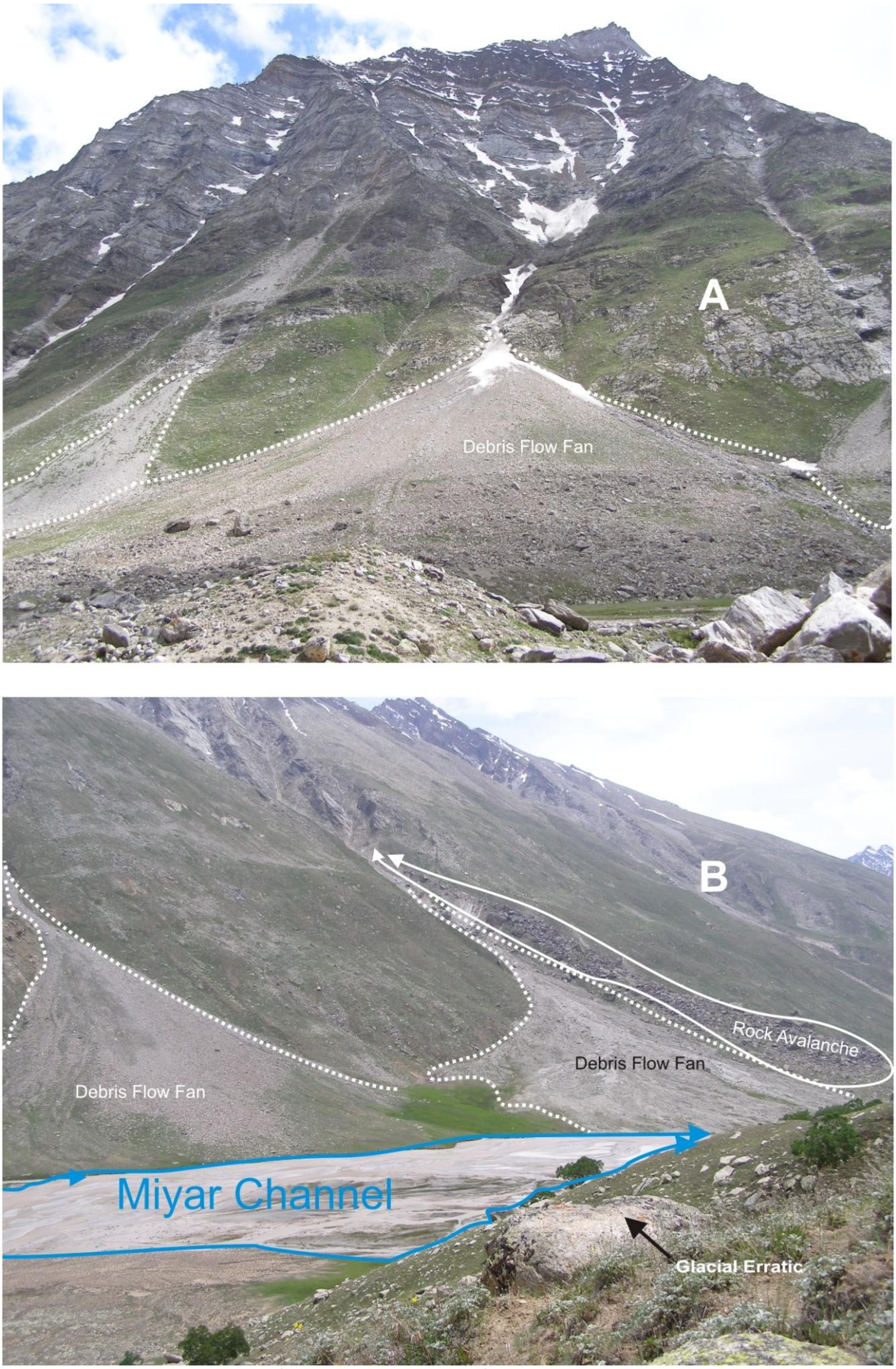

Plate 2.1 Paraglacial landforms as recorded from Miyar base camp at 3995m asl towards Keshar peak (A) and from Pimu base camp at 3950m asl towards Zardung (B).

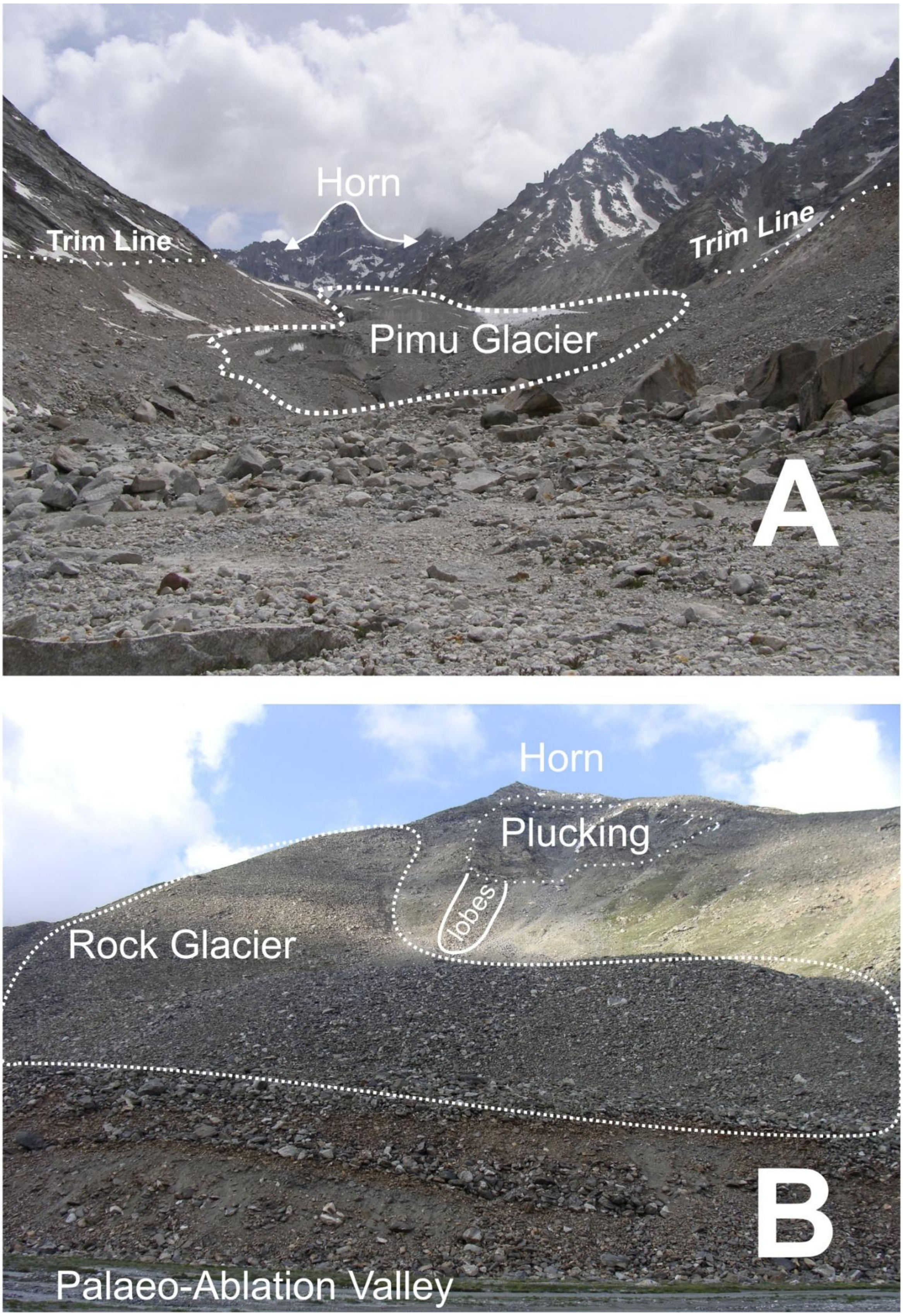

Plate 2.2 (A) Glacial and periglacial landforms of Pimu glacier 4600m asl and (B) Menthosa glacier margins 4500m asl on the backside of A.

However, the area above 4000-5000m asl accounts almost 47 percent of the total basin (453 km^2) and is dominated by glacial and periglacial processes, such as plucking, abrasion-ploughing, freeze-thaw, shattering and solifluction.

Plate 2.2 shows different periglacial landforms distributed between the ranges of 4000-5000m asl in the Miyar basin. The area above 5000m asl (6400m peak) consist almost 38 percent of the total basin and has almost 360 km^2 of area under its altitudinal zone (fig.2.3 and Table 2.1). It evidently indicates the very high altitude environment (High Himalaya) of the basin.

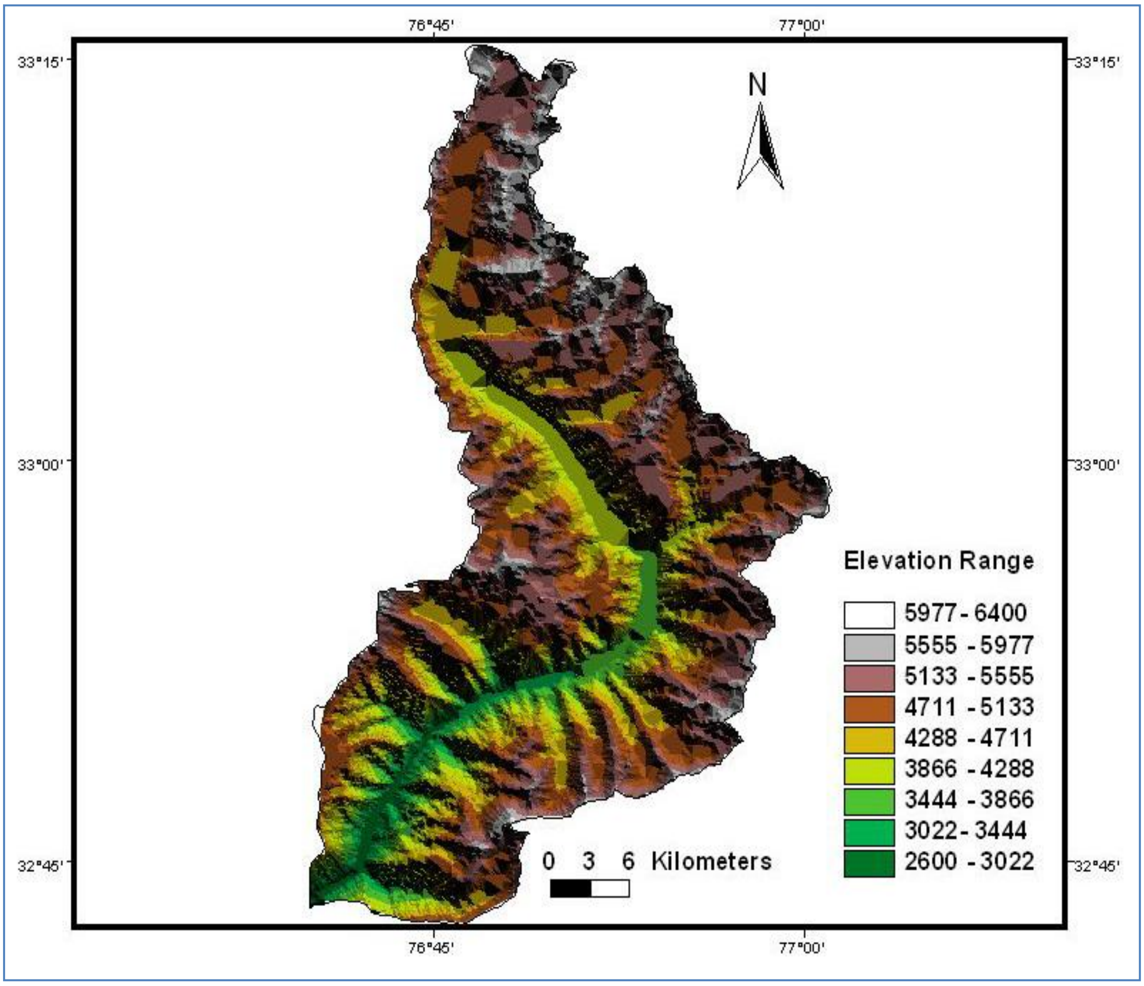

Fig. 2.4 Digital elevation model of Miyar basin (SRTM).

The digital elevation model of the basin clearly represent the four divisions of the basin and can be identified as narrow v shaped valley, broad U shaped valley, high elevation and peaks represented by dark green, light green, brown and white color respectively (fig. 2.4). The lowest point of the valley stands at 2600m asl on the other hand the highest point exist above 6400m asl (Menshosa peak 6443m asl). It indicates very steep and rugged nature of slopes in the basin as elevation changes abruptly from broad to narrow valley. The Miyar Nala (river) flows in the narrow stretch down the valley (through green margins) where the upper valley is relatively broad. This demarcates a clear cut distinction between glacial and fluvial margins of the basin. As an indicator, upper valley is dominated by glacial, periglacial and paraglacial processes whereas the lower valley is more by fluvial action. The dominance of fluvial processes in the lower margins has resulted into the vertical incision and therefore a gorge is found between Shakoli to Udaipur (plate 2.3). On the other hand, glacial processes dominate in the upper valley, resulting more lateral erosion and hence have broad valley.

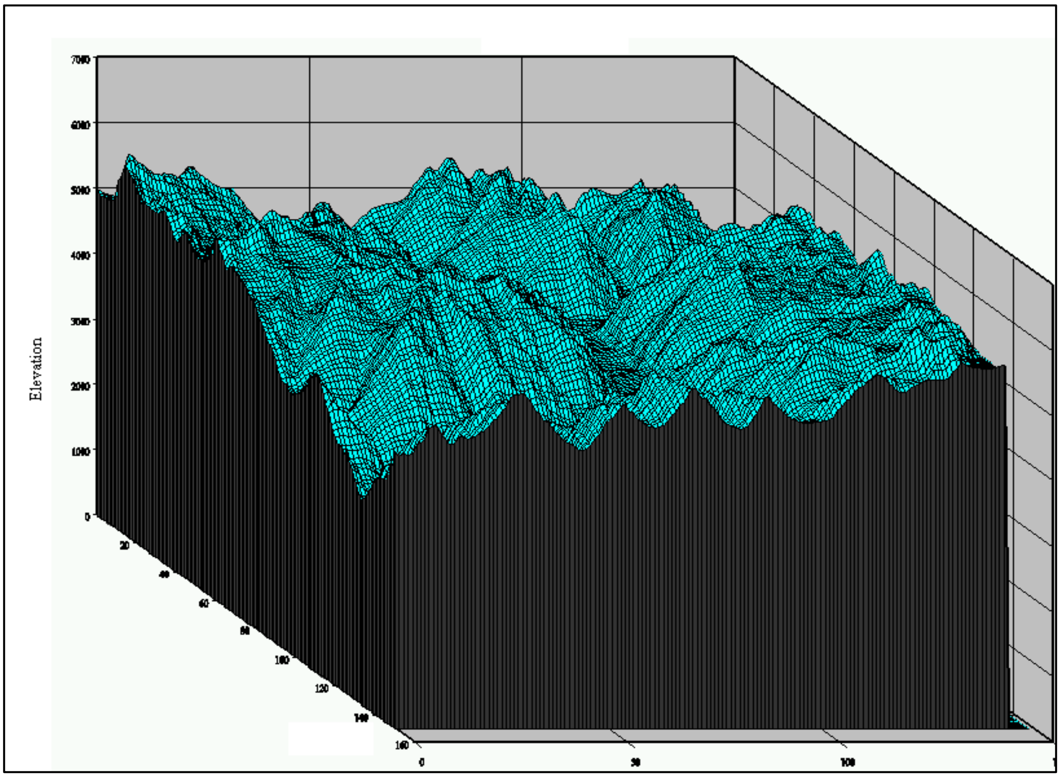

Fig. 2.5 Digital terrain of Miyar basin up valley from Urgus, (90m SRTM data).

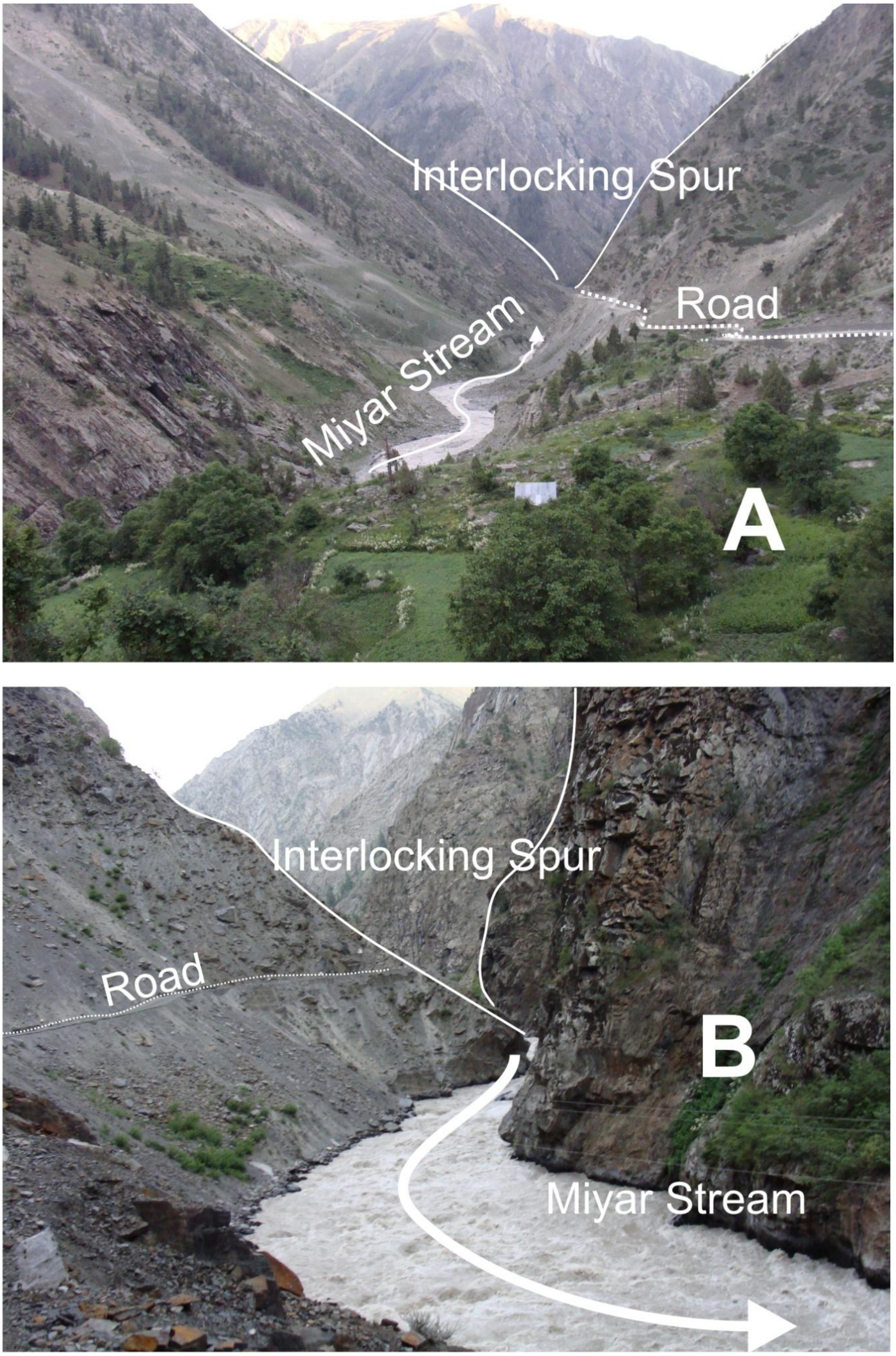

Plate 2.3 Narrow Miyar valley as observed at Shakoli village (A) and deep gorge as observed from Udaipur at 2645m asl (B) where only fluvial processes have dominated.

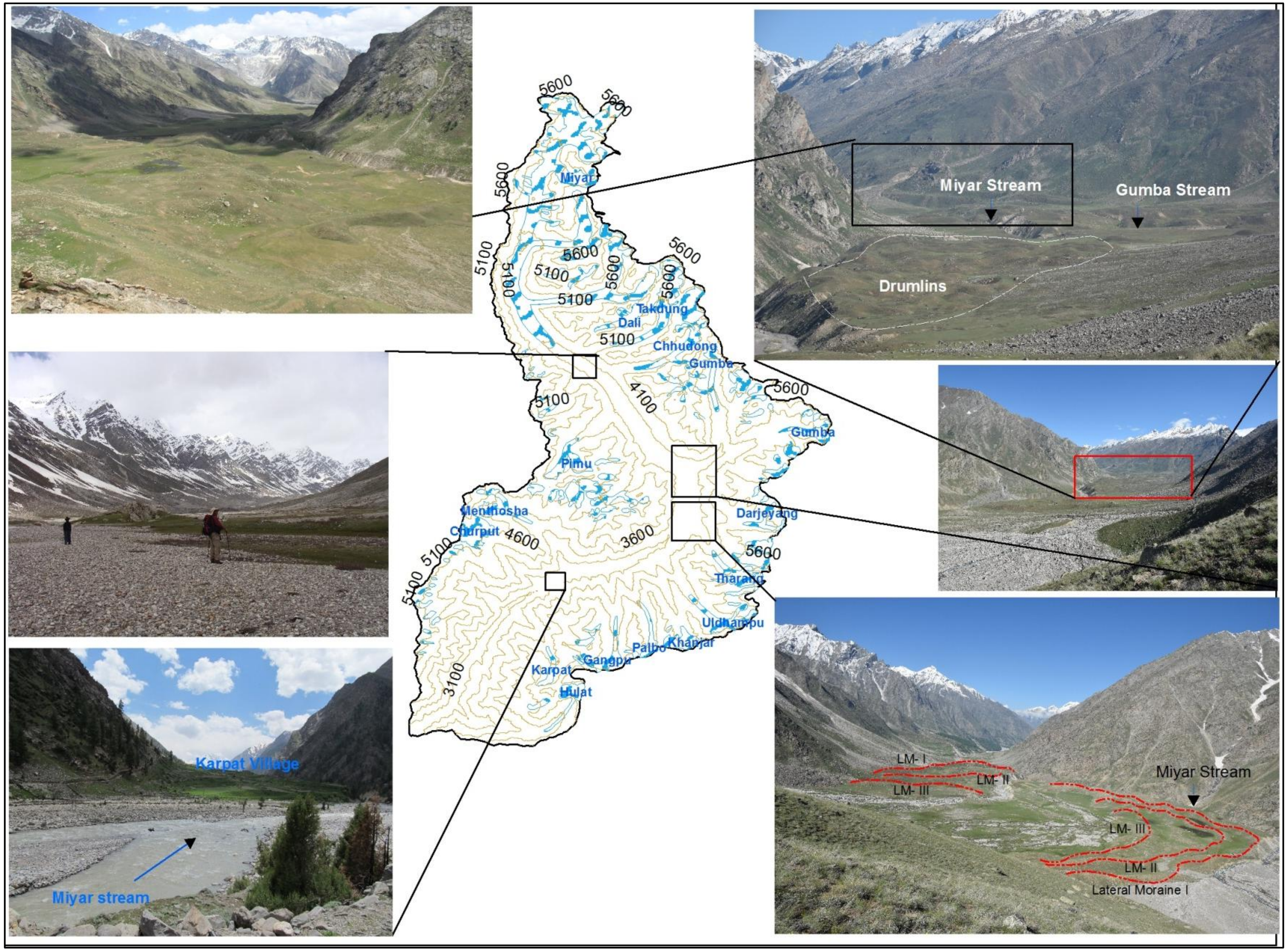

Fig. 2.6 Contour map of the Miyar Basin supported by field photographs indicating glacier dominated trunk valley.

The digital terrain model and congested contours further provide a synoptic view of the rugged terrain (Fig. 2.5 and 2.6). Settlement in such rugged terrain is bound to be on the flat terraces, fans made by streams and debris cones.

2.5 CLIMATE

2.5.1 Rainfall Pattern in the surrounding Region

The climate of this region is largely controlled by its orographic characteristics, western disturbance and jet streams. The Middle Himalaya (Pir Panjal range) blocks the northward movement of Indian Summer Monsoon (ISM), resulting in a typical rain shadow conditions in the basin. The ascending ISM winds cause heavy rainfall (1000- 2000 mm) in the southern slopes of the Pir Panjal range but cause a dry adiabatic effect in the northern slopes and result into no or scanty rain in the study area. The figure 1.2 reconfirms that the gradient of precipitation increases as one move south of the Pir Panjal range, on the other hand, the gradient decreases north of the range. Available precipitation data for few stations; at Kothi in Kullu district and at Koksar, Gondla, Keylong, Tandi and Udiapur in Lahaul and Spiti district of Himachal Pradesh further illustrates the variation (fig. 2.7). The data indicates that the long term average (1951-2005) annual rainfall at Kothi is 1660 mm whereas it is just 105 mm for Koksar. Markedly, the horizontal distance between Kothi and Koksar is about 12 km but within this short distance the stations records a huge difference of 1555 mm, with a negative rainfall gradient of 130 mm/km towards Koksar. Topographically, it is result of the aspect, as ascending ISM cause more rain on the southern slopes of the Pir Panjal range at Kothi whereas less rain on the leeward side at Koksar.

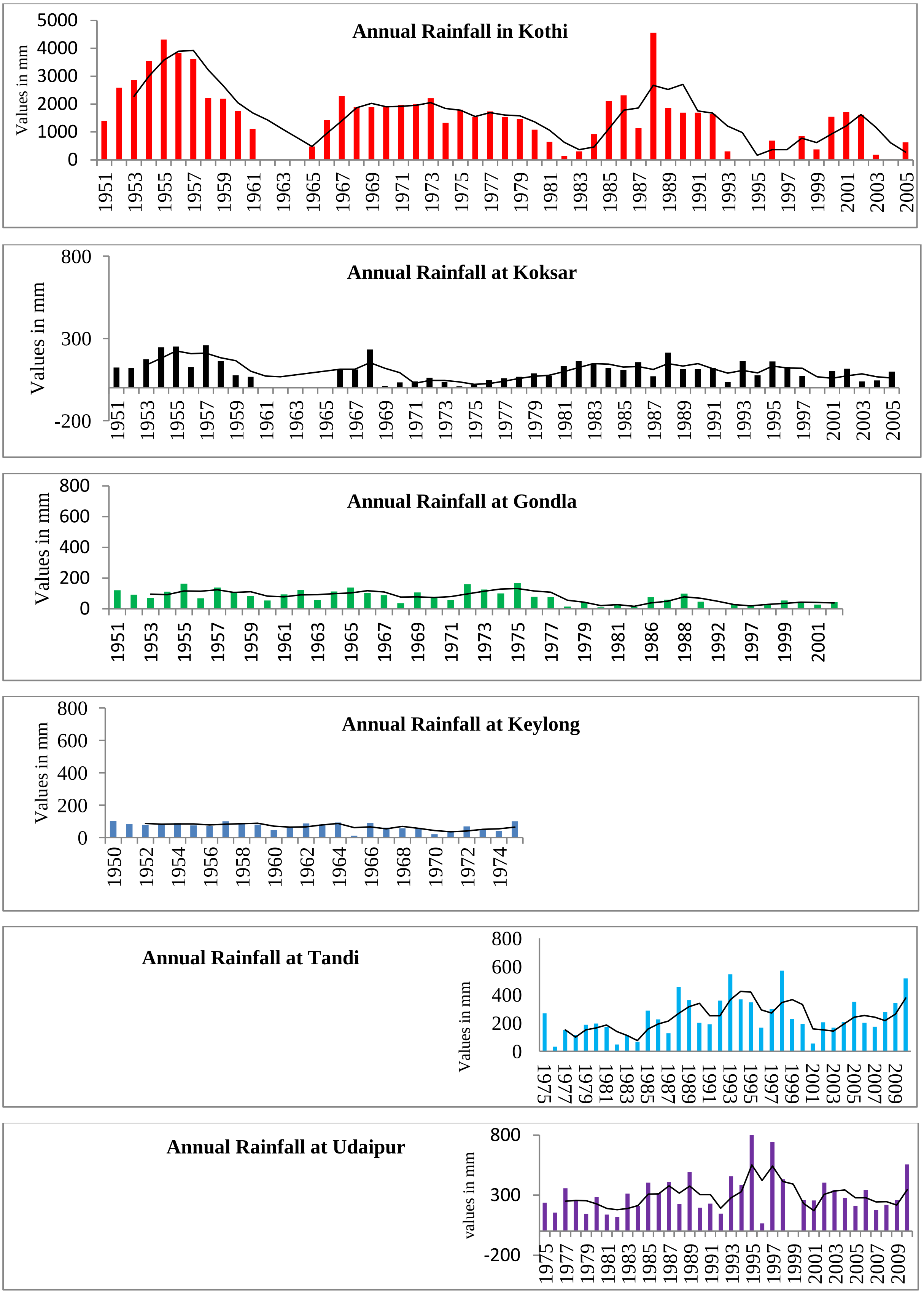

Fig. 2.7 Annual rainfall pattern (bar) over the Pir Panjal range. Note other than Kothi all the stations are located on the leeward aspect of the ISM. Curve indicates moving average over 3 years period.

Furthermore, the long term average (1951-2005) rainfall is found 76 mm at Gondla (1951-2002) and 69 mm for Keylong (1951-1976) and the horizontal distance between these station is almost 22 km but records a rainfall decrease of 29 mm with a negative rainfall gradient of 1.32 mm/km. Similarly, the horizontal distance between Gondla and Keylong is only 7 km but records the average rainfall difference of 7 mm with negative rainfall gradient of 1 mm/km (fig.2.7). The pattern continues (rainfall decreases and the aridity increases) as one move northward from the Pir Panjal range, towards Leh. In terms of the Tandi the long term average rainfall (1975-2009) is recorded 243 mm, whereas 301 mm for Udiapur, within a distance of 35 km and records a precipitation gradient of 1.65 mm/km (fig 2.7), as the valley open up in the lower Chandrabhaga basin. Such precipitation gradient pattern between Kothi, Koksar, Gondla, Keylong, Tandi and Udaipur suggest topographic controls over the precipitation distribution north of the Pir Panjal range. Location wise, all these stations are piedmont stations, situated on the northern slopes of the Pir Panjal range in the Chandrabhaga valley except Kothi which is located on the southern slope. Comparatively, Koksar being closest to the Rohtang Pass receives least rainfall.

Meteorological observations including rainfall in Miyar basin are limited, however, recent observation based on Automatic Weather Station (AWS) installed at Tingret (largest village in the basin) under Inter University Consortium on Climate Change (IUCCC, CSRD/JNU, New Delhi), limited data (since September 2016) for the basin is available now. But in absence of the long term data, Udaipur station (being the closest station; on the confluence point of the Miyar and Chandrabhaga stream) data are used to address the character of seasonal variations of weather phenomena in the study area. Monthly and seasonal characteristics of rainfall at Udaipur are reported in Table 2.2. The annual rainfall from 1975 to 2010 is found 301.56 mm with a standard deviation of 168.98 mm. The coefficient of variation of annual rainfall is 56.04%, indicating that it is highly unstable. Rainfall during May is the highest (60.38 mm) and contributes to 20.02% of the annual rainfall, followed by April (18.13%) and July (16.87%). Rainfall in February is the least as the month recorded no rainfall for the observed period. During December the coefficient of variation is recorded highest (382.41%), followed by January (346.28%) and October (200.27%) and the least during May (77.27%) except February which has no rain and hence has a zero coefficient of variation.

Table 2.2 Mean monthly and seasonal rainfall (mm) at Udaipur from 1975-2010.

	Normal	SD	CV (%)	Percentage contribution to annual rainfall
January	70.5	57.6	81.7	0.66
February	93.1	73.4	78.8	0.00
March	125.5	100.9	80.4	2.48
April	35.1	40.6	115.8	18.13
May	7.4	21.2	284.9	20.02
June	1.6	9.7	600.0	9.34
July	0.0	0.0	0.0	16.87
August	0.0	0.0	0.0	13.51
September	2.3	10.4	458.7	12.82
October	4.7	16.3	348.0	4.92
November	16.4	23.8	145.6	0.83
December	33.0	37.8	114.5	0.41
Annual (mm)	389.57	139.78	35.05	100.00
Pre Monsoon (March-May)	122.54	2.57	2.10	40.63
SW Monsoon (June- September)	158.43	3.82	2.41	52.54
Post Monsoon (October-November)	17.36	0.94	5.42	5.76
Winter (January- December)	3.23	0.26	7.90	1.07

Seasonally, the contribution of SW Monsoon to the annual rainfall is the highest (52.54%) followed by Pre Monsoon (40.63%), Post Monsoon (5.76%) and Winter (1.07%). The orbital satellite data from the Tropical Rainfall Measurement Mission (TRMM) product 3B43 version7 provides rainfall estimates with spatial resolution of 0.25° (~25 km) for the latitude between 50°N and 50°S.The TRMM data are available since 1998. Based on the TRMM data Figure 2.9 shows that annual rainfall in Miyar basin (76.4E, 32.6N and 77.2E, 33.2N) fluctuates between 112 mm and 51 mm for the observed period (1998-2017). In the observed period the highest rainfall is recorded in the year 1998 (112mm) whereas lowest rainfall is recorded in year 2004 (51mm). However, between 1999 and 2017 the annual rainfall is recorded steady and varied between 75 to 60 mm/annum (fig. 2.8).

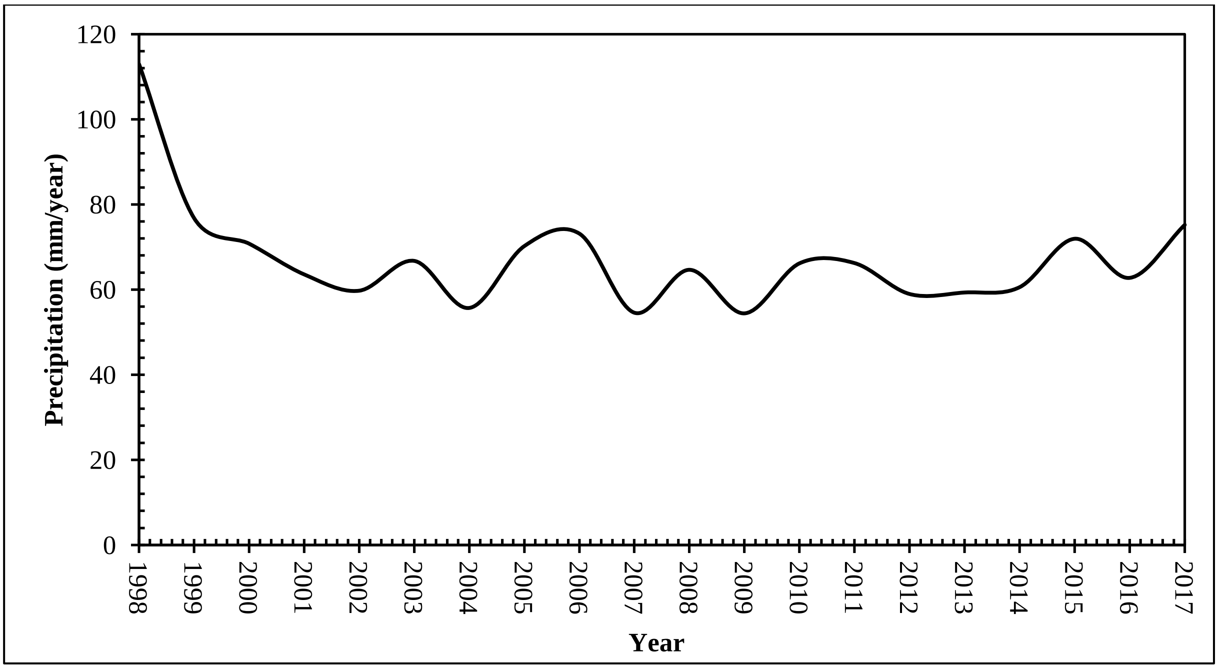

Fig. 2.8 Mean annual precipitation (mm/Annual) in the Miyar Basin 1998-2017 (bounding box 76.4E, 32.6N and 77.2E, 33.2N) as measured from TRMM_3B43_7_precipitation.

Table 2.3 provides monthly characteristics of rainfall at Miyar (76.4E, 32.6N and 77.2E, 33.2N) as observed based on TRMM_3B43_7 data. July records the highest rainfall (132 mm) and contributes to 16.29% of the total annual rainfall, followed by August (15.21%) and September (11.51%) whereas the lowest rainfall is recorded in November (10.86mm) and contributes only 1.33% of the annual rainfall. The low values of coefficient of variation suggest steady rainfall in the study area.

Table 2.3 Mean monthly rainfall (mm) at Miyar, 1998-2017.

	Normal	SD	CV	Percentage contribution to annual rainfall
January	73.05	65.87	8.97	8.97
February	86.24	42.07	10.59	10.59
March	71.15	54.65	8.73	8.73
April	61.88	52.84	7.60	7.60
May	48.31	48.64	5.93	5.93
June	68.86	49.94	8.45	8.45
July	132.70	41.82	16.29	16.29
August	123.91	37.40	15.21	15.21
September	93.78	57.31	11.51	11.51
October	23.05	126.64	2.83	2.83
November	10.86	67.30	1.33	1.33
December	20.76	68.73	2.55	2.55

2.5.2 Temperature Pattern in the Surrounding Region

Figure 2.9 shows mean monthly temperature pattern at Udaipur. June records the highest temperature (34.27^0 C) whereas the lowest temperature is found in February (-7.59^0C). The graph indicates two pronounced seasons, viz. summer and the winter. The summer starts around April and continues till September whereas the winter last between October and March. Winter is the longest and most severe season when the mean temperature remains below the freezing point. During these months precipitation occurs in the form of snow and cause snow avalanche. The basin is covered by deep

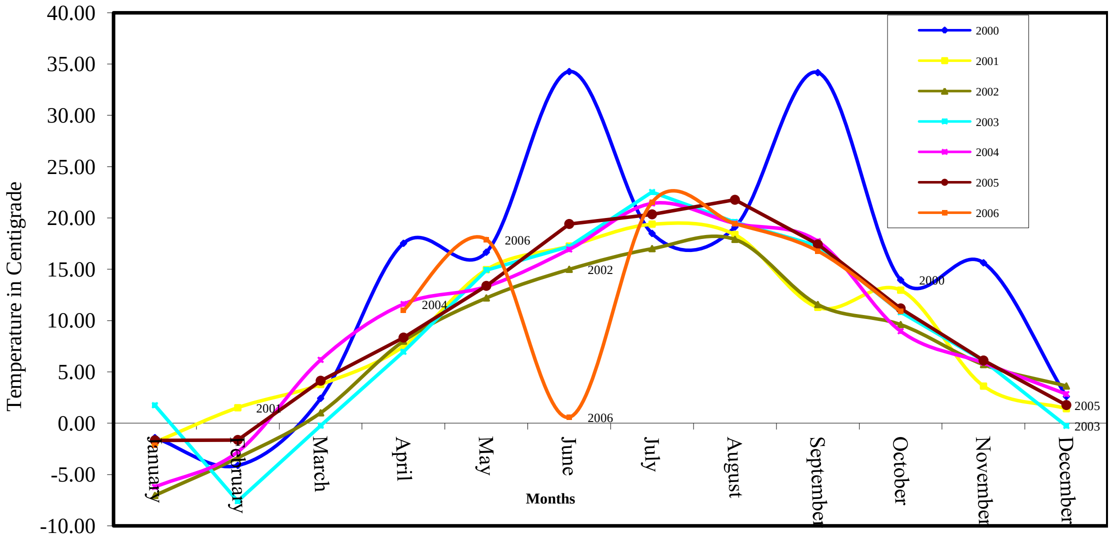

Fig. 2.9 Mean monthly temperature at Udaipur (Central Water Commission, Udaipur, Lahaul & Spiti).

snow and the only motorable roads remains closed (at Rohtang Pass) during these months (December to May). During these winter months people stay indoors and survive on the storage made during the summer months. With the increasing temperature by late March the snow starts melting and people comes out to tend to field for agriculture. Due to the increase in temperature by June, the higher areas (area above 3500m asl) raise good alpine pastures. The Thanpatan pastures in the upper Miyar valley are famous for pastoral activities. A large number of shepherds (Gaddis) from the south of Pir Panjal visit this area by late June for transhumance activities. The time period is full of activities and celebrated in the forms of different festivals. People engage themselves in fields for agricultural activities and grow different types of crops such as barley, wheat, buckwheat, and of vegetables such as potatoes, peas, cauliflower and cabbage. By September the cropping season is over as the mean temperature falls as low as 11^0 C. The farmers starts storing food, fodder and the shepherds start retreating back home south of Pir Panjal. Such characteristics are more like that of a temperate zone. As a result, the region is known as a typical mountain cold desert of the Himalayas.

Figure 2.10 shows the pattern of mean annual temperature across the Indian subcontinent and the relative location of the study area in the Himalayas. The figure reflects that the mean annual temperature decreases progressively from peninsular India in the south ($30\text{-}35^0$) to high Himalayas in the north (-29^0). The study area is part of the zone where the mean annual temperature fluctuates between 0^0 and -5^0 C.

Table 2.4 shows that the annual average land surface temperature (LST) in the Miyar basin had decreased over the years, 2000-2015. In the year 2000, the LST was -5.2°C but there onwards the LST recorded negative trend and reduced to -7.7° by 2006. Time being in the year 2007 the LST noticed some improvement with annual average of -6.3. However, from the year 2008 onwards the LST again followed the previous trend and receded to its lowest level (-8.4) in the year 2009 and 2012. The LST resumed to the -5.1 level only in the year 2016. But in general the LST indicates towards the cool conditions dominating the basin for the observed period.

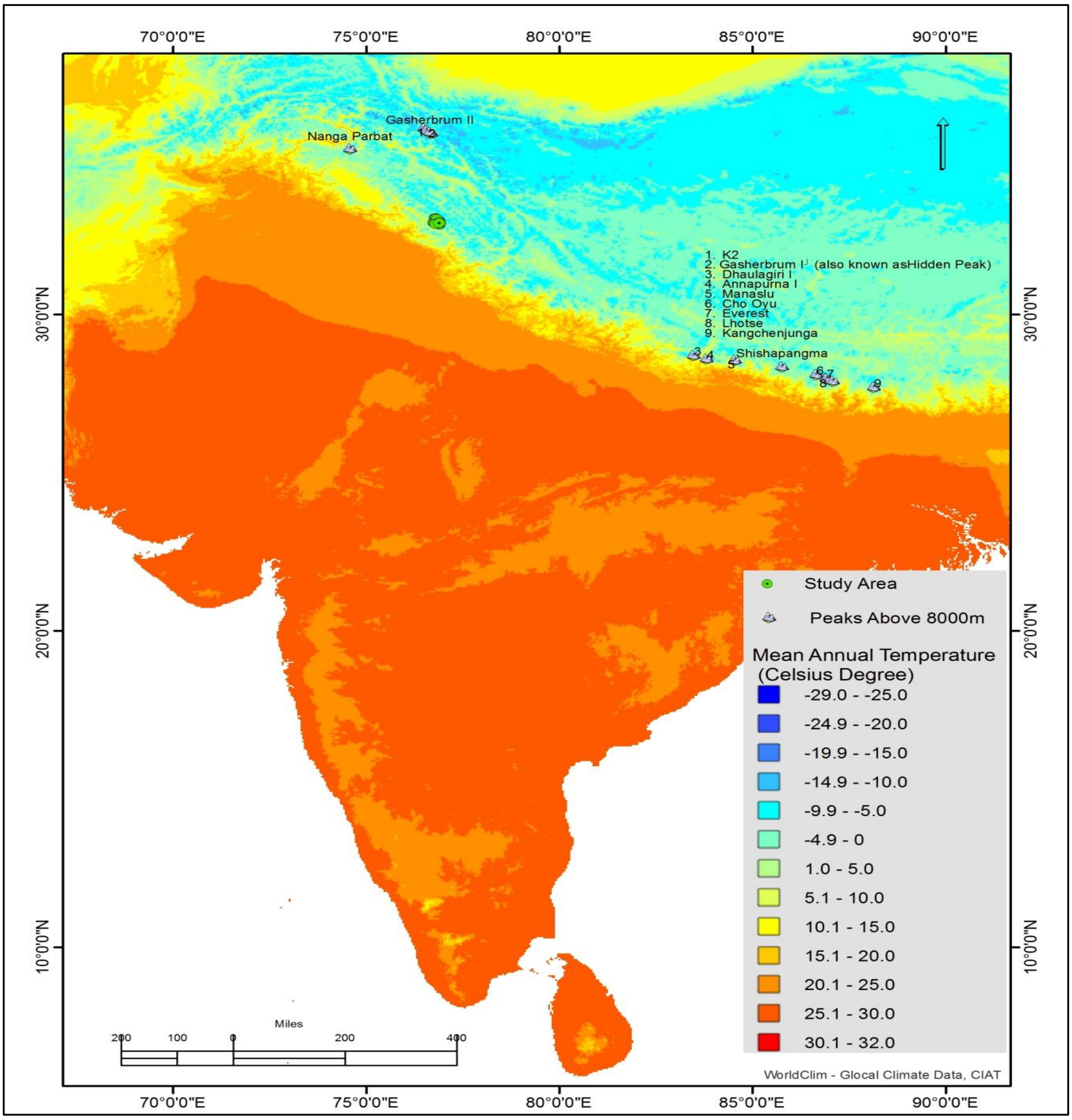

Fig. 2.10 Pattern of temperature across Indian subcontinent and relative location of the study area and peaks above 8000m in the Himalayas (mean annual temperature after Hijmans et al. 2005).

2.6 River Discharge:

Figure 2.11 shows the mean annual discharge of Miyar stream at Udaipur. Short term data however shows that the discharge has reduced during observed period for the Miyar Nala. The discharge was highest in the year 2001 but reduced to the lowest for the year 2005. The annual hydrograph denotes the decreasing discharge in the basin which may be due to the reduced solid precipitation in the basin in last couple of years, although winter in year 2007 recorded very good snowfall but the discharge data is not available for the analysis. Result indicates two points either the precipitation in the Miyar basin has reduced or the local area is witnessing a reduced temperature. In fact the reduced river discharge in the Miyar stream is result of the decreased temperature in the basin. The negative trend of LST between 2000 and 2016 and decreased Miyar stream discharge between 1999 and 2007 supports each other.

Figure 2.12 shows that the mean monthly discharge of the Miyar is highest in the Month of July (108 m3s−1), followed by August (95 m3s−1) and June (83 m3s−1). April (13.55 m^3s^{-1}) and October (20.47 m^3s^{-1}) mark the position of base flow of as the winter season ends with late April and begins with late September. The period between September to April being the winter season, temperature falls below freezing point and as a result ablation decreases causing reduced discharge. Whereas the period between April and September is of summer season, have relative high temperature, and cause greater ablation and snowmelt in the basin, resulting higher discharge.

2.7 Soil

Soil of Miyar watershed responds greatly to the physical setup of the area and correlate to the climate, vegetation and relief to a greater extent. According to the National Atlas and Thematic Mapping Organization (NATMO, 1999), soil of the watershed has been classified into three major groups. These groups are Skeletal, Mountain meadow and Snowfield soils. Skeletal is dominant group of soil in the

Table 2.4 Land Surface Temperature (LST) in the Miyar basin, 2000- 2016 (values in Degree C).

Year	January	February	March	April	May	June	July	August	September	October	November	December	Annual Average
2000		-18.9	-16.9	-9.6	-0.2	2.4	3.4	5.8	4.3	0.4	-9.5	-18.9	-5.2
2001	-20.3	-18.7	-16.0	-9.4	-2.3	2.8	4.5	5.5	3.3	-1.7	-13.6	-20.0	-7.2
2002	-20.9	-20.3	-15.6	-10.2	-4.9	1.8	5.2	5.6	-1.4	-4.4	-10.3	-17.2	-7.7
2003	-17.6	-20.0	-16.4	-9.3	-6.5	1.2	5.8	4.3	3.2	-2.0	-10.7	-17.9	-7.2
2004	-20.6	-19.4	-12.0	-7.6	-4.0	1.3	5.8	5.4	5.5	-10.2	-12.8	-16.7	-7.1
2005	-22.2	-20.5	-15.2	-11.3	-7.1	-0.1	3.3	6.2	4.1	-2.2	-9.2	-14.8	-7.4
2006	-21.1	-17.2	-16.4	-17.2	-1.3	0.4	5.6	2.8	3.5	-1.4	-11.1	-19.4	-7.7
2007	-20.0	-19.3	-15.2	-6.2	-1.4	4.3	5.4	6.2	2.9	-5.6	-8.5	-18.2	-6.3
2008	-23.4	-20.4	-13.9	-9.8	-3.4	4.5	5.6	4.6	-0.7	-6.1	-10.2	-15.6	-7.4
2009	-21.7	-19.7	-14.8	-10.4	-5.5	-0.3	3.4	6.2	0.8	-4.1	-13.8	-20.8	-8.4
2010	-20.4	-19.2	-12.9	-8.3	-5.3	-2.0	2.1	3.6	1.0	-3.4	-11.1	-15.1	-7.6
2011	-22.6	-20.3	-14.8	-10.1	-3.2	2.3	4.4	5.3	1.9	-4.3	-10.6	-15.2	-7.3
2012	-22.1	-20.4	-16.1	-10.0	-5.8	-0.8	5.3	4.7	0.3	-5.9	-10.9	-19.4	-8.4
2013	-21.8	-19.8	-19.8	-10.0	-4.0	2.3	6.8	2.8	3.1	-0.1	-13.6	-16.1	-7.5
2014	-20.7	-21.1	-16.3	-11.0	-5.6	0.3	5.3	6.2	2.7	-2.2	-12.1	-16.9	-7.6
2015	-20.5	-18.9	-15.0	-9.2	-5.1	-0.9	5.8	5.0	1.8	-4.9	-10.9	-18.6	-7.6
2016	-20.5	-17.6	-12.9	-9.5	-2.7	3.5	5.2	3.9	4.9	-0.5	-5.6	-9.4	-5.1

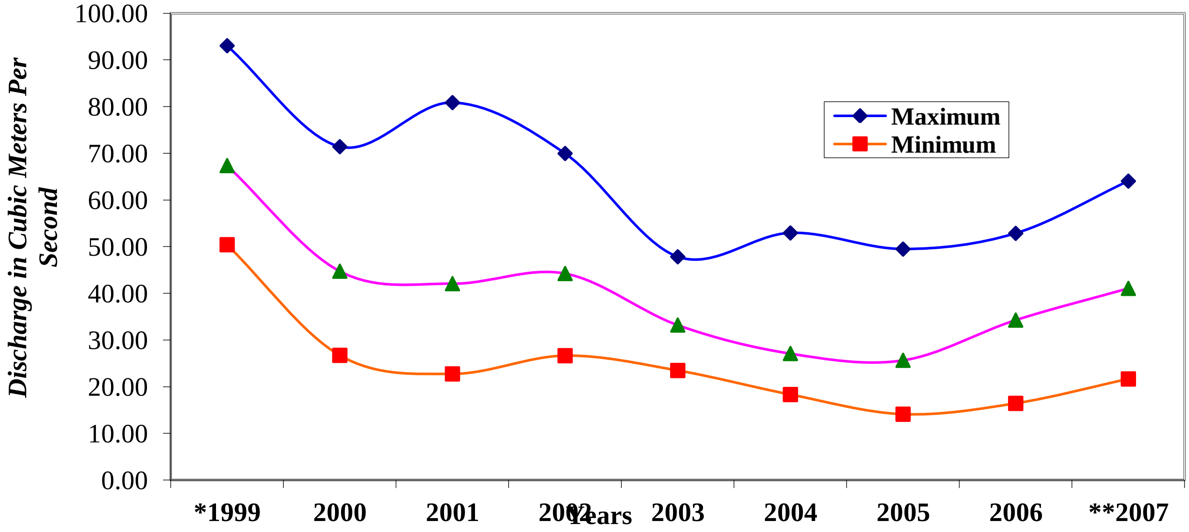

Fig. 2.11 Mean annual discharge of the Miyar Nala at Udaipur.

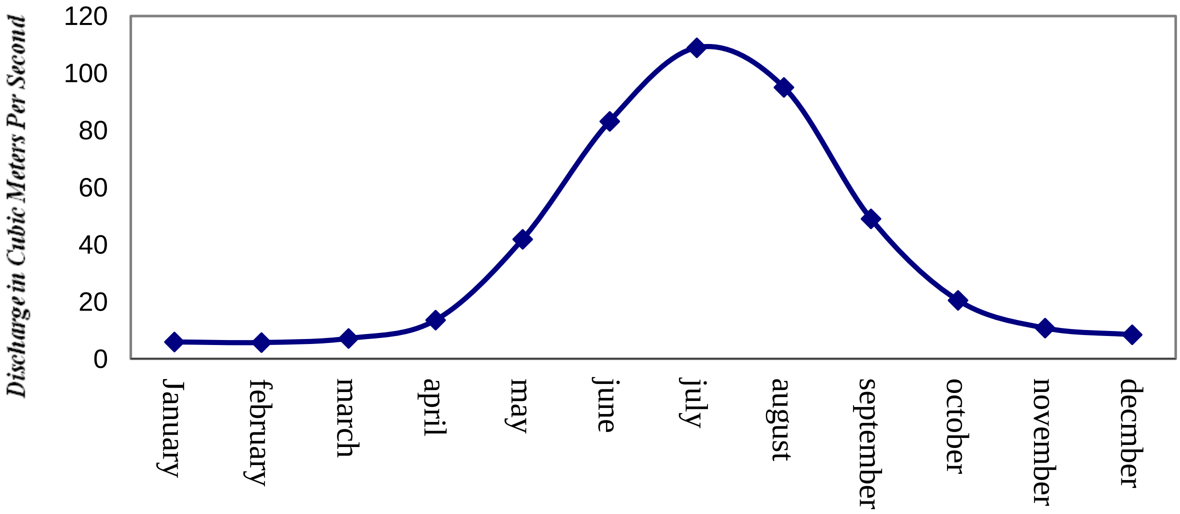

Fig. 2.12 Mean monthly hydrograph of the Miyar Nala at Udaipur.

watershed. According to soil taxonomy of United State Department of Agriculture (USDA) skeletal soil comes under Entisol group which is characterized by absence of pedogenic horizon and great variation in texture, colour and composition. These soils are mixed with pebbles, shingles and gravels in many localities. Some angular and sub-angular fragments of the parent rocks are mixed with lower layers of the mountain and hill soil in many localities. Next major soil group is snowfield soil. These soils come under Histosol class of USDA'S soil classification and are generally found above the snow line. Action of ice, either moving or static, results in the evolution of these soils. No vegetation grows on such soils. Another group of soil is Mountain Meadow soil. USDA has classified these soils into Mollisoil class and is found at higher altitude having youthful landscape. These soils occur under the alpine pastures near the snowline.

2.8 Vegetation

Tree line in the basin is found upto 3500m a.s.l. however, few pockets of trees are observed up to 3800m a.s.l (Pimu base). The modern vegetation in the study area is characterised by desert steppe and alpine steppe plant communities. Deshmukh and Jain (2016) described almost 117 plant species in which 11 are trees, 12 shrubs and 94 herbs. In terms of trees junipers and deodars are most common species which are found between Udaipur to Khanjar (the last sedentary village 3500m asl). Vegetation cover in the upper Miyar basin (above 3500m) is dominated by alpine grass. The vegetation distribution of the region can be divided into three zones.

First zone extends from 2590 m to 3500 m and contains the maximum vegetation with nearly all the trees that exist in the watershed viz. Cedrus deodara, Pinus wallichana and birch and the shrub community includes Rosa webbiana, Lonicera quinquelocularis, Sorbaria tomentosa and Juniperus (Deshmukh and Jain 2016).

Second region ranges from 3500m to 4000m having moderate vegetation without trees. Here juniper, birch, andromeda and rhododendron are found in shrub form. Small patches of short grasses and wild flowers are also found. The Yellow poppies and blue poppies of Himalayas are found between Tharang to Thanpatan but only during summer months (plate 2.4).

Third region extends above 4000m (glacier free) and is dominated by perennialherbs like Androsace muscoidea, Biebersteinia odora, Draba oreades, Draba setosa, Potentilla atrosanguinea, Sibbaldia purpurea, etc (Deshmukh and Jain 2016). Some nutritive grasses are also found which attract many herds of sheep and goats. The dominant grasses are *Poa sp*. and *Agropyron sp.* (plate2.5). Glaciers are devoid of any vegetation while a narrow belt below glacier margin contains lichen and mosses. Main guiding principles of vegetation distribution are climate, soil and altitudinal variations of the watershed.

Plate 2.4 Blue Poppies (A) and Yellow Poppies (B) of the Himalayas as observed between Tharang and Thanpatan pastures.


Plate 2.5 Flocks grazing in the pastures (*Poa sp*. grass) of the Doksa (3600m asl) above Khanjar village, Miyar Basin.

2.9 Agriculture Practice

Agriculture is the main land use which dominates the lower part of the Miyar valley (upto 3500m). The same can be noticed between Shakoli to Khanjar (the highest sedentary village 3500m asl.) during the summer months. Due to the rain shadow location, agriculture practice in the region is largely dependent on irrigation (Kuhl system). Channel diverted water from glacier through gravity controlled channels are used for irrigation in the fields. Agriculture includes different types of field crops; (barley, wheat, buckwheat), pulse (Rajmash), Oilseeds (mustard), medicinal plants (Kuth, Mannu, Kala Zeera), vegetables (potato, peas, cauliflower, cabbage, French beans, summer squash, onion) and horticulture (apple, apricot, cherry, sea buckthorn, plum and flowers).

These crops obtained popularity due to comparatively more economic returns as well as their easy adaptability to the short growth season of the cold desert environment (Kuniyal et al., 2005). In addition, Kuth was introduced around 1930's. Up to 1962 Kuth was the major commercial crop of the region, thereafter the area of Kuth decreased substantially (Department of Agriculture, 2009). Potatoes were first introduced in 1960s by Moravian Missionaries whereas the peas was introduced in 1880s. Hops plantation flourished during 1990s and has become the sole producer in the country (Department of Agriculture, 2009). The seed potato, green peas and hops are the cash crops of the region.

2.10 Population

Inhospitable geomorphic and climatic conditions sustain only a small population in the study area of the district of Lahul and Spiti. The Miyar basin has a total number of 352 households which account a sum population of 1836 persons, out of which 929 are male and 907 are female (Table 2.5). The further categorization of the population indicates that there are only forty villages in the basin out of which 12 are inhabited. Shakoli with 625 persons is the most populated village of the basin, followed by Tingrat (324), Karpat (224), Chamrat (152), Chhaling (141), Ghari (130), DPF Churput (90) Khanjar (66), Shiling (55), Tumru (55), Jhatul (6), DPF Shakoli (3) (Table 2.5). In terms of areal coverage Dhar Thanpatan is the largest uninhabited village which covers 21190.35 hectares of land, but due to high altitude (3800m), the area witnesses rather extreme climatic conditions. However, this location contains signatures of earlier human habitatation in the form of ruins. Such high altitude former villages with vulnerable climatic conditions are denoted as DPF (District Protected Forest).

As per Census 2011, out of the total inhabited villages only the households of Dhar Bhitar and Dhar Chutradrun were dwelling in permanent house whereas majority of the households in other villages were staying in semi permanent house structures (fig.2.13). The dwelling information is wrongly indicated in the 2011 Census as no house exists in reality in the field at Dhar Bhitar and Chutradrun. The high altitude villages (Khanjar, DPF Chaling, DPF Ghordhar, Karpat and DPF Shiling) are used during summer months for agriculture activities in the fields but with inception of winter people return to their lower altitude houses, some time such houses are out of the basin as well.

Figure 2.14 shows the type of fuel used for coking by the households in the Miyar basin. Firewood is the most used fuel for cooking and village such as Dhar Bhitar, Dhar Chutradrun, Khanjar, DPF Chaling, Chaling, DPF Ghordhar, DPF Dibri, DPF Jatul, DPF Shakoli and DPF Churput mainly depend on the same. DPF Tumru is the only village which used LPG primarily for the cooking.

Table: 2.5 Distribution of population in the Miyar basin, 2011.

Sl. No	Village Code	Village Name	Area (in Hectares)	Total Households	Total Population	Male Population	Female Population
1	12173	Shakoli (157)	181.59	117	625	310	315
2	12146	Tingrat (176)	208.53	73	324	172	152
3	12164	Karpat (196)	257.72	36	224	113	111
4	12170	Chamrat (202)	128.68	29	152	75	77
5	12154	Chaling (191)	65.58	28	141	65	76
6	12172	Ghari (204)	113.4	24	130	70	60
7	12160	D.P.F.Churput (175)	132.61	14	90	46	44
8	12150	Khanjar (186)	294.34	15	66	33	33
9	12167	D.P.F.Shiling (198)	142.34	12	55	30	25
10	12176	D.P.F.Tumru (203)	364.3	2	20	7	13
11	12168	Dhar Jhatul (193)	610.36	1	6	6	0
12	12171	D.P.F.Shakoli (168)	260.59	1	3	2	1
13	12137	Dhar Bhitar	1333.57		0		
14	12138	Dhar Parla Bhitar	1906.77		0		
15	12139	Dhar Daraone (183)	558.93		0		
16	12140	Dhar Than Pattan	21190.35		0		
17	12141	Dhar Churdrun (188)	19570.18		0		
18	12142	Dhar Gumba (184)	19623.03		0		
19	12143	Dhar Kundri (189)	336.69		0		
20	12144	Dhar Chutradrun	2919.28		0		
21	12145	Dhar Chetal (174)	2719.31		0		
22	12147	D.P.F.Urgus (177)	253.73		0		
23	12148	Dhar Ahan (179)	1356		0		
24	12149	D.P.F.Thani (178)	97.98		0		
25	12151	Dhar Lamgarh (200)	13544.48		0		
26	12152	D.P.F.Khanjar (187)	101.57		0		
27	12153	D.P.F.Chaling (190)	187.16		0		
28	12155	D.P.F. Uwang (192)	147.02		0		
29	12156	Dhar Chanooh (199)	2989.6		0		
30	12157	Dhar Tentigahar	1148.87		0		
31	12158	Dhar Karpat (194)	2024.18		0		
32	12159	D.P.F.Karpat (195)	250.81		0		
33	12161	Dhar Ghordhar (173)	3952.37		0		
34	12162	Dhar Tamlu (171)	2207		0		
35	12163	D.P.F.Ghordhar	113.87		0		
36	12165	D.P.F.Dibri (197)	105.82		0		
37	12166	D.P.F.Tamlu (170)	195.54		0		
38	12169	D.P.F.Chamrat (201)	90.79		0		
39	12174	Dhar Shugaru (169)	2322.21		0		
40	12175	D.P.F.Hulega (167)	196.82		0		
		Miyar Basin Total	**104204**	**352**	**1836**	**929**	**907**

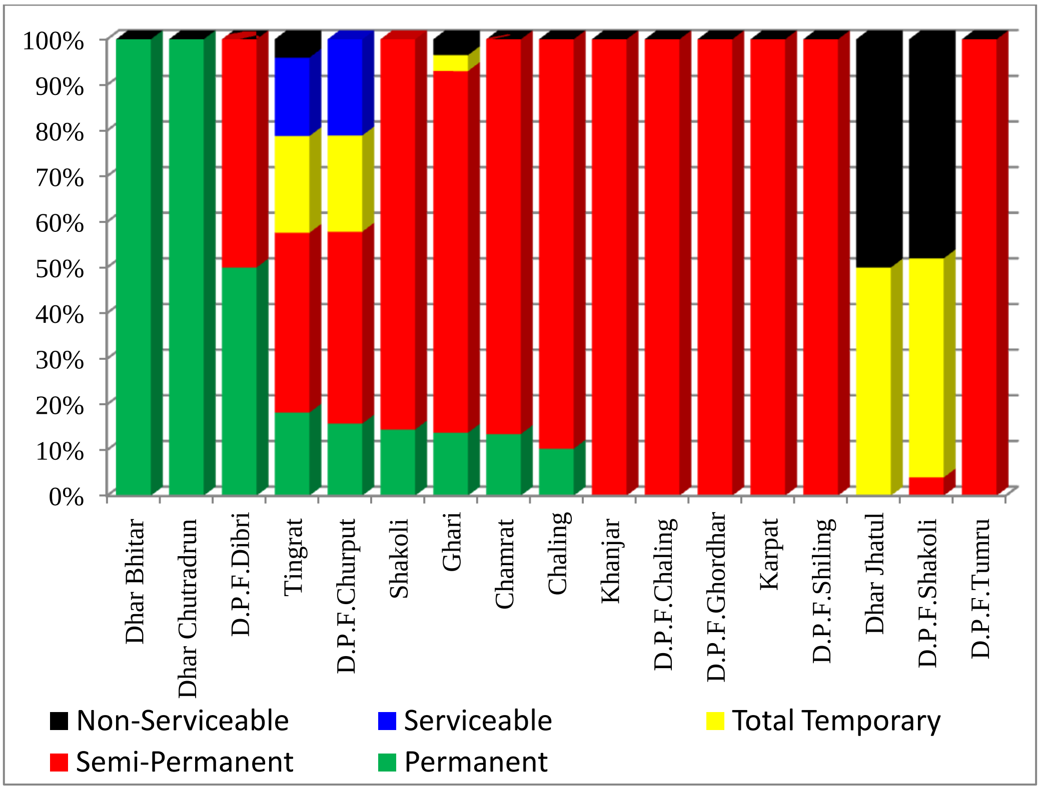

Fig.2.13 Percentage of Households by Type of Structure of House (as per Census 2011)

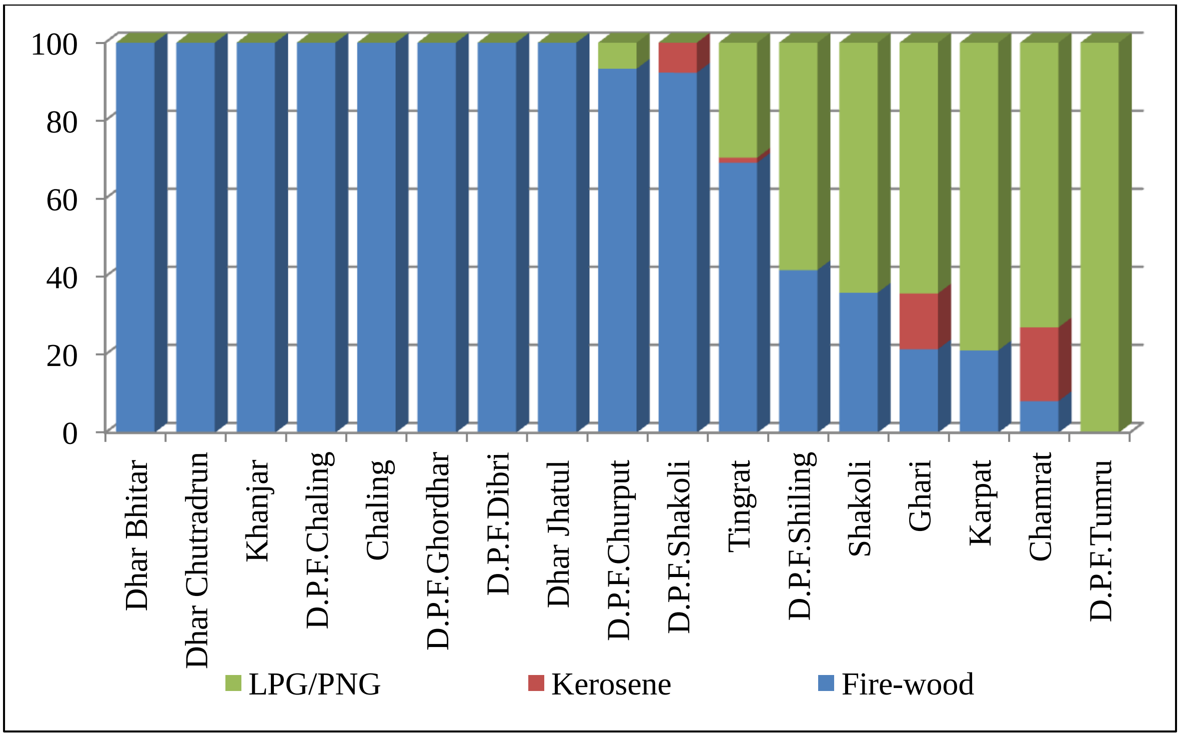

Fig. 2.14 Type of Fuel Used for Cooking (As per Census 2011).

Field observations suggest that the Dhar Bhitar and Chutradrun are transhumance sites and the shepherds primarily make use of the cowdung in cooking. These areas (3700-4000m) are well above tree line (i.e.<3500m) and hence in absence of firewood depend on the only available cooking fuel which is cowdung. Other than firewood and LPG, kerosene is also used for the cooking, and village like DPF Shakoli, Gari, Chamrat and Tingrat use them noticeably (fig. 2.14).

Table 2.6 shows the availability of water in the basin by source and by location.. Tap is the main source of water drinking water in the basin as majority of the villages have 100% households having access to tap water, however spring is the second most source of water used in Dhar Bhirtar, Dhar Chutrdrun, DPF Ghordar and DPF Jhatul. Handpump is also used for drinking at Tingrat. As per location of the drinking water source a limited number of households receive water within the house premises throughout the Miyar basin except at DPF Tumru where all the households receive the same being in the house premises only. However, most of the village have drinking water available near the house premises (Table 2.6).

In brief the Miyar basin is very remote in terms of its location, topographic barriers further makes it inaccessible. The climate of the basin is very harsh and provide limited time period for agriculture and subsistence activities, people migrate from lower valley to upper valley with Summer conditions However such anthropogenic activities are bound below 3500m a.s.l on regular basis.

Table 2.6 Availability of drinking water in the Miyar basin (values in %).

Area Name	Main Source of Drinking Water				Location of drinking water source		
	Tap water from treated source	Tap water from un-treated source	Handpump	Spring	Within premises	Near premises	Away
Dhar Bhitar	0	0	0	100	0	100	0
Dhar Chutradrun	0	0	0	100	0	100	0
Tingrat	89.7	0	10.3	0	1.3	89.7	9
Khanjar	0	100	0	0	0	100	0
D.P.F.Chaling	0	100	0	0	0	100	0
Chaling	0	100	0	0	0	100	0
D.P.F.Churput	86.7	6.7	0	0	0	86.7	13.3
D.P.F.Ghordhar	0	0	0	100	0	100	0
Karpat	0	100	0	0	0	100	0
D.P.F.Dibri	0	100	0	0	0	0	100
D.P.F.Shiling	0	100	0	0	25	75	0
Dhar Jhatul	0	0	0	100	0	0	100
Chamrat	100	0	0	0	0	100	0
D.P.F.Shakoli	100	0	0	0	0	100	0
Ghari	100	0	0	0	0	100	0
Shakoli	100	0	0	0	7.7	42.7	49.6
D.P.F.Tumru	100	0	0	0	100	0	0

Source: Houselisting Census 2011, DCO, HP, Shimla.

2.11 Reference

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Chapter III

GLACIO-ARCHAEOLOGICAL HISTORY OF THARANG END MORAINE RUINS

3.1 Introduction

The High Himalayan glacial environments are generally devoid of suitable organic material for radiocarbon (^{14}C) dating (Sharma and Owen, 1996; Spencer and Owen, 2004; Owen, 2009). Tree line in parts of the Himalayas is restricted below 3000-3700m asl (depending upon the moisture regime across the Himalayas) whereas, the glacial environments are found beyond 4000m asl. High topography (the average height is 6000m) and prevailing harsh climatic conditions restrict the growth of soil profile and resultant flora-fauna and history of peopling in this region (Harcourt, 1871). Human colonisation in such high altitude environment is subject to ice free landscape, availability of water and fuel material as well as highly productive soil profile (Meyer et al., 2009).

There are limited number of sites where ^{14}C dates may be obtained and used to infer glacial-human interactions, and thus associated climatic links. Due to the lack of suitable material for dating the glacial chronologies and associated glacial-human interactions and climate, attempt have been made to understand the same based on climatic proxies such as dendrochronology (Yadav, 2011a; 2011b), lake and lacustrine mineralogy (Juyal et al. 2009; Phartiyal et al. 2009; Wunnemann, et al. 2010; Srivastava et al. 2013; Mishra, et al. 2014; Bali et al. 2017) and speleotherm (Sinha et al. 2011; Sanwal et al. 2013; Liang et al. 2015). The available multi palaeo-climatic proxies are ambiguous suggesting both weaker (Gupta et al., 2003; Sinha et al., 2011; Yadav, 2011) and stronger monsoon (Liang et al., 2015) during the last millennium in general, and the period of Little Ice Age (1300-1600AD) in particular. Glacial archaeology and historical records are the only direct method that provide a better understanding of climate, glacier fluctuations and human migration (Biagi and

Cremaschi 1988; Zhang, David D., Li 2002; Nussbaumer and Zumbühl 2012; Brantingham et al. 2003; Meyer et al. 2009; Dixon et al. 2014) however, such studies are limited. Existing glacio-archaeological remains and historical maps provide direct record of the understanding of climate, glacier fluctuation and human migration at least within the present study area prevailing at that point of time.

The Tharang glacier end moraine ruin complex in the Miyar basin, Lahaul Himalaya contains a valuable record of glacio-archaeological significance. The particular significance of these ruins result from its close proximity, relative to the Tharang glacier terminus, and available historical maps that marks the positions of contemporary glaciers and archaeological remains. This study based on the glacio-archaeological, geomorphological and historical evidence presents the first account of human migration in the high altitude villages (<3700m asl) of the study area for the last millennium. The results are compared and analysed in context of the existing glacial and other palaeo-climatic proxies of the North West Himalaya. This study also provides a relative framework for both the glacial history and human migration in the Lahaul Himalaya during the last 1000 years.

3.2 Materials and Methods

The mapping of the geo-archaeological and geomorphological features were conducted in the course of five field expeditions during 2008-2016. The archaeological features such as relict house structures, agriculture fields and irrigation channels were mapped at a scale of 1:5000. Whereas, the geomorphological features such as glacier margins, lakes, moraines, hummocks and erratic were mapped at a scale of 1:10000. The field mapping was further supported by laboratory work in the

GIS Laboratory of CSRD/SSS III JNU, New Delhi. Free online high resolution images have been analysed from ESRI ArcGIS10.3 software, and Google Earth Pro images were used to cross-check the field maps. Declassified aerial photographs and Landsat images are downloadable from USGS earth explorer (https://earthexplorer.usgs.gov/*)* whereas Cartosat images available from Bhuvan *(*http://bhuvan.nrsc.gov.in/data/download/index.php*)* have been used extensively in the present study. The Survey of India topographical sheets (surveyed during 1962-1966) have been used as base maps in many earlier studies for glacier monitoring (Oberoi, et al. 2001; Dobhal, et al. 2004; Kulkarni, et al., 2007; Nainwal, et al. 2008) but resulted into providing exaggerated rate of retreat of glaciers mainly due to cartographic misrepresentation (Bhambri and Bolch, 2009). However, in this study the toposheets have been used only as a reference guide whereas the detailed mapping of contemporary glacier has been done using high resolution satellite images.

To constrain the chronology of the ruins, organic rich samples were extracted from the dilapidated house remains of the Tharang end moraine complex for radiocarbon (^{14}C) dating. The glacial chronology of the moraines is based on the Optically-Stimulated Luminescence (OSL) dates of Deswal et al., 2017.

3.2.1 Mapping

Extensive mapping was carried out in the Tharang end-moraines complex, and the dilapidated settlement within the lateral moraine confines. The mapping included delineation of glacial, glaciofluvial, periglacial and paraglacial landforms, and collapsed walls of the once large buildings on each location. Field mapping technique used for the present study is elaborated as:

3.2.1.1 Field Mapping

Chain & tape survey, calibrated using clinometers, compass and GPS, were carried out in at 1:10000 scale within the confines of the lateral moraines between 2008 and 2016. Monitoring the terminus of Tharang glacier and other six glaciers was also initiated using hand-held Garmin-76CS GPS and DGPS in 2008. In addition, the DGPS (Trimble-GeoXT) survey was carried out simultaneously, installing a base station within the Tharang glacier forefield (at 3600 m a.s.l.) for continuous GPS reception, with continuous power supply using Honda-Poratble Genset at the base. The rover was taken up to the terminus (4043m a.s.l.) of Tharang glacier. Terminus and the proglacial area along with lateral moraines were mapped using point, line and area feature class. Between the years 2010 and 2012, physical identification of shattered settlements and mapping of palaeo irrigation systems (Kuhl), along with agriculture fields were accomplished using GPS 76CS, along with detailed photographic recording. Mapping of shape, size and association of ruins was completed using plain table and chain-tape survey methods, calibrated with HH-GPS. Based on the above parameters, these relics were identified as dwellings; common room, kitchen, store, cowshed and place of worship in addition to dry toilet. In the year 2015, mapping of the end moraine complex, water-harvesting bodies, agriculture fields and irrigation systems was completed using the Robotic Total Station (Trimble), calibrated with Juno-5 3D GPS. Fourteen samples were collected with a high degree of confidence for radiocarbon dating of the organic material extracted from these remnants after excavation at each site.

3.2.1.2 GIS Mapping

In-house mapping included incorporation of all field-based data into a GIS environment of ESRI Arc GIS 10.3 software. The chain & tape survey maps were scanned and georeferenced as a raster image. The maps were vectorised, based on point, line and polygon feature class in personal Geo Data Base using ArcGIS 10.3 software. The .kmz/.kml files of Google Earth were directly converted as a feature class into ArcGIS 10.3 software. These feature classes (point, line polygon) were labelled in the Google Earth software environment as moraines, fields, houses and irrigation channels etc. Similarly, the GPS/DGPS and Total Station data were processed to incorporate as shapefile in ArcGIS software. The hand-held GPS data were processed using GARMIN MapSource software whereas the DGPS rover and base data were processed in Trimble Pathfinder software. The Survey of India topographical sheets, Landsat; TM, ETM+, OLI, and IRS; LISS III data sets were used for mapping land cover in the valleys, whereas high-resolution data such as Cartosat, ASTER and declassified Corona images were used for detailed vectorisation of the feature class. Google earth 3D visualization of terrain between the scales of 0.1-3 vertical exaggerations was used for mapping geo-archaeological features. High-resolution Google Earth 3D visualization was used to differentiate moraines, hummocks and palaeo-ablations valley. In addition, each of the settlement, agriculture field, temples, water-harvesting ponds and irrigation channels (*kuhl)* system were identified and mapped, wherever possible.

Historical maps (Great Trigonometric Map 1874 and Harcourt's Map 1871) have also been used as reference map for the historical position (LIA) of glaciers. The position and dimensions of glacier expansion marked on the historical maps have been verified through field expeditions carried out between 2006 and 2016 for the selected glaciers (Miyar, Pimu, Menthosa, Tharang, Karpat and Uldhampu). The fieldwork was conducted using GPS/DGPS and Total station mapping. Google Earth Pro images with vertical exaggeration between the scale of 0.5 to 3 were again used for the LIA moraine mapping.

3.2.2 Radiocarbon Dating

Fourteen Radiocarbon samples were processed following Reimer et al., (2015) methods. Out of the 14 samples, 09 samples (Lab Code as UBA) were processed at the 14CHRONO Centre of Queen's University Belfast, Northern Ireland, United Kingdom and 5 samples (Lab Code as THMCS) were processed at the Inter-University Accelerator Centre (IUAC), New Delhi. As per the Lab protocol, the samples were processed at three stages; namely pre-treatment, combustion and graphitization, and finally determining age using Oxford Accelerator Mass Spectrometry (AMS) Unit. At Pre-treatment stage the samples containing charcoal, wood and sediment (UBA-30064, 30069, 30074, 30075, UBA 30076, 30077, THMCS02, 03, 04, 05, 06) were placed in a clean 100 ml beaker and immersed in HCL (4%, 30-50 l). The samples were heated on hotplate (80°C for 2-3 hours), subsequently the samples were washed with deionised water until neutral. Whereas the bone samples (UBA-30065,30072, 30078) were prepared following ABA treatment, gelatinization (Longin 1971) and ultrafiltration (Brown et al. 1988) using Vivaspin® filter cleaning method (Bronk Ramsey et al. 2004). Subsequently, the dried samples were combusted to carbon dioxide at 850° C for 8 hours into quartz tubes with an excess of copper oxide and silver foil, sealed under vacuum.

At Graphitisation stage, zinc with an iron catalyst was used to remove the oxygen from the carbon dioxide. The 14C/12C and 13C/12C ratios were measured by AMS on NEC 0.5 MV compact accelerator. The sample 14C/12C ratio have been background corrected and normalised to the HOXII standard. The radiocarbon ages are corrected for isotope fractionation using the AMS measured δ13C which accounts for both natural and machine fractionation. The fractionation and background corrected quantity F14C were calculated following Reimer et al. (2004) equation. The value of F14C is for two minute exposure of caesium on the sample. The Conventional Radiocarbon Age (CRA) have been determined using the Libby half-life of 5568 years, following the methods of Stuiver and Polach (1977).

The CRA has been calibrated in the OxCal 4.3 (online) RADIOCARBON CALIBRATION PROGRAM 1986-2016 using IntCal13 Northern hemisphere calibration curves (Reimer, 2013). The uncertainties for the calibrated ages are given up to 2σ (Table3.1).

3.3 Results & Discussion

3.3.1 Settlements and Irrigation System at Tharang End Moraine Complex

A large number of abandoned settlements are strewn over Khanjar to Gumba with most concentrated within the Tharang glacier end moraine complex area in the study area (fig.3.1). Based on the relative proximity and highly dilapidated condition of these settlements at Tharang glacier end moraine complex, three abandoned village sites (*Tharang*, *Phundang* and *Patam)* and associated drainage system were identified, mapped and sampled for radiocarbon dating between 2008 and 2015.

Table 3.1 Characteristics of Radiocarbon (^{14}C) samples and obtained ages.

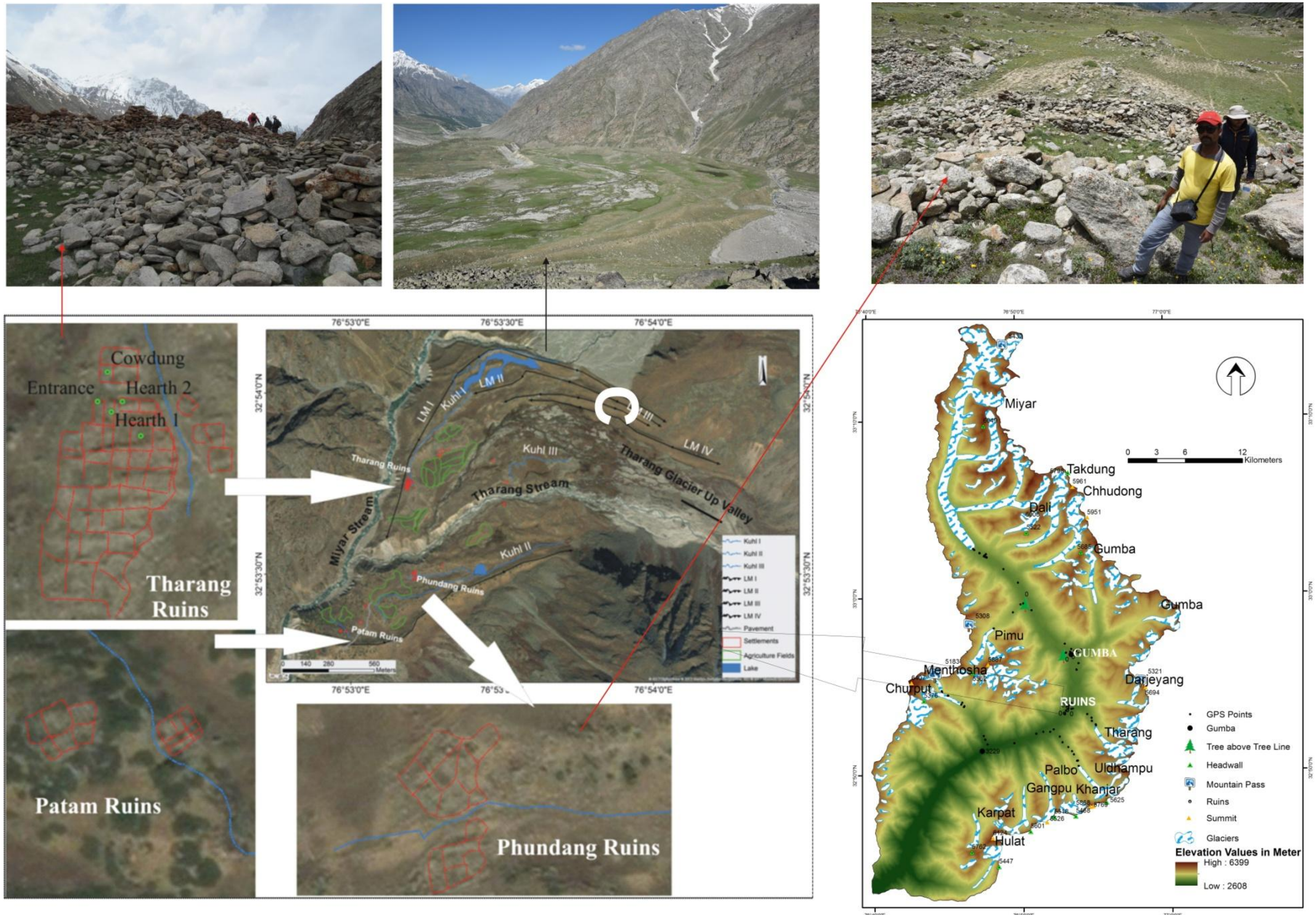
Lab Code	Material Type	Latitude	Longitude	Altitude (m)	Site Location	14C age	lower cal range AD	upper cal range AD	**Median Age AD**
UBA-30075	Wood/charcoal (Hearth)	32°53.750'N	76°53.201'E	3739	Tharang	838±28	1159	1260	**1206**
UBA-30064	Charcoal (Hearth)	32°53.342'N	76°52.969'E	3681	Patam	654±21	1283	1317	**1358**
UBA-30076	Soil (Hearth)	32°53.753'N	76°53.196'E	3731	Tharang	489±22	1412	1444	**1429**
UBA-30077	Soil (Cattle shed)	32°53.760'N	76°53.195'E	3734	Tharang	378±27	1446	1524	**1501**
UBA-30074	Wood (hearth)	32°53.756'N	76°53.197'E	3730	Tharang	327±21	1488	1603	**1565**
UBA-30078	Horn	32°53.849'N	76°53.210'E	3739	Tharang	212±34	1641	1690	**1768**
UBA-30069	Wood (hearth)	32°53.792'N	76°53.197'E	3729	Tharang	123±22	1681	1739	**1836**
UBA-30072	Bone (Hearth)	32°53.735'N	76°53.189'E	3735	Tharang	108±32	1693	1727	**1836**
UBA-30065	Bone (Hearth)	32°53.499'N	76°53.208'E	3699	Phundang	101±27	1684	1734	**1840**
THMCS02	Pine Wood	32°53.342'N	76°52.970'E	3681	Patam	393±41	1462	1642	**1556**
THMCS03	Pine Wood	32°53.342'N	76°52.975'E	3681	Patam	860±42	1044	1101	**1179**
THMCS04	Pine Wood	32°53.845'N	76°53.210'E	3738	Tharang	892±42	1032	1221	**1133**
THMCS05	Pine Wood	32°53.848'N	76°53.210'E	3737	Tharang	826±42	1052	1080	**1212**
THMCS06	Pine Wood	32°53.850'N	76°53.210'E	3738	Tharang	1058±44	885	1040	**980**

Calibration of the CRA is based on Oxcal 4.3 (online) RADIOCARBON CALIBRATION PROGRAM 1986-2017 using IntCal13 calibration curves NH2 (after P. Reimer 2013). The uncertainties for the calibrated ages are given up to 2σ. Note: The samples were superficial covered with shattered stone and has been dug out after removal of the same. For hearth based samples, the soil profile of the hearth dugout around 1 foot. However, horns sample was open exposed on the animal sacrifice point. The UBA samples were processed at 14CHRONO Centre of Queen's University Belfast, Northern Ireland, United Kingdom whereas the THMCS were processed at Inter-University Accelerator Centre (IUAC), New Delhi

Based on the mapping it is established that *Tharang* was the largest village (with a group of ~50 rooms spread in ~1700 m^2) (fig.3.2), followed by *Patam (*5 separate group of settlements having 6 rooms on an average) and *Phundang (*3 separate settlements having 7 rooms on an average) (fig.3.3). In terms of size, number and proximity, these settlements are many degree different from nomadic activities. Present day transhumance (Gaddis) settlements have a single dome shaped room (Plate.3.1) and maintain at least 2 kilometres distance from the neighbouring Gaddi settlement, as large area is required for the grazing of the sheep-goat flocks (on an average 300 sheep& goats).

Based on the mapping carried out, the study identified three *Kuhls* (irrigation channels marked as *Kuhl-I, II, III*), draining into the villages and fields there of (fig. 3.1, 3.2, 3.3). A robust system of gravity channels were constructed to divert waters from the rivulets for domestic as well as irrigation needs of these settlements and agriculture fields. The *Kuhl-I*, after originating at the *Darjeyang* glacier, runs along the crest of the highest lateral moraine (LM-I) in the north extends upto the open yard of *Tharang*. ruins (fig. 3.1, 3.2). The channel is contained within two-sided stone bounding and an intervening trench (Plate 3.2). Before reaching the settlement, the Kuhl debouched into two sequential lakes (upper and lower lakes); in the recessional end moraines complex (fig. 3.1. and Plate 3.2). We presume that when the upper lake attained its threshold, water overflowed to the lower lake. A distributory channel was formed from the lower lake to feed the irrigation needs of the field further down the ridge.

The *Kuhl-II* is located on the left flank of the *Tharang* channel (fig. 3.1 and 3.3). It originates from the eastern edge of *LM-I* marked on the left flank of the *Tharang* channel.



.**Fig. 3. 1** Map shows the relative location and environment of the Tharang, Phundang and Patam ruins within the Miyar basin.

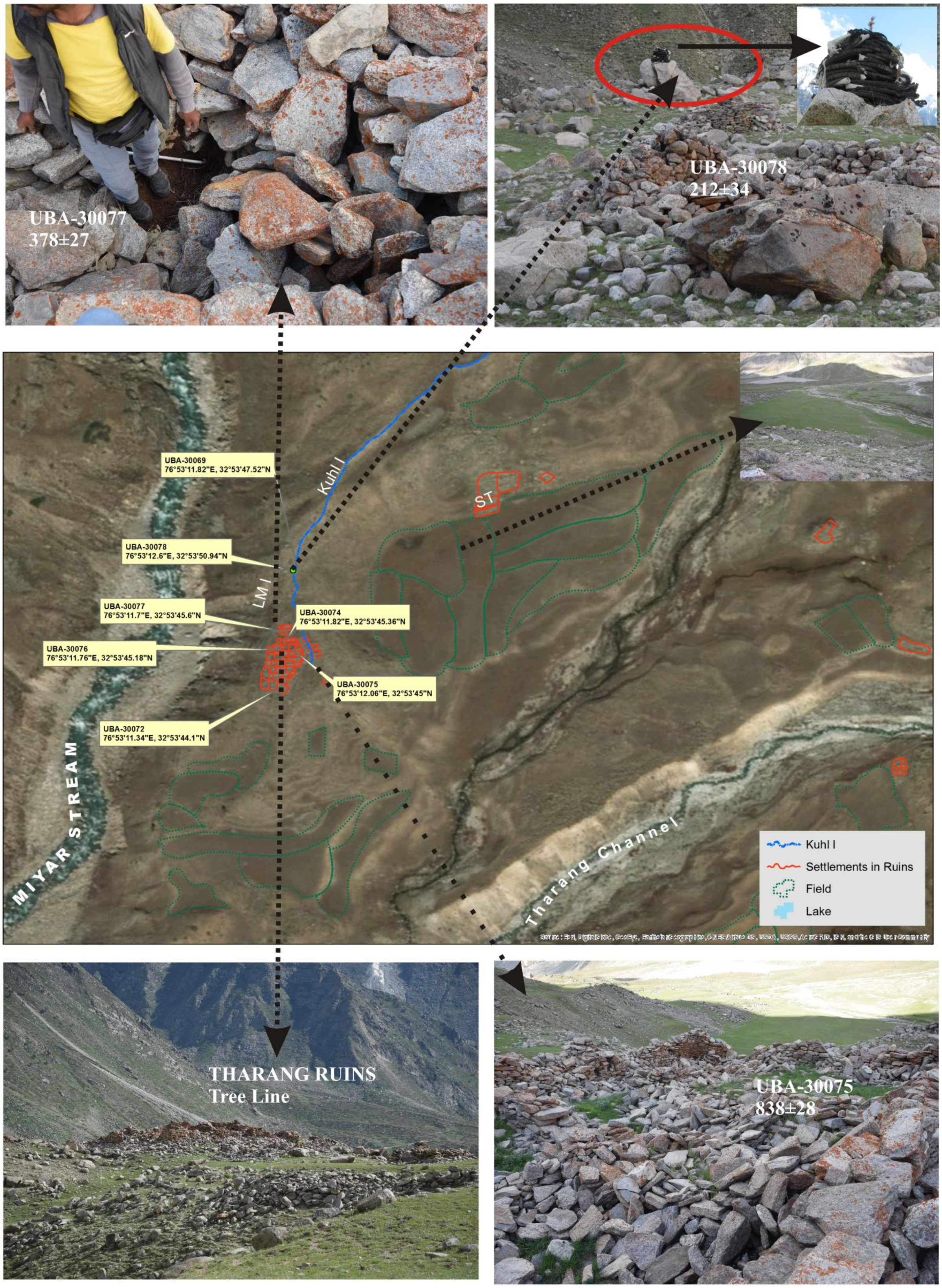


Fig. 3.2 Map showing the environmental setting and location of the radiocarbon samples.

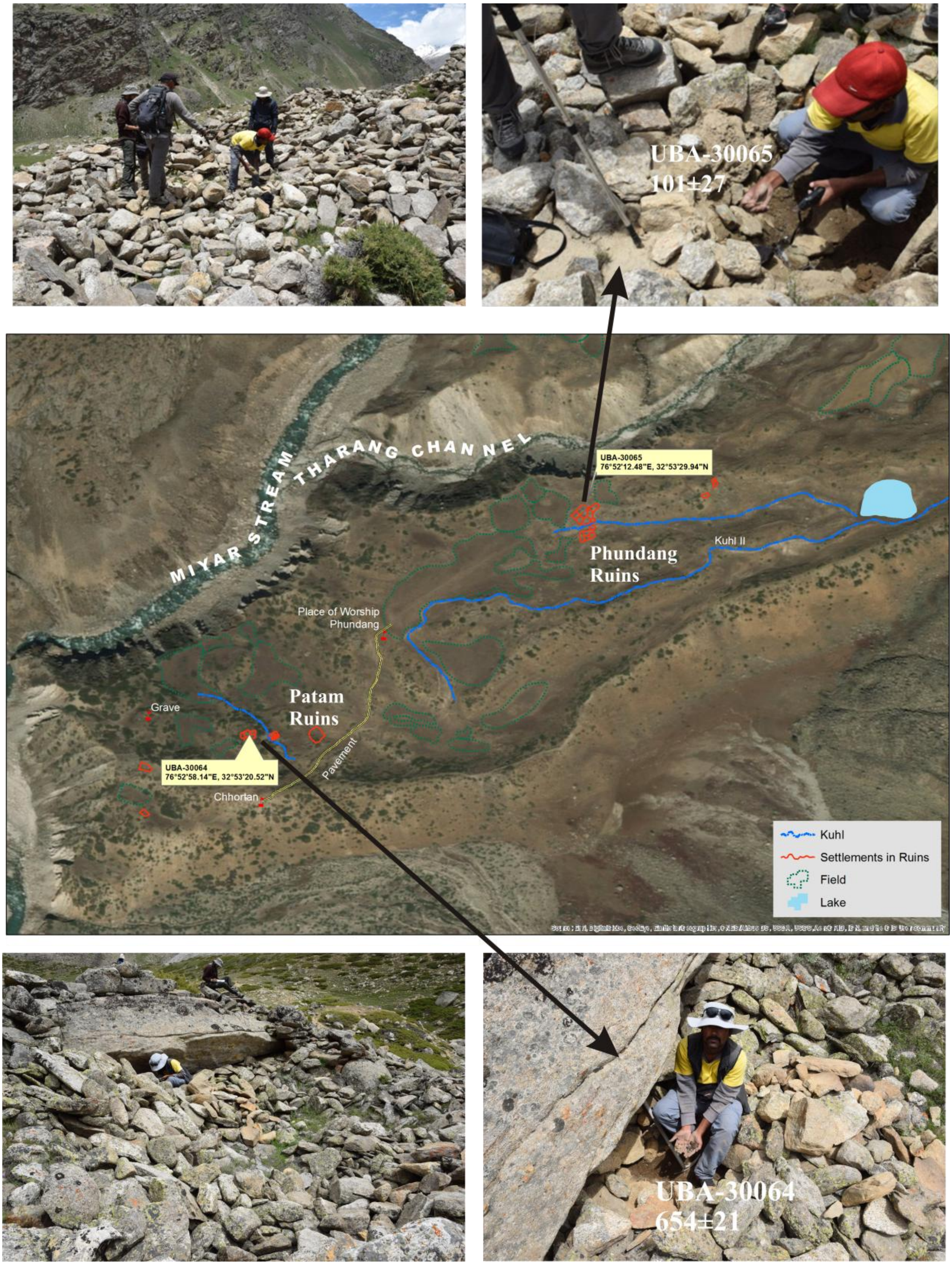


Fig. 3.3 Map showing the environmental settings and location of the radiocarbon samples.

This *Kuhl* flows through the ablation valley between *LM-I* and *LM-II*, feeding *Phundang* ruins and associated agriculture fields by one channel and *Patam* ruins by its distributary. The *Kuhl-III* is located in the centre of outwash plain, anabranches water from Tharang stream, and feeds few settlements along the hummocks (fig.3.1). Two sites for religious rituals; one at Tharang and another in between Phundang and Patam were also mapped (Plate 3.2 and 3.3).

Plate 3.1 Contemporary nomad (Gaddi) settlement (single dome) at Gumba.

3.3.2 Chronology of the Ruins

A set of fourteen radiocarbon samples belonging to charcoal (2), wood (7), horn (1), bone (2) and soil (2) were dug out from the ruins (Table3.1). Out of these, seven samples (2 charcoals, 2 bones, 2 woods and 1 soil) were picked up from hearths in the floors of the shattered buildings. Whereas six samples (5 wood and 1 soil) were picked from floors and one horn sample was picked from a wall. These samples were picked up systematically by removing collapsed walls from the floors (Plate3.4). The study depended on these Radiocarbon samples (14) to establish the chronology of the settlement (Table3.1).

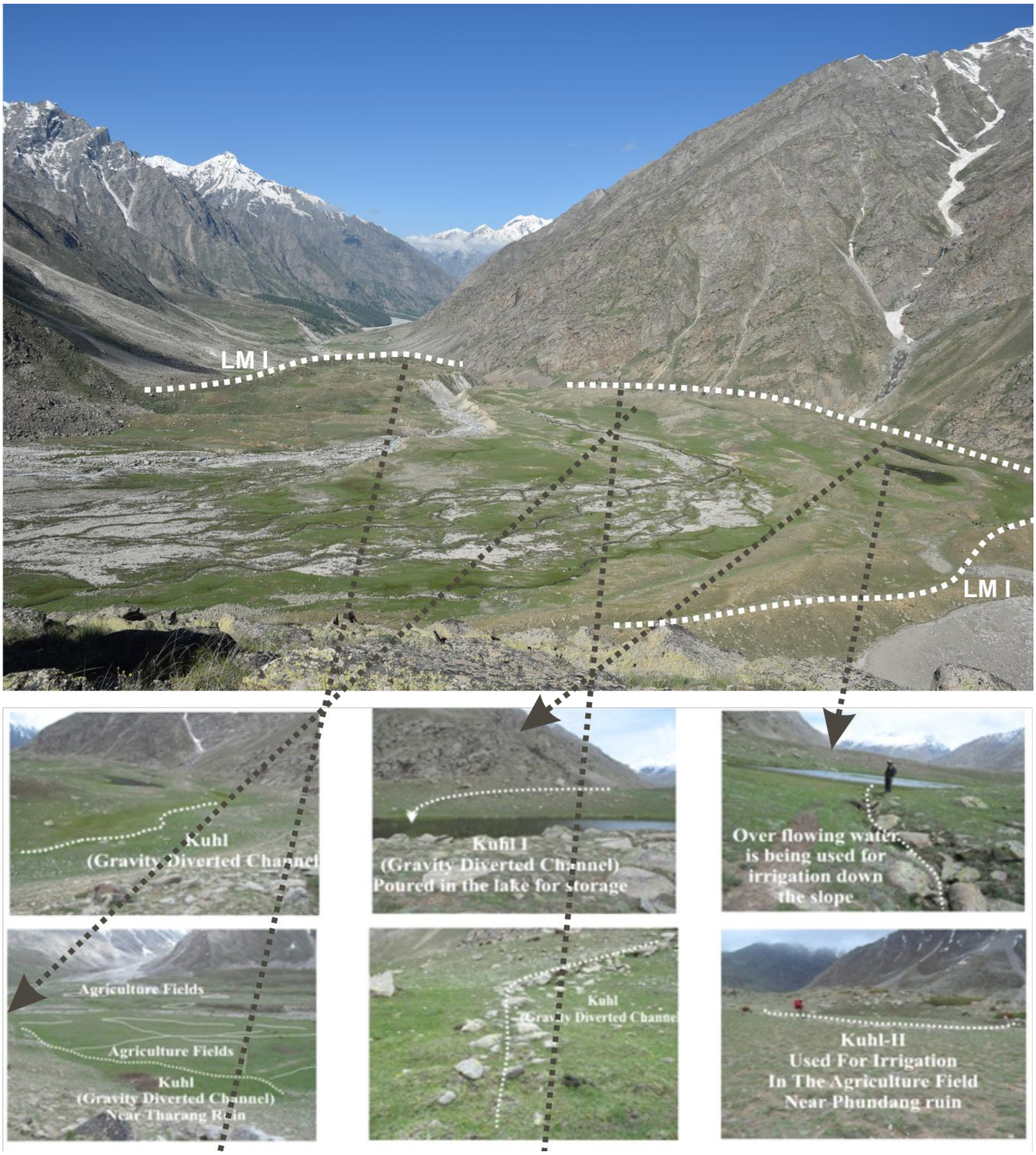


Plate 3.2 Archaeological features within the Tharang moraine complex.

Plate 3.3 Places of worship; (A) temple at Phundang ruins and (B) place of sacrifice at Tharang.

Out of these fourteen samples, 10 samples (UBA-30069, UBA-30072, UBA-30074, UBA-30075, UBA-30076, UBA-30077, UBA-30078, THMCS04, THMCS05, and THMCS06) were collected from *Tharang* ruins whereas, UBA-30064, THMCS02, THMCS03 and UBA-30065 were collected from *Patam* and *Phundang ruins* respectively (Table3.1).

The UBA-30065 sample (bone) was extracted from a hearth underneath a stone pile at *Phundang* ruins (Plate 3.4) and probably denotes the earliest activity of peopling in the area. Another bone (sample UBA-30072) was extracted from *Tharang* complex with similar settings as that of the previous sample (Plate 3.4). The wood sample (UBA-30069) was found in the hearth covered by stone within the same complex and probably stored at the same period (Plate3.4). The Ibex (Capra sibirica hemalayanus) horn (UBA-30078) was from the place of worship within the *Tharang* complex (Plate 3.3 B, 3.4). The sample holds much significance in interpreting the history as there is a normal practice in the valley of placing animal head/trophy on the walls/top of the temple. Each village has a separate deity and place of worship, generally on the prominent landform. A wood sample (UBA-30074) was extracted from a hearth within the *Tharang* ruins, after removing piles of stones. The wood was integral part of the hearth structure and found along with the small pieces of charcoal. The sample of wood may be the remnants of fuel wood once stored for the use. The conditions of the hearth, within each house were as similar. The soil sample (UBA-30077) was dugout from the cattleshed (a separate structure of four rooms) at Tharang (fig.3.2, Plate3.4). The four room structure of 20’×20’ is full of organically rich soil otherwise absent in other rooms. We assume that like the present day practice in the valley cattle-shed was localised next to one’s living structure. .

Plate 3.4 Sites of radiocarbon samples obtained and conditions of once teaming settlements at Tharang end moraine complex.

This served not only an easy access but also keeping watch at any animal encounter. The soil sample (UBA-30076) was picked up from a buried hearth of a house. This was burnt (dark) and had carbon layered on the hearth stone. The charcoal sample (UBA-30064) was picked from a buried hearth at Patam (Plate3.4, fig.3.3). Whereas, the wood/charcoal sample (UBA-30075) is from a living room (the biggest room) at Tharang (fig. 3.2, Plate 3.4). It was recovered from a hearth, located in the centre of the room, and partially covered by stone and soil, having charcoal and small pieces of un-burnt wood. Other than the hearth material, five samples of pine wood (THMCS02, THMCS03, THMCS04, THMCS05, and THMCS06) were also obtained from these ruins, excavated from the piles of stones (Table3.1, Plate3.4). The first two juniper pine samples belong to Patam and the other three be to Tharang complex.

Chronologically, the sample THMCS06 yielded the oldest radiocarbon age (1058±44) followed by THMCS04 (892±42), THMCS03 (860±42), UBA-30075 (838±28), THMCS05 (826±42), UBA-30064 (654±21), UBA-30076 (489±22), UBA-30077 (378±27), THMCS02 (393±41), UBA-30074 (327±21), UBA-30078 (212±34), UBA-30069 (123±22), UBA-30072 (108±32), UBA-30065 (101±27) (Table3.1). The calibration of first six dates indicate that during the Medieval Warm Period (Mann, 2002), the samples thrived within the Tharang end moraine complex at 95% confidence level where the median age of these samples range from 980AD to 1358AD (Table3.1). The individual calibration indicates a lower age range of 885, 1032, 1044, 1075, 1052 AD and a higher range of 1040, 1212, 1101, 1260, 1080 AD, respectively. These calibrated dates are based on the charcoal (firewood in hearth) and excavated pine wood samples. In the contemporary conditions, firewood and pine tree line is limited to 3650m a.s.l., exist almost 5 kilometres down the valley at Khanjar village. Firewood is a daily use item, required for cooking and heating the dwelling at this altitude and location year-round (Table3.1, fig.3.1). It is assumed that the household would not have extracted the firewood on daily basis from 5 kilometres down the valley. It is therefore a natural and assumed that this area (Tharang complex) had sufficient vegetation to suffice the needs of firewood at this altitude (≥ 3710m a.s.l.).

This finding is also supported by the temperature anomaly and precipitation data for the last millennium for the Western Himalaya (Yadav, et al. 2009; Yadav 2011a, 2011b). Yadav et al. (2009) have reported periods of protracted warmth from 11th to 15th centuries and decrease in mean summer temperature since the 15th century with the 18–19th centuries being the coldest interval of the last millennium. It is quite possible that during these warm periods, the basin contained large vegetation cover extending to these altitudes. To strengthen thuis assumption, three irregular pockets of trees exist in the present conditions of the Miyar valley at Tharang (32°53'25.38"N & 76°54'18.26"E), Gumba (32°56'35.45"N & 76°52'56.17"E) and Pimu base (32°59'32.11"N & 76°50'24.79"E) (Plate3.5). These patches are odd land cover in otherwise vegetation scanty environment. There is also the practice of using small trees or young branches (short-lived) for firewood in such environments.

Therefore, we suggest that the dates of the charcoal denote the activity performed in the then houses rather than an old tree (long-lived) used for firewood. Moreover, the relative area coverage of these dates shows the higher precision of these ages (Table3.1). The consistent ages (median age 980, 1133, 1179, 1206, 1212 and 1358) indicate that during the medieval warm period the settlements existing as bustling

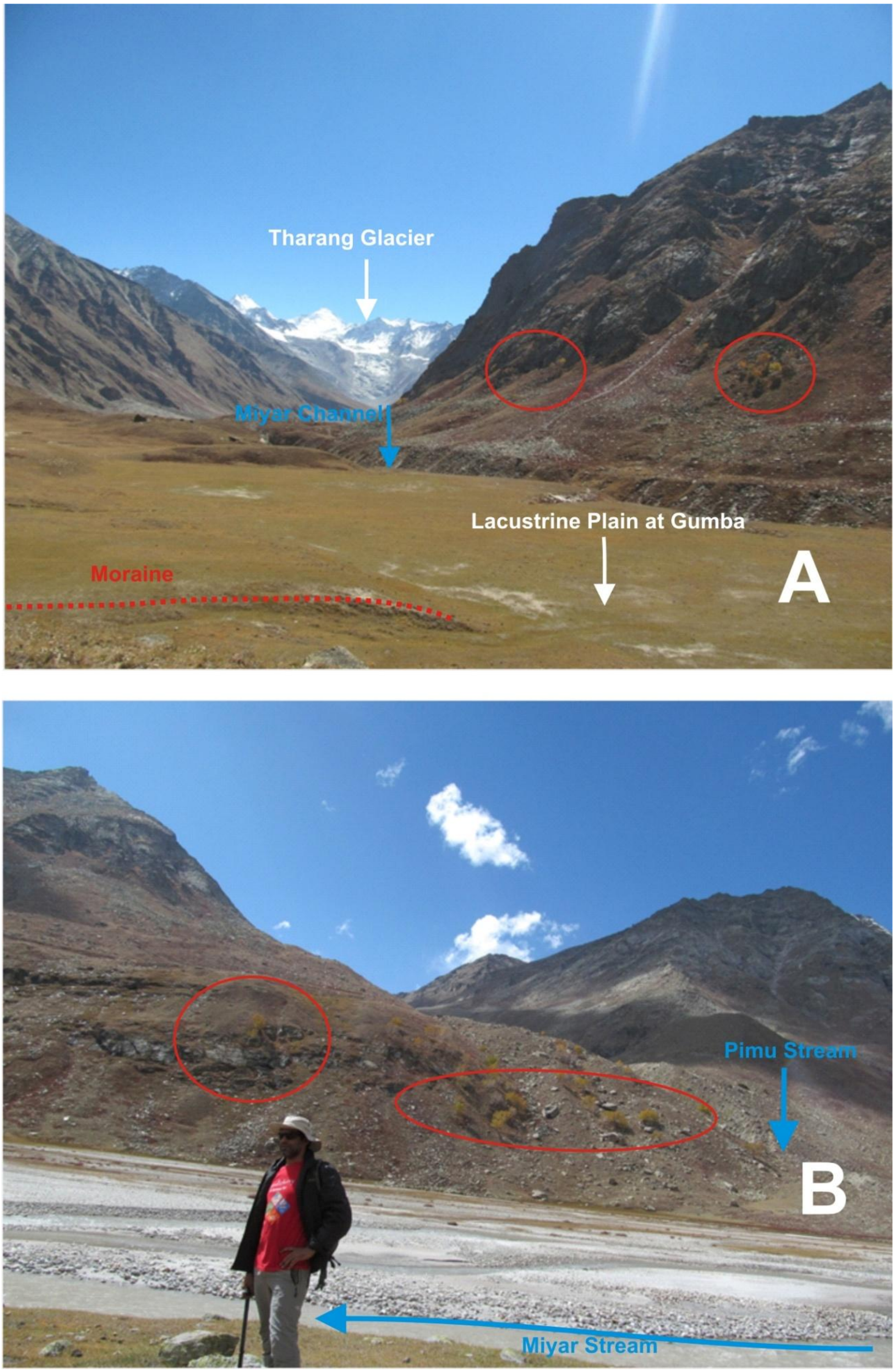


Plate 3.5 Patch of trees observed at Gumba (A) and Pimu base (B) indicating a misfit feature in the trim line zone.

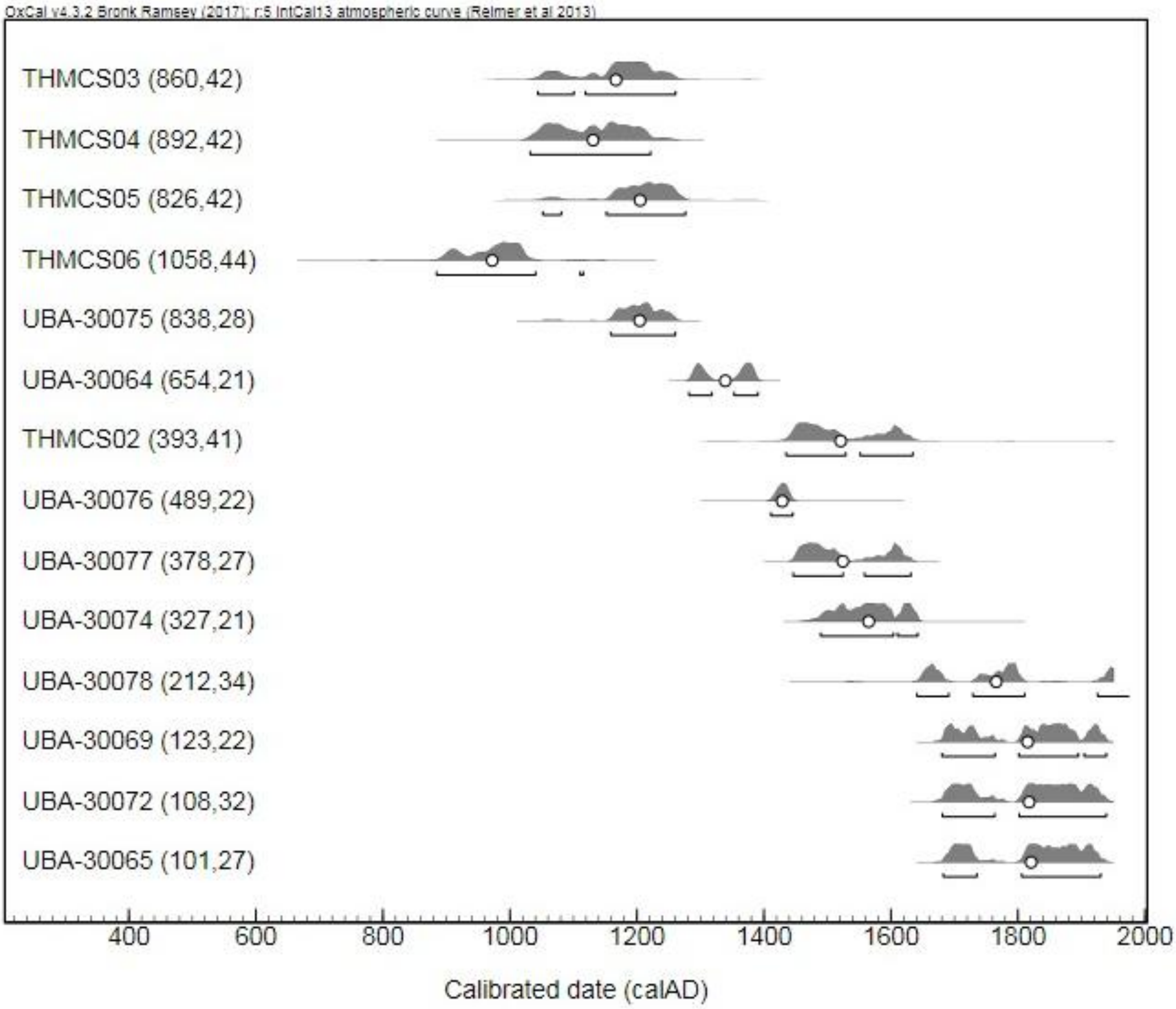


Fig. 3.4 showing the calibrated radiocarbon dates extracted from the Tharang end moraine ruins.

villages. The other eight conventional radiocarbon ages (CRA) of 489 ±22, 378 ±27, 393±41, 327 ±21, 212 ±34, 123 ±22, 108 ±32 & 101±27 yr BP (Table3.1) belong to the period probably of Little Ice Age as calibrated median dates span from 1429 to 1836 AD (Table3.1). The soil sample UBA 30076 and 30077 extracted from the cattleshed and hearth provide a more reliable and realistic ages, indicating towards settled human activity at these sites. At 95% confidence level, the calibrated timing of the sample UBA-30076 spanned between 1412 and 1444 AD, with median date of

1429 AD (Table3.1, fig.3.4). The sample UBA-30077 range 1446-1631 AD with median date of 1501 AD.

Furthermore, the wood (small piece of pine) samples; THMCS02 and UBA-30074 at 95% provide a time span of 1462-1642 and 1488- 1641 AD with a median date of 1556 and 1565 AD. The Ibex horn sample UBA-30078 yields a time span of 1641-1949 AD with median calendar age of 1768 AD at 95% confidence level. The horn sample indicates about the ritual history of the people. Based on the average ibex life span (16 years), the timing of the animal sacrificed in the temple of the deity can be worked out, i.e. 1784/1752 AD.

Keeping in view, the above discussed dates, it is clear that the ruins remained inhabited in the end moraine complex of the *Tharang* glacier during 980-1768 AD, a part of the peak of the Little Ice Age (1300-1600 AD) period in other parts of the Himalaya (Xu and Yi, 2014; Rowan, 2016). Furthermore, the samples UBA-30069, 30072 and 30065 yield the most recent dates i.e. 1836, 1836 and 1840 AD (median age), respectively. The samples containing wood and bone material extracted from the hearths in *Tharang* and *Phundang* and suggest the time period when the inhabitants probably abandoned these villages, although, the recent dates have larger uncertainty, yet can be interpreted in relation to other available proxies.

The available temperature (Yadav et al. 2009) and snowfall (Yadav and Bhutiyani, 2013) proxies of the last millennium for the region suggest that the period between 18^{th}-19^{th} centuries was the coldest interval of the last millennium along with increased snowfall. The proxy of the snowfall is based on the dendrochronological studies sampled in the lower parts of the study area (Kukumseri, Udaipur, Madgram, Ratoli, Khursad and Tindi). In view of the radiocarbon dates (Table 3.1, fig. 3.4) and available temperture and snowfall proxies of the region it is infered that these settlements abandoned by the end of 18th or early 19th century. The available Great Trigonometric Survey map (1860-70) of the basin (fig.3.5) support these results as the map marks the *Tharang* end moraine complex as ruins. We suggest that at the time of GTS survey 1860-70 the area was already abandoned probably due to cooling and advancing glaciers. Glaciers from other parts of Himalaya & Tibetan Plateau are also reported to have advanced during this period (Xu and Yi 2014). The GTS map (1860-70) also shows advanced positions of at least *Tharang* glacier that correlates with the snowfall data reported by Yadav and Bhutiyani (2013) and other precipitation records from similar moisture stressed settings in north west Himalaya (Yadav, 2011a; Yadava et al., 2016).

These proxies, map records and abandonment timing of the ruins indicate that due to decreased temperature and increased snowfall between the late 18th and early 19th centuries the basin experienced glacier advance to some extent. As a consequence of increased snowfall and decreasing temperature the cropping probably failed for many years, creating inhospitable conditions by shortening cropping season. Since barley and buck wheat are the traditional crops that necessitate standard temperatures and limited precipitation; still grown at lower altitudes within this basin. It would have been rather impossible to sustain and support large population and therefore, migration was the only alternative. Similar high altitude village of *Yurnwal* in the Chandrabhaga valley had similar tale, and now in totally shattered but agricultute fields stand tall as witness of yester year’s thriving activity.

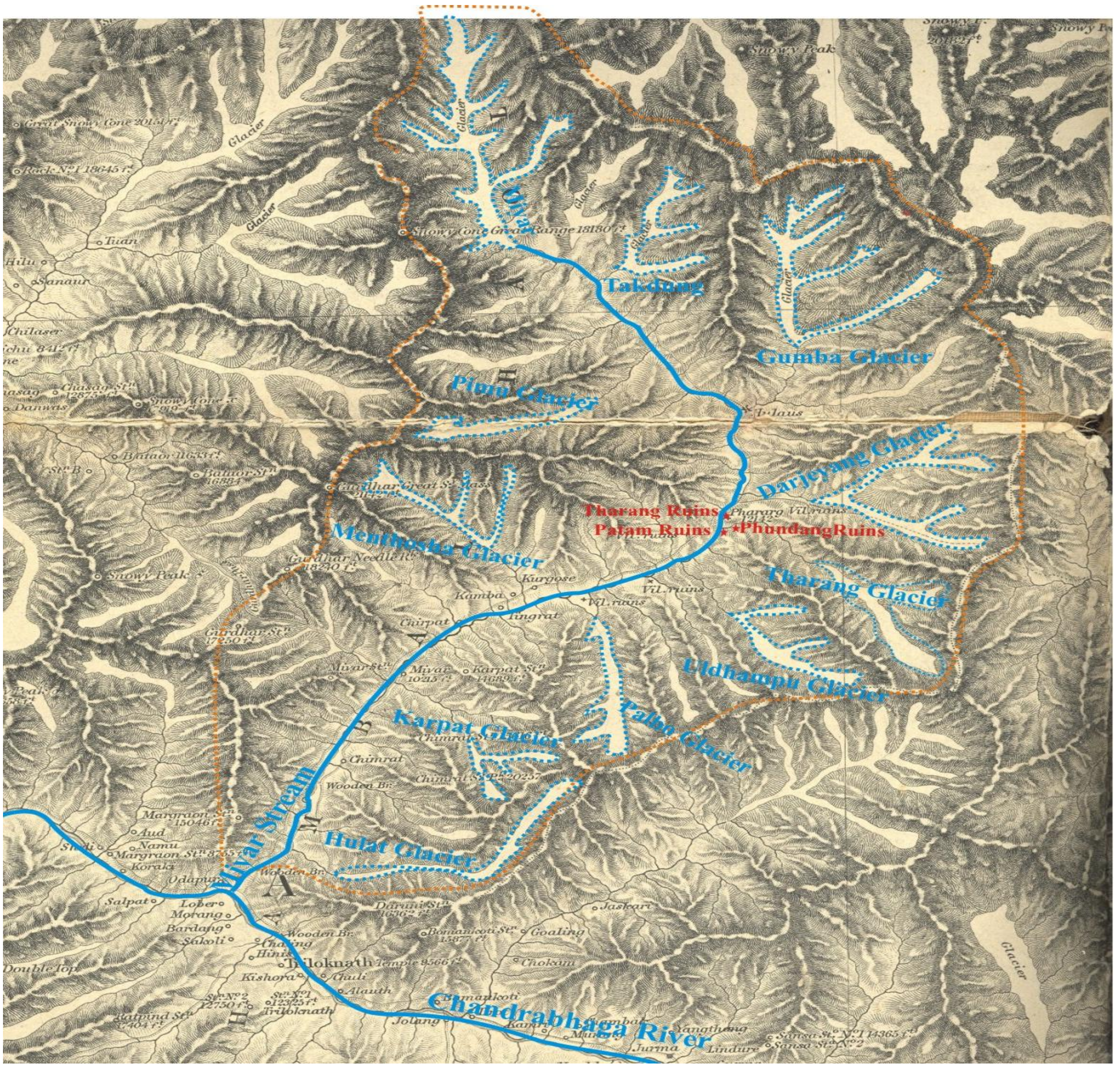


Fig.3.5 The Great Trigonometric Survey (GTS) Map (1874) of the basin and surrounding regions shows the positions of the glaciers along with present study site of Tharang glacier end moraine complex.

Folk history in the contemporary villages of the Miyar valley also refer to repeated failure of crops (cursed by the Flying Lama of Gumba) for years on an end, and the reference of last people surviving on boiled animal skin before finally migrating out of this site to lower areas within the Miyar basin. Two families having lineage (six generations) of Phundang (Phun Phundang Pa) and Tharang (Chhe Chung Garad) continue to inhabit Tingret and Urgos (3300m a.s.l.). The down valley people in the basin narrate the stories of these ruins, and climate-induced migrants from these villages are settled at *Tingrit* (3225 m) and *Urgos* (3300 m), ~10 km down valley, as *Phun Phundang Pa* and *Chhe Chung Garad*, who trace their family genealogy for six generations to these dated sites.

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3.4 Conclusions

Palaeo-climatic data from the Lahaul Himalaya and glacio-archaeological records from Miyar basin support our assumption that there had been settled colonization in the higher reaches within the moraine complex during the late 10th century to early 19th century. Existence of three abandoned sites (Tharang, Phundang and Patam), indicate exclusively towards prolonged period of settled agriculture that coincide with relatively warm temperature and limited snowfall in this region. The timing of abandonment of these villages and increased snowfall with low temperatures for the region is well supported by the available historical maps, and limited glacial fluctuation after late 18th & early 19th Century expansion.

We present direct and indirect evidences of limited glacier during the LIA peak. However, further investigations are required, both in the basin and in the surrounding region of the Lahaul Himalaya, to validate and refine the period of human colonization and limited glacial expansions.

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Chapter IV

GLACIER FLUCTUATIONS IN THE STUDY AREA

4.1 Introduction

The Himalayas contain the most significant cluster of glaciers outside the polar region and is a source of water for the 800 million population (Bolch et al., 2012). Glacier fluctuations in the Himalaya can have glacier related hazards and associated water shortage issues in minutes to decades (Richardson and Reynolds, 2000). Therefore, an understanding of past glacier dynamics is must to infer the future estimates. The style and timing of the late Quaternary glacial fluctuations in the Himalaya had been asynchronous to global Last Glacial Maximum (Gillespie and Molnar, 1995; Sharma and Owen, 1996; Solomina et al., 2015). However, we know little about the recent glacial fluctuations that occurred in the last millennium (Xu and Yi, 2014; Rowan, 2016; Solomina et al., 2016). In the absence of robust glacial chronology for the last millennium, the relative size and extent of the Himalayan moraines were compared with that of the Little Ice Age (LIA) glaciers of Europe (Mayewski and Jeschke 1979). In Europe, the LIA is considered for the period from ~1300 to 1850 (with a peak between 1300-1600), when a notable glacier expansion, along with lower temperatures, were experienced in the northern hemisphere (Bradley and Jones 1993; Mann 2002). Observation of the available 2k glacial chronology in the Himalaya indicates towards variation in timing and extent of glacial advance, and most are based on relative rather than absolute chronologies (Owen et al. 1996; Sharma and Owen 1996; Derbyshire and Owen 1997; Taylor and Mitchell 2000; Mehta et al. 2012). Wherever the numerical dating has been applied, only a limited number of dates (≤ 2) have been produced (Iwata, 1976; Richards et al., 2000; Owen et al., 2001). Areas which have been historically accessible such as Khumbu (Bendict, 1976; Iwata, 1976; Fushimi, 1978; Muller, 1980; Rothlisberger and Geyh, 1986; Richards et al., 2000), Garhwal (Sharma and Owen 1996; Barnard, et al. 2004; Murari et al. 2014), Milam (Barnard et al., 2004a), Gonga Shan (Owen et al. 2005) have produced the most dated chronologies. Chronology of the last two millennium is dominated by Central Himalaya (Khumbu and Garhwal Himalaya). Consequently, more studies from the inner parts of the Himalaya are needed for the robust glacial chronology of this period for most of the region.

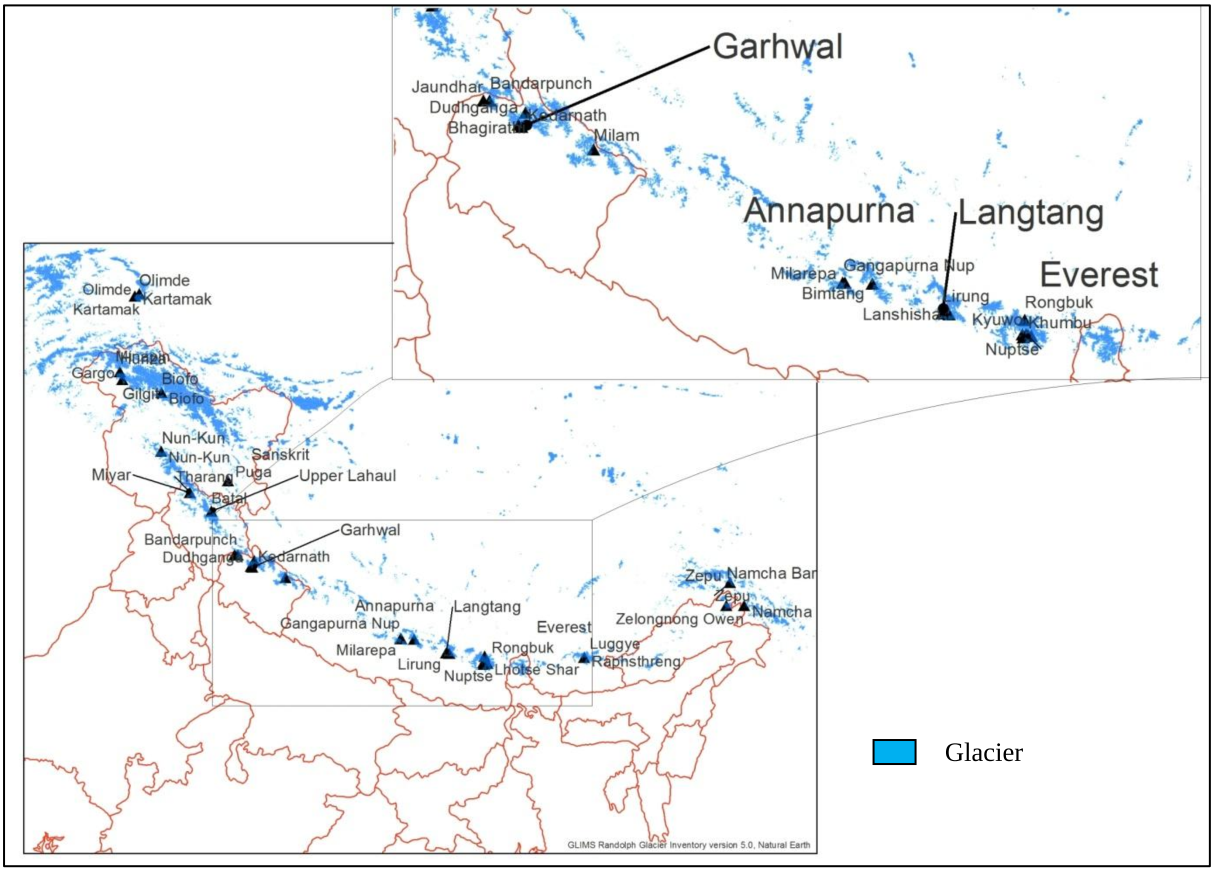

Fig. 4.1 Location of major glaciers for which glacial chronology for the last millennial available in the Himalayas.

This chapter analyses different geomorphological mapping of the landforms, historical maps in reconstructing the extent and timing of the LIA glacier advance in the Miyar basin, Lahaul Himalaya in Himachal Pradesh.

4.2 Material and Methods

Detailed (scale 1:10,000) geomorphological mapping was conducted in the course of five fieldworks between 2008 and 2016 aided by Trimble-Geo XT DGPS and photographs. The mapping was further supported by topographic maps of Survey of India (1:50000) and the high resolution imageries of ESRI ArcGIS base maps along with 3D imageries of Google Earth Pro. Survey of India topographical sheets (surveyed during 1960s) have been used as base maps in many studies for glacier monitoring (Oberoi, et al. 2001; Dobhal, et al. 2004; Kulkarni, et al., 2007; Nainwal, et al. 2008) resulted into alarming retreat of glaciers. However, in this study the toposheets have been used for the reference point of view whereas the detailed mapping of contemporary glacier has been done using high resolution satellite images (table) available through ESRI ARCGIS base maps, Google Earth Pro software. Landsat images are freely downloadable from USGS earth explorer (https://earthexplorer.usgs.gov/*)* while the IRS LISS III and IRS LISS IV images have been procured from NRSA Hyderabad, selected LISS III and Cartosat images are also available on *Bhuvan (*http://bhuvan.nrsc.gov.in/data/download/index.php*)*.The Google Earth 3D visualization of terrain between 0.1 and 3.0 vertical exaggerations scale was used to further identify and map the different moraines, hummocks, terminus positions of former and present glaciers and irrigation systems.

Historical maps (Great Trigonometric Survey Map 1874 and Harcourts 1871) have also been used as reference map for the historical position (LIA) of glaciers. The position and dimensions of glacier expansion marked on the historical Maps have been verified through field works carried out between 2006 and 2016 for the selected glaciers (Miyar, Pimu, Menthosa, Tharang, Karpat and Uldhampu). The fieldwork was conducted using GPS/DGPS and Total station mapping. Google Earth Pro images with vertical exaggeration between the scale of .5 to 3 were again used for the LIA moraine mapping.

4.2.1 Equilibrium Line Altitudes (ELA) Estimation

It is necessary to estimate ELAs for areas like the Himalayas for which no direct mass balance observations are available, or to estimate the ELAs for former glaciers, to infer one from the geomorphological features. The glacial history can be inferred from ELA reconstruction in the absence of numerical ages (Fort, 1983). Benn et al. (2005) suggested that a glacier with a wide accumulation area and a narrow snout will have a different AAR as compared to one with a narrow accumulation basin and a broad snout. Therefore, AAR values may be erroneous in many of the Himalayan glaciers and one should take an average value of various methods for better accuracy. Based on the extent of contemporary and LIA glaciers in the basin the modern and former equilibrium line altitudes (ELA) were measured using the toe to Headwall Ratio (THAR 0.5) and the Toe to Summit Altitude Method (TSAM) for the selected major glaciers in the basin (Meierding, 1982; Benn and Lehmkuhl, 2000).

The local Last Glacial Maximum (LGM) ELA in the Miyar basin are calculated by averaging the values of THAR and TSAM to further minimize the errors originating from individual method. The altitude of the local LGM terminus has been recorded 3063 meter (near Karpat village) on the basis of the geomorphic evidence of truncated spurs, trimeline and glaciogenic deposits. Position of the Holocene advance of all the glaciers is well preserved as end-moraines reaching almost the trunk valley in most cases.

The THAR method of estimating ELA is based upon the assumption that the line of balance between the accumulation and ablation zones lies at midway altitude i.e. altitudes of the terminus of a glacier and the altitude of the base of its headwall (Benn and Lehmkuhl, 2000; Benn et al., 2005; Osmaston, 2005). Much care has been taken in marking the altitude of the headwall as it always lies at the base of the headwall and not the top of crestline. Judicious use of Google Earth 3-D has been made to demarcate altitude at the bergschrund.

The ELAs also vary from one region to another within the Himalaya and Tibet orogen (Benn et al. 2005 & Table1.1). Contemporary ELAs in Miyar basin vary between 4900-5200 (Deswal et al., 2017), while in Lahul it varies between 4800-5500m asl (Owen et al., 1996; 1997; 2001). ELAs in Ladakh vary between 5200 and 5400 m a.s.l. (Dortch et al., 2010), while in Zanskar values vary from 4800 to 5500 m asl (Taylor and Mitchell, 2000; Orr et al., 2017; 2018). Sharma and Owen (1996) showed mean ELAs in Garhwal Himalaya varied between 4510 and 5390 m asl using the average of multiple methods for reducing possible error in individual techniques.

4.3 Results

4.3.1 Type of Glaciers in the Miyar basin:

Glaciers in the Miyar basin have been defined according to their morphology and topographic characteristics. These range from typical valley glacier to Ice cap, hanging glacier and cirque. The basin has valley glacier such as Miyar, Pimu, Uldhampu, Palbo, Gangpo, Gumba, Hulat and Khanjar, of which Miyar is the largest, covering 26 kilometer in length and occupying almost 106 km^2 in area. Churput glacier is an explicit example of an Ice Cap and Tharang in its own fashion provide a typical sense of a hanging glacier, whereas Karpat portrays a cirque glacier. Small cirque glaciers are also found near Khanjar & Urgus villages and Gumba Goth. According to Srivastav & Siddiqui (1999) Miyar basin had 120 glaciers. However, the study found that there are only 16 valley glaciers fed by about 100 small ice bodies and snow fields.

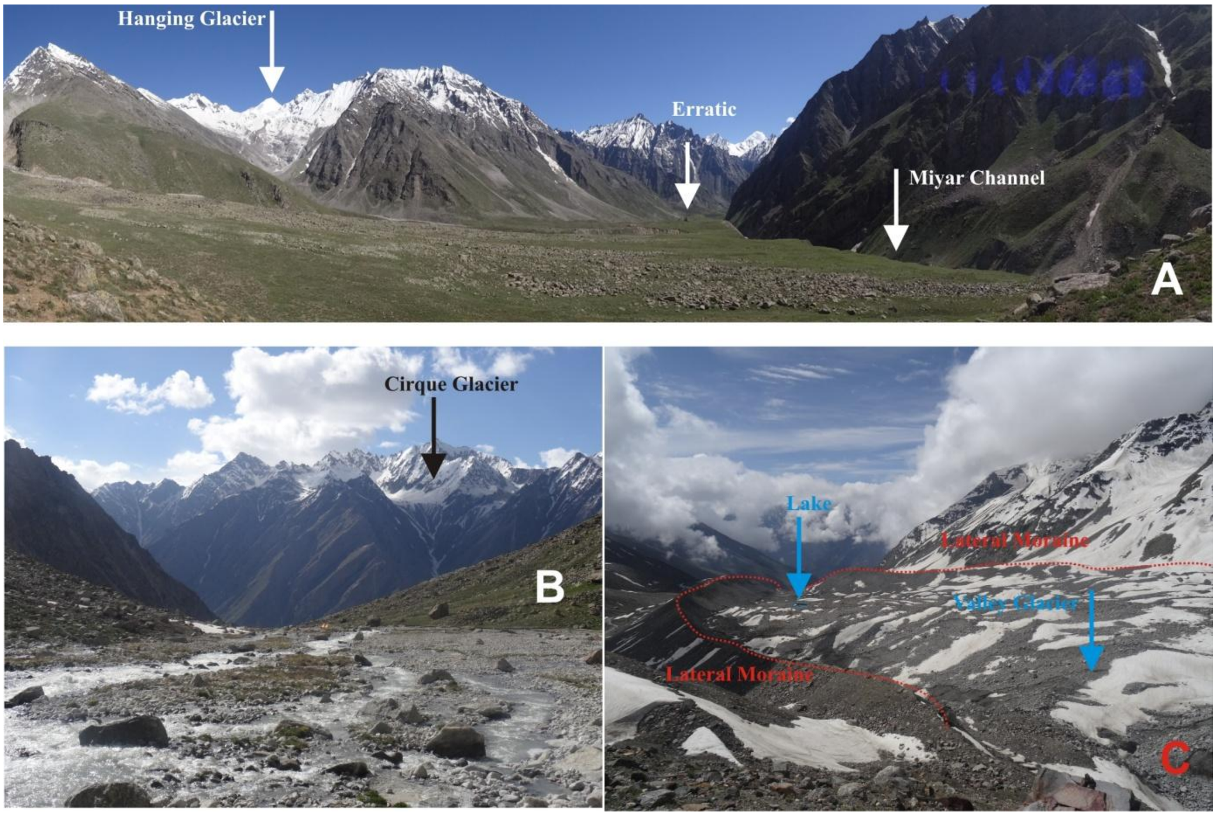

Plate 4.1 Different types of glaciers in the Miyar basin. (A) Tharang glacier is hanging in the main trunk valley of Miyar glacier. (B) Small cirque glacier as seen down the valley from Uldhampu base camp. (C) Menthosa glacier and lateral moraine marked on either side.

4.3.2 Glacier Advances and Landforms

Based on the relative considerations of the scoured valley (main trunk valley) and well deposited lateral moraines up valley to Karpat in the Miyar basin, Saini (2012) reported a first account of the glacial history of the Miyar basin, and referred one Glacial Stage and three phases of glacial advance. In addition, Deswal et al., (2017) has discussed the late Holocene glacier dynamics of the Miyar basin and provided data of three stages of Glacier expansion; Miyar glacial Stage (MR-I; prior to global LGM), Khanjar Stage (KH-II 6.6 ka OSL dates) and the Menthosa Advance (M-III; historical). However, glacial behaviour during the Little Ice Age period (1300-1600) in the basin is still obscure, available glacial chronology of this period in other parts of Himalaya has suggested multiple number of glacial advances (Xu and Yi, 2014; Rowan, 2016).

4.3.2.1 Local Last Glacial Maximum (LLGM)

The glacial stage was associated to local Last Glacial Maximum (Plate 4.2) when *Miyar*, the largest glacier in the basin, coalesced with the tributary glaciers, expanding down-valley by ~35 km to reach Karpat, with an ELA depression of ~530 m relative to contemporary ELA at 5000 m. This most extensive glacial advance in the basin is recorded as a large U-shaped trunk as well as tributary valleys, scoured shoulders and bedrock walls, along with truncated spurs. This stage still remains to be dated however, considering the size and extent of the glacial landforms and features, the stage is proposed to be contemporaneous with the Chandra Stage proposed by Owen et al. (1996b, 2001) in the upper Chandrabhaga valley.

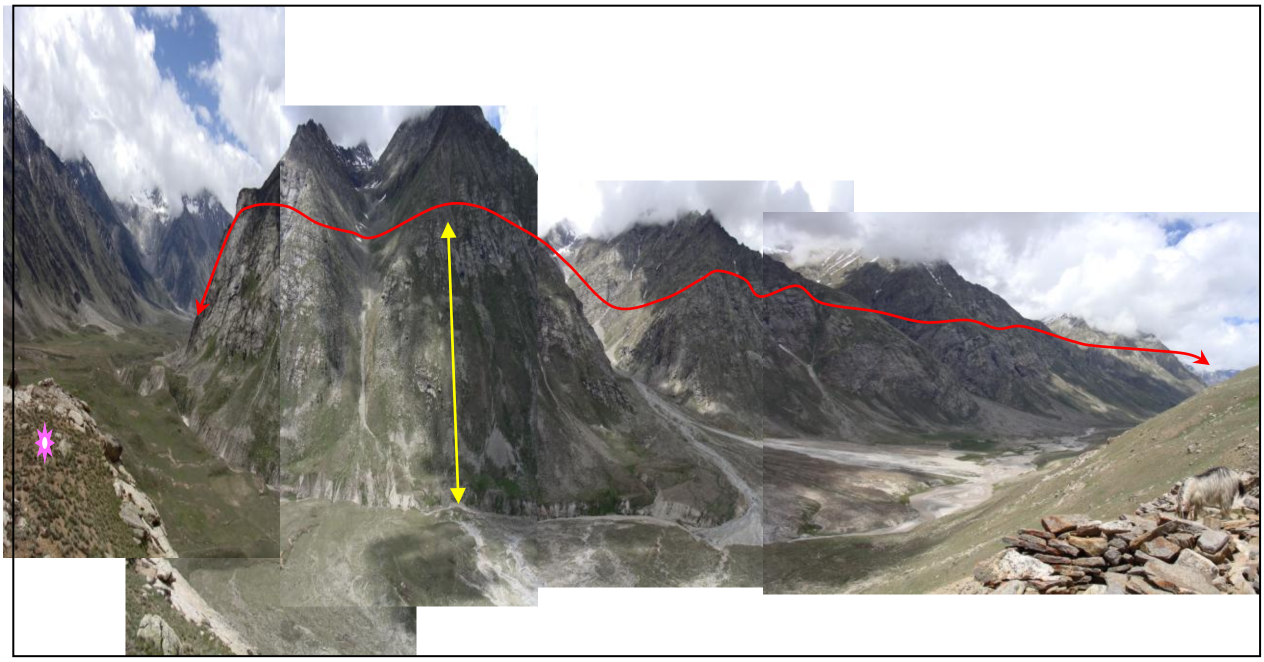

Plate 4. 2 The red line mark the upper limit of Miyar glacial maximum at Gumba and yellow denotes the thickness during local LGM. Star denoting the position of Miyar starth from where the photograph was taken.

The antiquity of Chandra stage however, can be anticipated by the age of subsequent stage i.e. Batal stage (43.4 ± 10.3 ka BP). Further, a less extensive glacial event, the Kulti is dated at 36.9 ± 8.4 ka BP in Lahul Himalaya (Owen et al., 1996, 1997, 2001). Major tributary glaciers coalesced to form the Miyar stage, a gigantic valley glacier almost 2.5 times the present cover (Deswal et al., 2017). This episode considerably predates the global LGM, given the ELA depression of 708 meter compared to the contemporary ELA. Similar ΔELA (640 meter) has been calculated by Sharma and Owen (1996) for local LGM in Garhwal Himalaya (Bhagirathi stage at ~63 ka). Most of the landform records of this major event are destroyed by the subsequent modifications. Thickness of former glacier ice, inferred from difference between the contemporary valley floor and edge of the polished surface of truncated spur in the present valley floor. Table 4.1 shows the ELA fluctuations between LGM, Holocene and the Present.

4.3.2.2 Early Holocene Advance (Khanjar Stage)

The Khanjar stage in the basin has been established on the basis of vast and widespread occurrence of lateral moraines and end-moraine complexes in almost every tributary valley. This episode is termed as the Khanjar stage from the prominent local site, constrained within 10-8 ka (OSL), i.e. early Holocene (Deswal et al., 2017). Time gap between these two phases of glaciations appears to be of many tens of thousands of years, thus leaving oldest stage landforms exposed to the vagaries of various processes, resulting into complete destruction of previous landforms. In the lower part of the basin, sharply crested lateral moraines of tributary glaciers descend from ~4600 m a.s.l. to ~3000 m a.s.l. within a short distance of 3.7 to 5.4 km, controlled strongly by slope characteristics (fig. 4.2).

Tributary valleys on the left bank in the lower basin viz. Tharang, Uldhampu, Khanjar and Karpat have the largest accumulation of end-moraine complex. A vast and nearly flat plain (Lacustrine fill) at Thanpatan (confluence of Miyar and Gumba streams) contains the drumlins (fig. 4.2). Long axes of drumlins are aligned in NE-SW direction from Gumba glacier and further down-valley it turns to E-W direction, controlled by Tarsalamu glacier (Plate 4.3). Some are aligned N-S along the valley wall (Gumba glacier) from which a section has been dated to be 4.3±0.6 ka (Deswal et al., 2017). Field mapping of the section between Gumba to Tarsalamu complex in the basin show a complexity of the landforms (Plate 4.3). .

Table 4.1 Equilibrium Line Altitude (ELA) change between local LGM (Miyar Stage), Holocene advance (Khanjar Stage) and contemporary glaciers.

	Headwall	LGM	Holocene	Present	Local LGM ELA	Holocene ELA	Present ELA	Change in ELA between Holocene & Local Glacial Maximum	Change in ELA between Present & Local Glacial Maximum	Change in ELA between Present & Holocene
Miyar	5924	3063	3974	4046	4494	4949	4985	-456	-492	-36
Dali	5756	3063	3963	4878	4410	4860	5317	-450	-908	-458
Takdung	5725	3063	3951	4536	4394	4838	5131	-444	-737	-293
Chhadung	5746	3063	3917	4315	4405	4832	5031	-427	-626	-199
Pimu	5778	3063	3900	4578	4421	4839	5178	-419	-758	-339
Gumba	5703	3063	3836	4410	4383	4770	5057	-387	-674	-287
Darjeyang	5671	3063	3702	4680	4367	4687	5176	-320	-809	-489
Tharang	5845	3063	3608	4527	4454	4727	5186	-273	-732	-460
Uldhampu	5334	3063	3488	4507	4199	4411	4921	-213	-722	-510
Khanjar	5569	3063	3442	4586	4316	4506	5078	-190	-762	-572
Palbo	5498	3063	3455	4590	4281	4477	5044	-196	-764	-568
Gangpo	5493	3063	3317	4416	4278	4405	4955	-127	-677	-550
Menthosa	5774	3063	3299	4396	4419	4537	5085	-118	-667	-549
Karpat	5571	3063	3017	4250	4317	4294	4911	23	-594	-617
MIYAR BASIN	**5671**	3063	**3634**	**4480**	**4367**	**4652**	**5075**	**-285**	**-708**	-423

Shape and orientation of the mounds do not match with true drumlins except a few and well developed lateral moraines are also absent. These mounds resemble hummocky moraines more closely.

Tributary valleys on the left bank in the lower basin viz. Tharang, Uldhampu, Khanjar and Karpat have the largest accumulation of end-moraine complex. A vast and nearly flat plain (Lacustrine fill) at Thanpatan (confluence of Miyar and Gumba streams) contains the drumlins (fig. 4.2). Long axes of drumlins are aligned in NE-SW direction from Gumba glacier and further down-valley it turns to E-W direction, controlled by Tarsalamu glacier (Plate 4.3). Some are aligned N-S along the valley wall (Gumba glacier) from which a section has been dated to be 4.3±0.6 ka (Deswal et al., 2017). Field mapping of the section between Gumba to Tarsalamu complex in the basin show a complexity of the landforms (Plate 4.3). Shape and orientation of the mounds do not match with true drumlins except a few and well developed lateral moraines are also absent. These mounds resemble hummocky moraines more closely.

We suggest that these hummocks and drumlins formed between 6.6±1.0 and 4.3±0.6 ka in this region, response to a warm phase of climate. Average ELA of the basin during early Holocene have been estimated to be 4652 m asl with ΔELA of 423 m asl from present to Holocene. On expansion of tributary glaciers, main trunk valley was chocked at many places. This resulted into a considerable length of blockade of the main trunk river, thus filling the space available with large and thick lacustrine fills. Samples from Gumba lacusrine fill have been dated 8±2 ka, 8±1 ka and 10±1 ka, meaning thereby the maximum extent of Gumba glacier at around 10-8 ka B.P (Deswal et al., 2017). We assign these advances to the early Holocene intensification

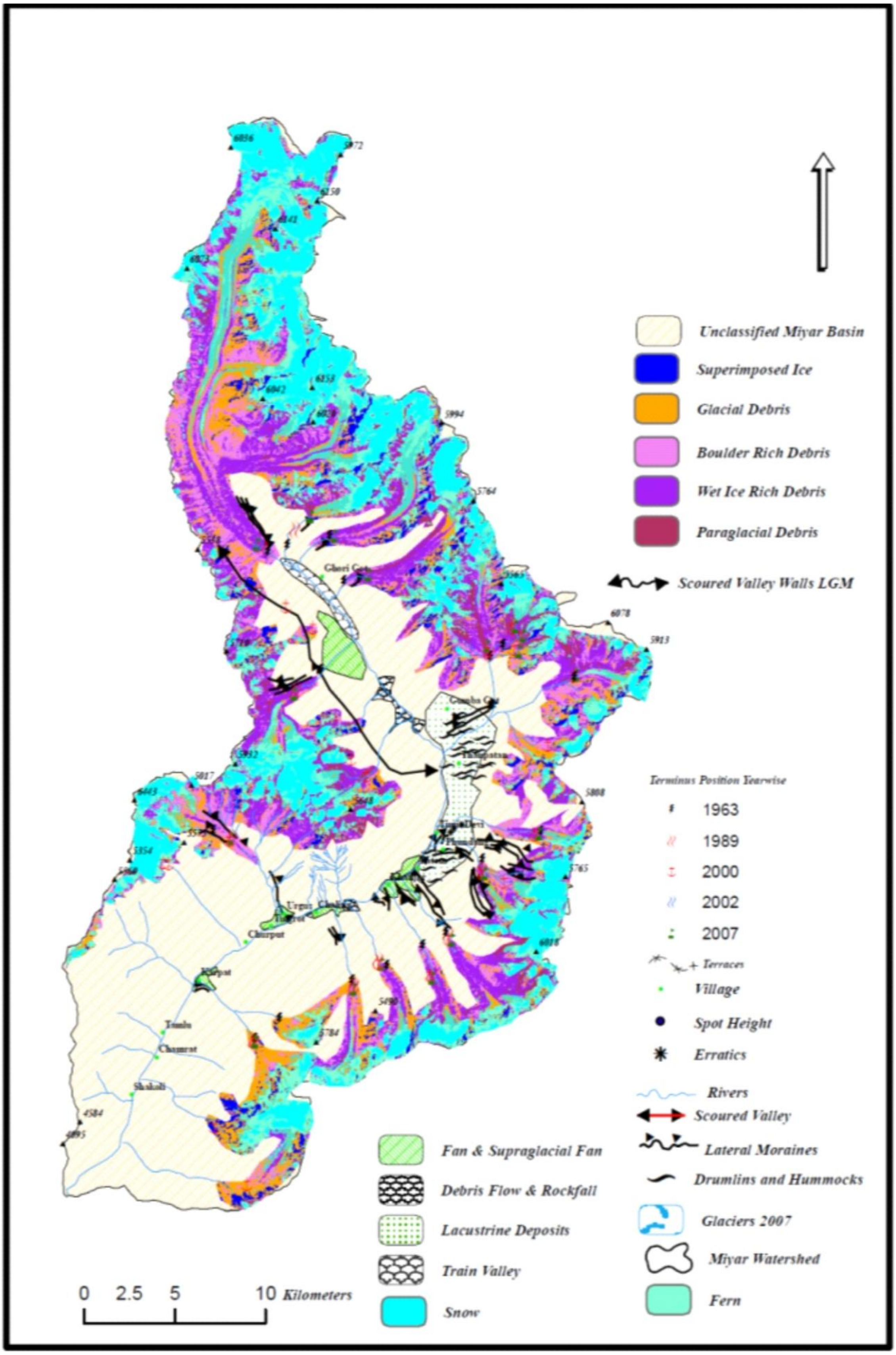

Fig. 4.2 Geomorphological map of the Miyar basin.

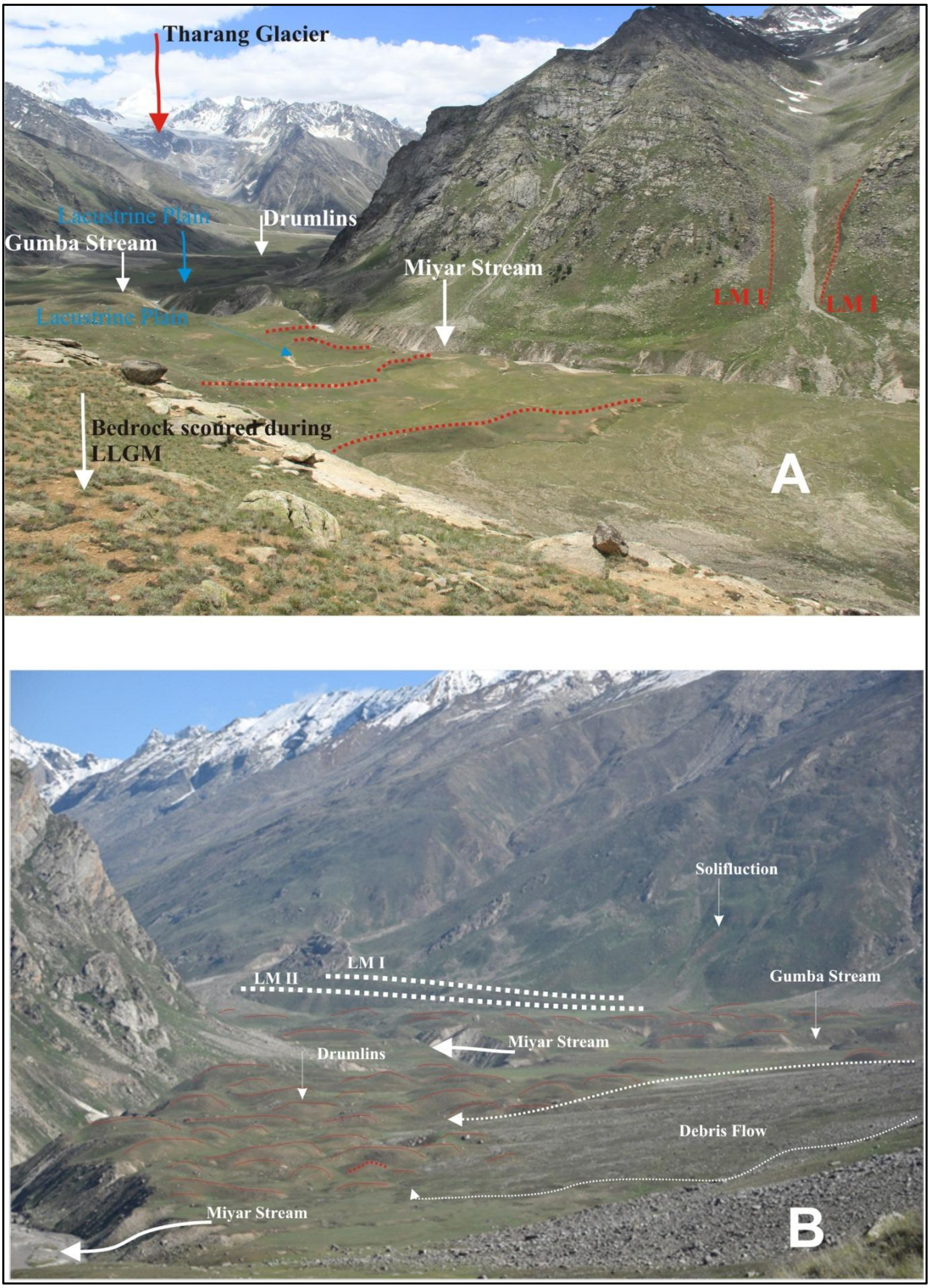

Plate 4.3 Drumlins along the confluence of Miyar and Gumba, formed by Gumba glacier during the Khanjar Stage. (A) View down the valley from Gumba Strath to Tharang. (B) View up valley from Darjeyang to Gumba.

of the ISM (Dortch 2013; Murari, et. al 2014), which is further supported by radiocarbon date obtained from the peat bog at Chandratal indicating that the peat growth began 9160 ± 70 years BP (Owen et al., 1997), thus inferring an increase in either temperature or precipitation in the Lahul Himalaya during early Holocene. Present study support the idea of increased precipitation during early Holocene instead of increased temperature. Owen et al. (2001) provided the Cosmomgenic Radio Nuclide Surface Exposure dates for some valleys in Lahul viz. Rape (9.0±0.1), Sissu (9.5±0.5), Batal (11.4±0.3 and 12.0±0.1), thus suggesting an extensive glaciations in Lahul in early Holocene similar to present study.

Geomorphology of Tharang end-moraine complex is a written history of recession of Tharang glacier during Holocene (fig 4.3). The terminal moraine of Tharang end-moraine complex at the confluence of the Tharang channel with the Miyar stream has been dated to be 6.6±1.0 ka, (Deswal et al., 2017). This phase of the glacier advance has been referred as Khanjar Stage (early Holocene) earlier. During this stage, Tharang glacier descended to ~3595 m in comparison to its present terminus position at ~4471m a.s.la vertical drop of ~880 m in a distance of ~4.96 km (fig. 4.3).

The advance produced the highest existing lateral moraine of the *Tharang* complex, marked as LM-I (lateral moraine-I) on the either flank of the rivulet (fig 4.4). Similar expansions in other tributary glaciers in the basin resulted in blockades of the main trunk river Miyar at each junction (fig. 4.2). Within the inset area of LM-I, there are set of three crescentic moraine ridges, albeit smaller, marked as LM-II, III, and IV, on the left flank of the channel, sequentially reducing in relief, denoting a progressive retreat of the *Tharang* glacier (fig.4.4).

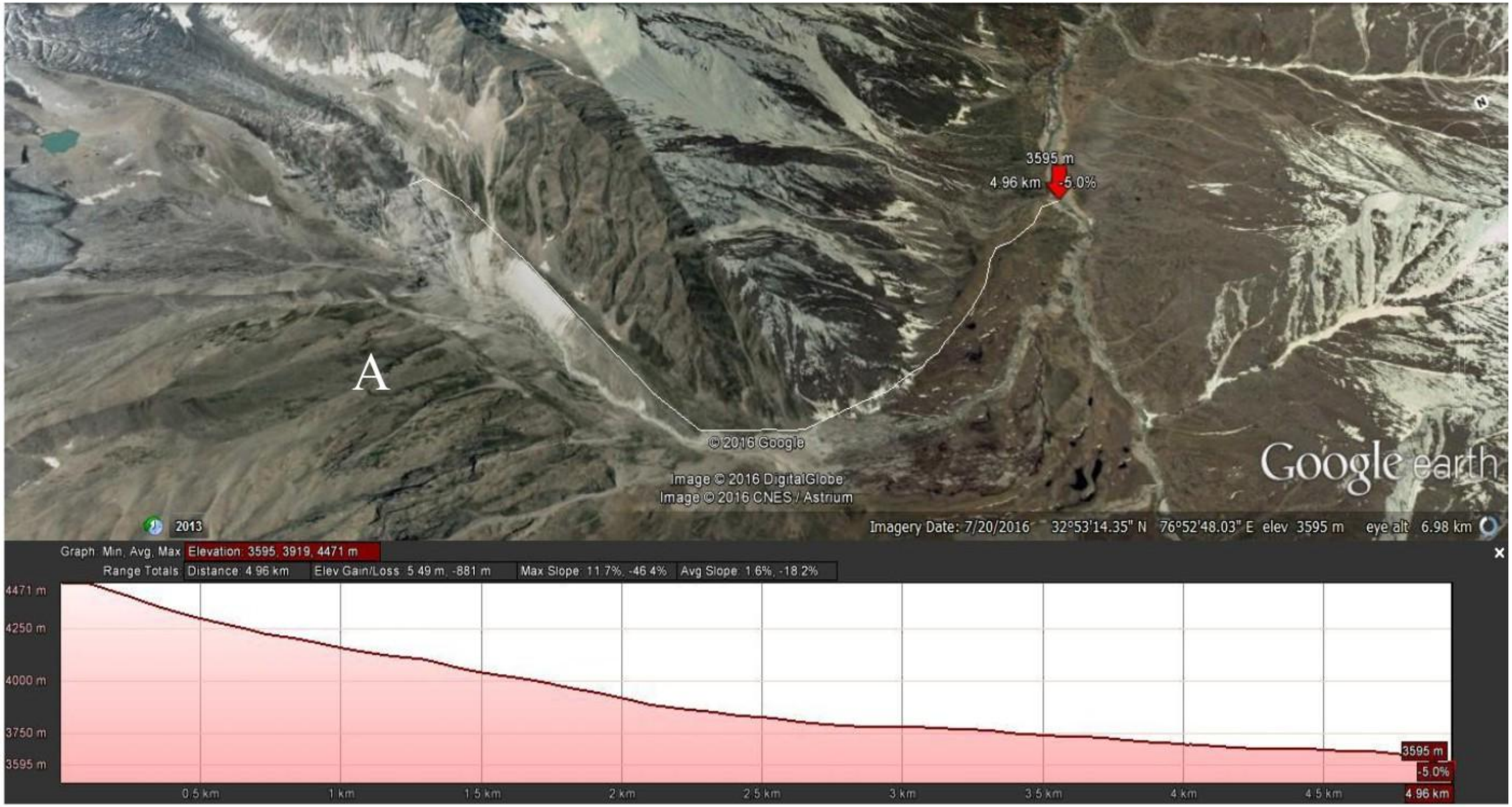

Fig.4.3 Profile of *Tharang* glacier during Khanjar Stage.

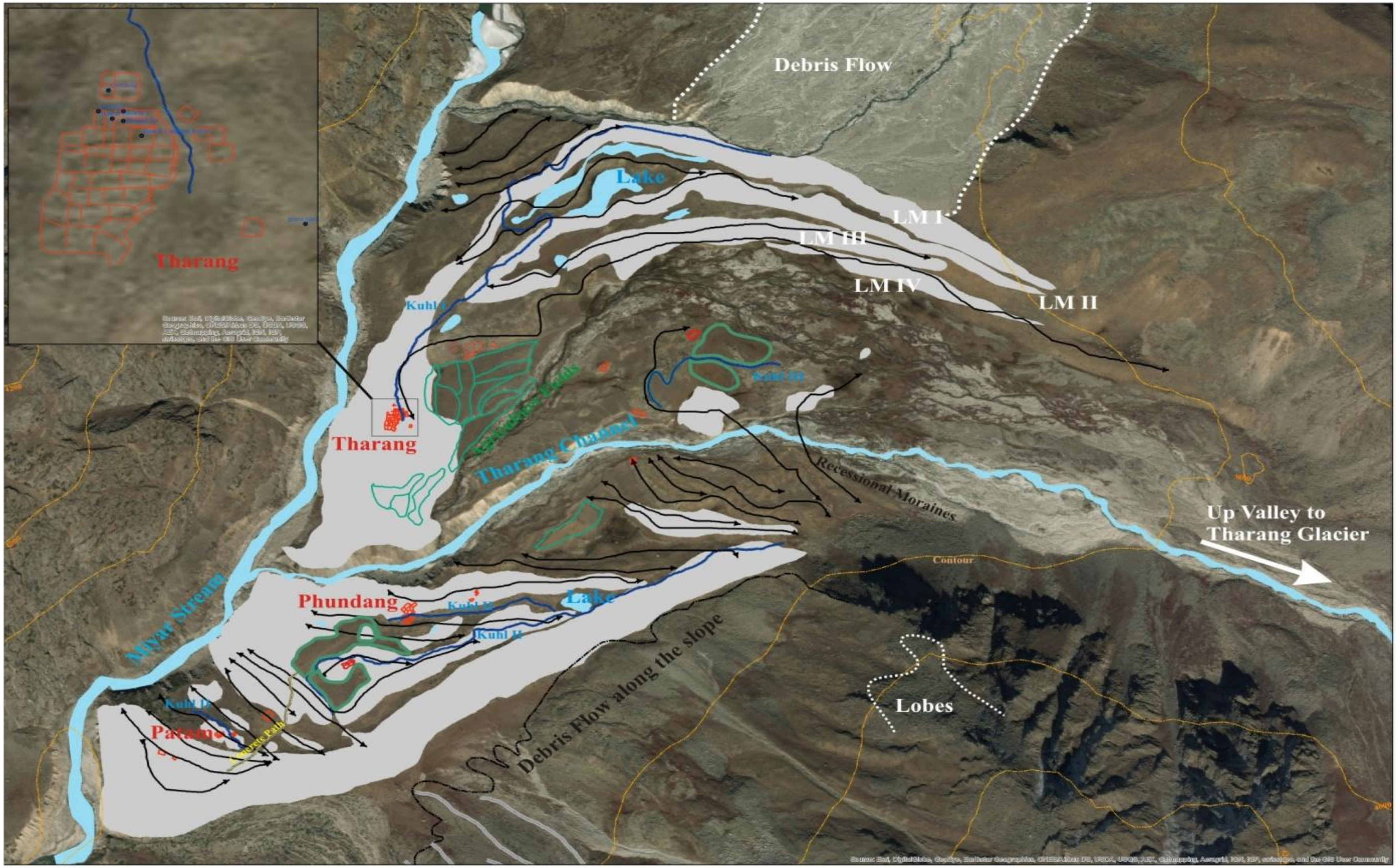

Fig.4.4 Geomorphological settings of Tharang end moraine complex.

Profile of moraine ridges II, III and IV suggest that, at times, retreat must have been slow enough (perhaps stand-still) to have produced rounded crests. However, the recessional moraines on the right flank of the *Tharang* channel indicates otherwise of continuous retreat. The OSL date from the Karpat lacustrine deposit indicates that the glacier (Karpat glacier) blocking the Miyar stream at this location (32°48’56.46”N and 76°44’5.27”E) by 6.611±0.14 ka (Table 4.2). During this stage (Khanjar Stage), the Karpat glacier recorded a vertical drop of 1230m from its contemporary terminus position of 4256m to 3018m in the past. The episode was limited to the tributaries to advance within 4-6 km of the present terminus, whereas, the Miyar (4046) glacier expanded by ~14 km to have terminated near Gumba (3800m asl).

Table 4.2 OSL characteristics of the Karpat Lacustrine Deposit.

Sample Code	Unit	Location	Elevation	Radioactive Element Concentration	ED (Gy)	Dose Rate (Gy/ka)	Age (ka)
Karpat 2	Lacustrine deposit	32°48’56.46” N 76°44’5.27”E	3018m	6.611±0.14	21.76±0.95	3.92	6.44±0 .27

4.3.2.3 Late Little Ice Age (Historical) Advance

Following the Holocene glacial advance, the succeeding yet distinctive glacier signatures in the basin were identified based on fresh sediments and landforms assemblage within 2 kilometres from the present glacier terminus (fig. 4.5) and similar glacier extent marked on available historical GTS map (fig 3.5). The former terminus of a few glaciers, including Tharang, were incorporated and shown in the historical map of captain Harcourt (Harcourt, 1871) and in the Great Trigonometrical Survey (1874) map. The moraines are morpho-stratigraphically distinct from the earlier Holocene moraines (Plate 4.4).

Proxy record of the last 600 years (1460-2008AD) of snow water equivalent data for Kukumseri (Yadav and Bhutiyani 2013), as well as temperature data for the last millennium for the western Himalaya (Yadav et al. 2009) is available. There are other proxies for precipitation in the north west Himalaya (Yadav et al., 2004; 2014; 2017; Yadav, 2011; Yadava et al., 2016). Given the field and historical records from different proxies, we suggest that by late 18th and early 19th century the glaciers recorded expansion in the basin. This assumption is in consistency with Thompson et al. (2000); Xu and Yi (2014) and Rowan (2016) who reported late LIA advance between the late 18th and early 19th century in other parts of the Himalaya and trans Himalaya.

We suggest that during this advance (late 18th to early19th Century) Tharang glacier expanded down-valley by ~1.8 km, terminating at 3936m asl from its present position of 4486m asl, with an ELA depression of ~275 m relative to the contemporary ELA at 5130 m (Table4.3 & fig. 4.6). Well preserved pair of lateral moraines in the upper Tharang valley marks the limit of this advance (fig. 4.6). The moraines are similarly marked on the GTS map (fig. 3.5).

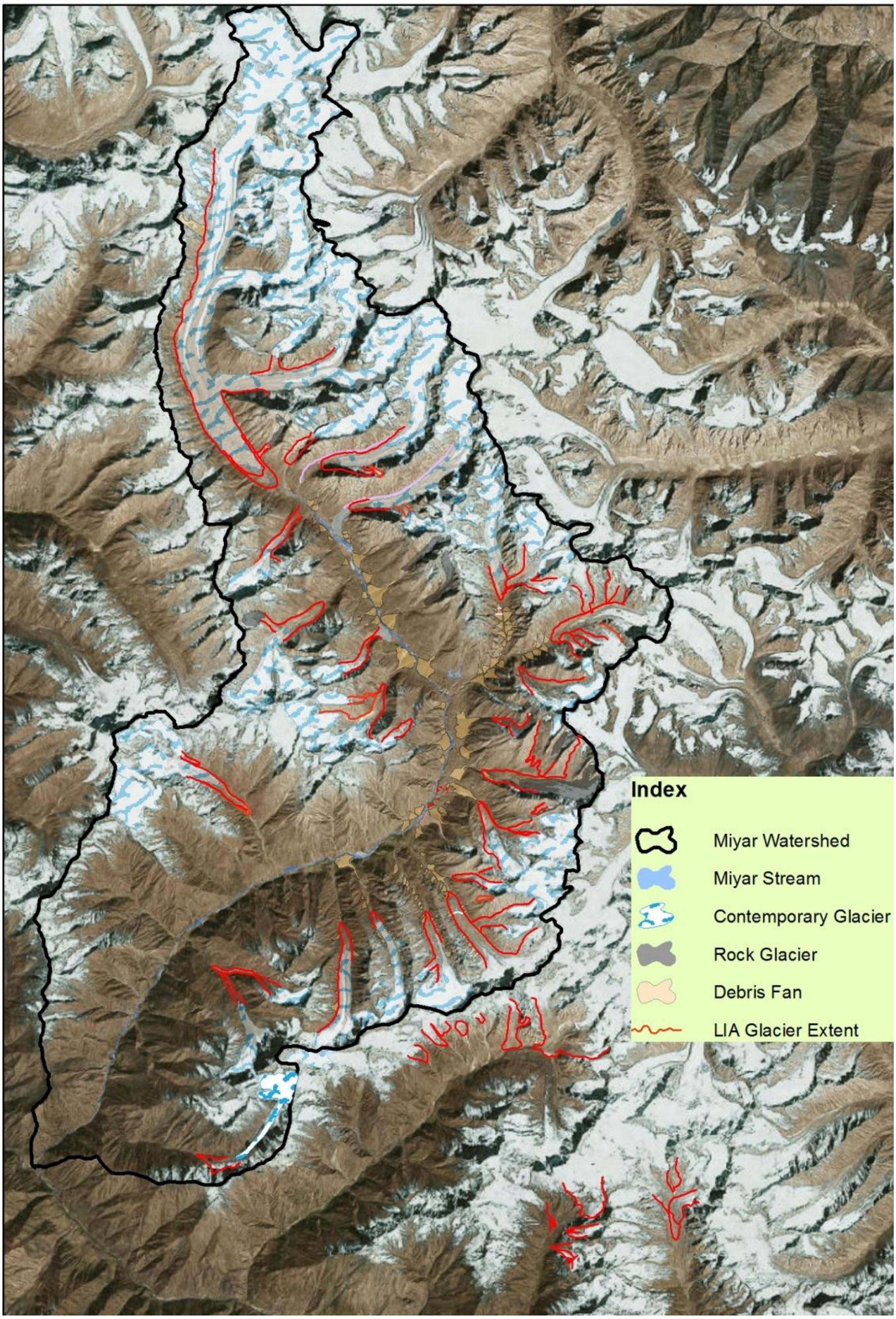

Fig. 4.5 Extent of contemporary and the Little Ice Age (LIA) glaciers in the Miyar basin and surrounding regions.

Plate 4.4 Landforms marking the position of early 19th century glacier advance in Miyar basin. **(A & A')** for upper and lower *Menthosa* valley, (B& B') for *Miyar* glacier & its surroundings, (C& C') for *Uldhampu* glacier and its surroundings, (D& D') for *Tharang* glacier and (E&E') for *Pimu* glacier and its surroundings.

Comparatively, during the same advance, Pimu glacier experienced more expansion (~2.35 km), with terminus extending down to ~4276 m a.s.l. compared to the present position at ~4579 m asl (fig.4.7). Similar size of advance is recorded in Karpat (~2.33 km) and Khanjar (2.31 km) glaciers (Table 4.3). Relatively moderate advances (1-2 km) are observed from the landform records of Darjeyang, Menthosa, Dali, Miyar, Tharang, Gumba and Hulat glacier, whereas lesser (<1km) expansion is recorded in Takdung, Chhudong, Uldhampu, Palbo and Gangpo glaciers (Table 4.3, fig.4.8).

These varying sizes of glacial expansion within the same valley during the late LIA are probably the result of different headwall and summit ratio (Table 4.3) and other topographic characteristics. In terms of modern terminus elevations, *Miyar* glacier is located at the lowest elevation (4060m) and Dali at the highest elevation (4882m), followed by Karpat (~4256m) and Gumba (4715m), respectively. However, during the late LIA expansion, the glacier with the lowest terminus were Karpat at ~3506m, followed by Menthosa at ~3885m and Tharang at 3939m asl (Table 4.3). Such varied response again suggests topographic and relief controls on glacier advance.

Table 4.3 provides the ELA values of different glaciers in the Miyar basin and figure 4.5 provides the hypsometry in the basin as it is suggested that ELA of the glacier lies at the hypsometric maximum (Barr and Clark, 2012). Contemporary ELAs range from 5062 to 5324 meter a.s.l. and the mean ELA of the Miyar basin is 5145m asl. However during the Little Ice Age period, the ELAs varied between 4833 to 5193m. All these valley glaciers experienced noticeable depression in equilibrium line altitude

Table 4.3 LIA Equilibrium Line Altitude (ELA) and length change characteristics of the major glaciers in the Miyar basin.

	Terminus	**Summit**	**Headwall**	**THAR (0.5)**	**TSAM**	**AVG ELA**	**Terminus LIA**	**THAR (0.5)**	**TSAM**	**AVG ELA**	**ELA Change**	**Length Change**
Tharang	4486	5875	5672	5079	5181	5130	3936	4804	4906	4855	275	1.81
Darjeyang	4665	5694	5505	5085	5180	5132	4067	4786	4881	4833	299	1.97
Gumba	4715	5871	5754	5235	5293	5264	4574	5164	5223	5193	71	1.73
Chhudong	4305	5951	5685	4995	5128	5062	4213	4949	5082	5016	46	0.94
Takdung	4559	5961	5798	5179	5260	5219	4457	5128	5209	5168	51	1
Dali	4882	6008	5522	5202	5445	5324	4373	4948	5191	5069	255	1.87
Miyar	4060	6290	6049	5055	5175	5115	3977	5013	5134	5073	42	1.82
Pimu	4579	5887	5562	5071	5233	5152	4276	4919	5082	5000	152	2.35
Menthosa	4402	6407	5376	4889	5405	5147	3885	4631	5146	4888	259	1.91
Uldhampu	4518	5868	5625	5072	5193	5132	4481	5053	5175	5114	19	0.71
Khanjar	4635	5769	5468	5052	5202	5127	4444	4956	5107	5031	96	2.31
Palbo	4574	5526	5518	5046	5050	5048	4295	4907	4911	4909	140	0.55
Gangpo	4430	6124	5601	5016	5277	5146	4359	4980	5242	5111	36	0.44
Karpat	4256	6124	5762	5009	5190	5100	3506	4634	4815	4725	375	2.33
Hulat	4364	6124	5447	4906	5244	5075	4048	4748	5086	4917	158	1.61
Miyar Basin Average	**4495**	**5965**	**5623**	**5059**	**5230**	**5145**	**4193**	**4908**	**5079**	**4993**	**151**	**2**

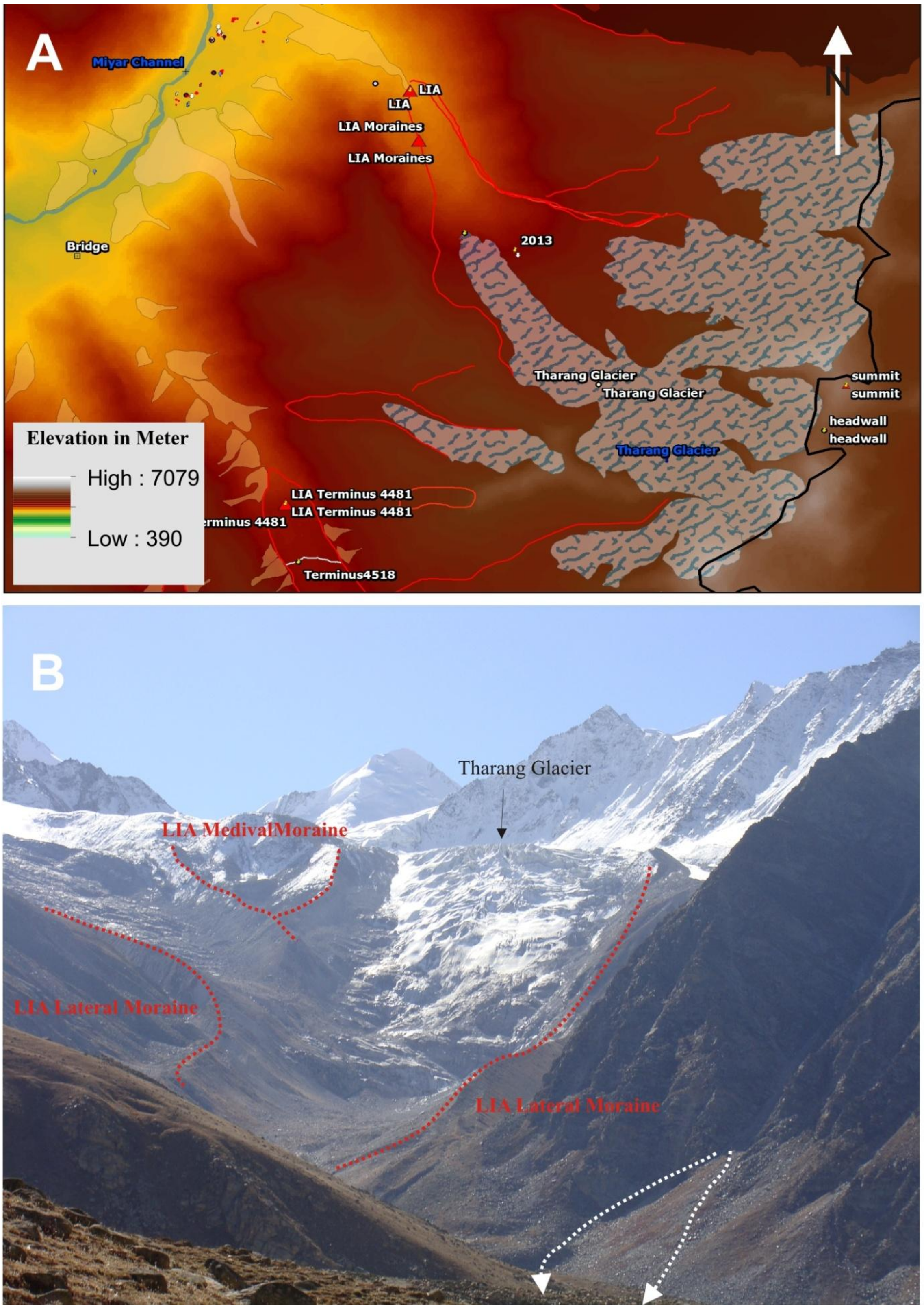

Fig. 4.6 (A) Little Ice Age & contemporary extent of Tharang glacier superimposed on SRTM, (B) Tharang Glacier & its LIA moraines as viewed from Darjeyang forefield.

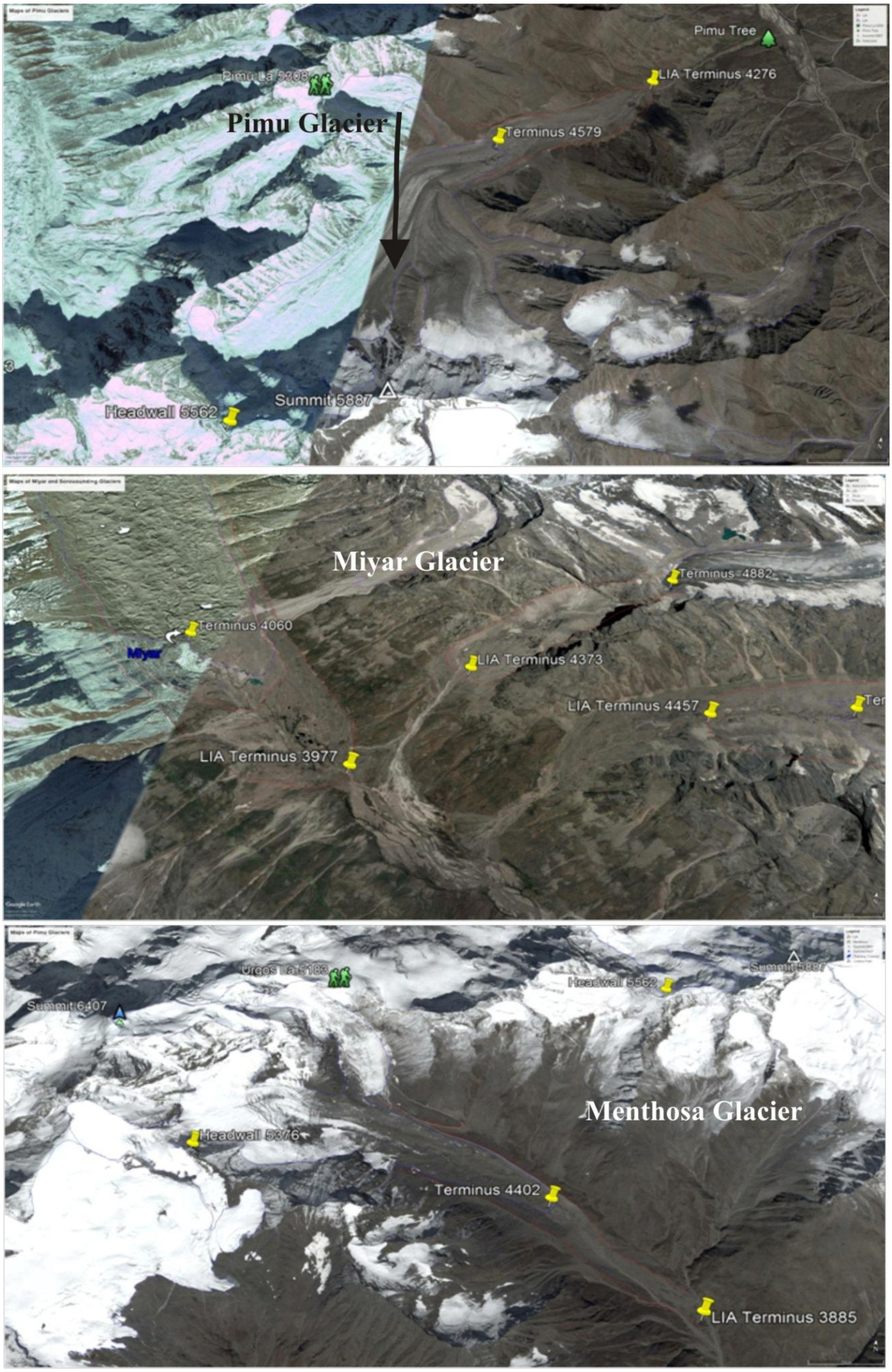

Fig. 4.7 Contemporary glaciers and their relative extent during the Little Ice Age.

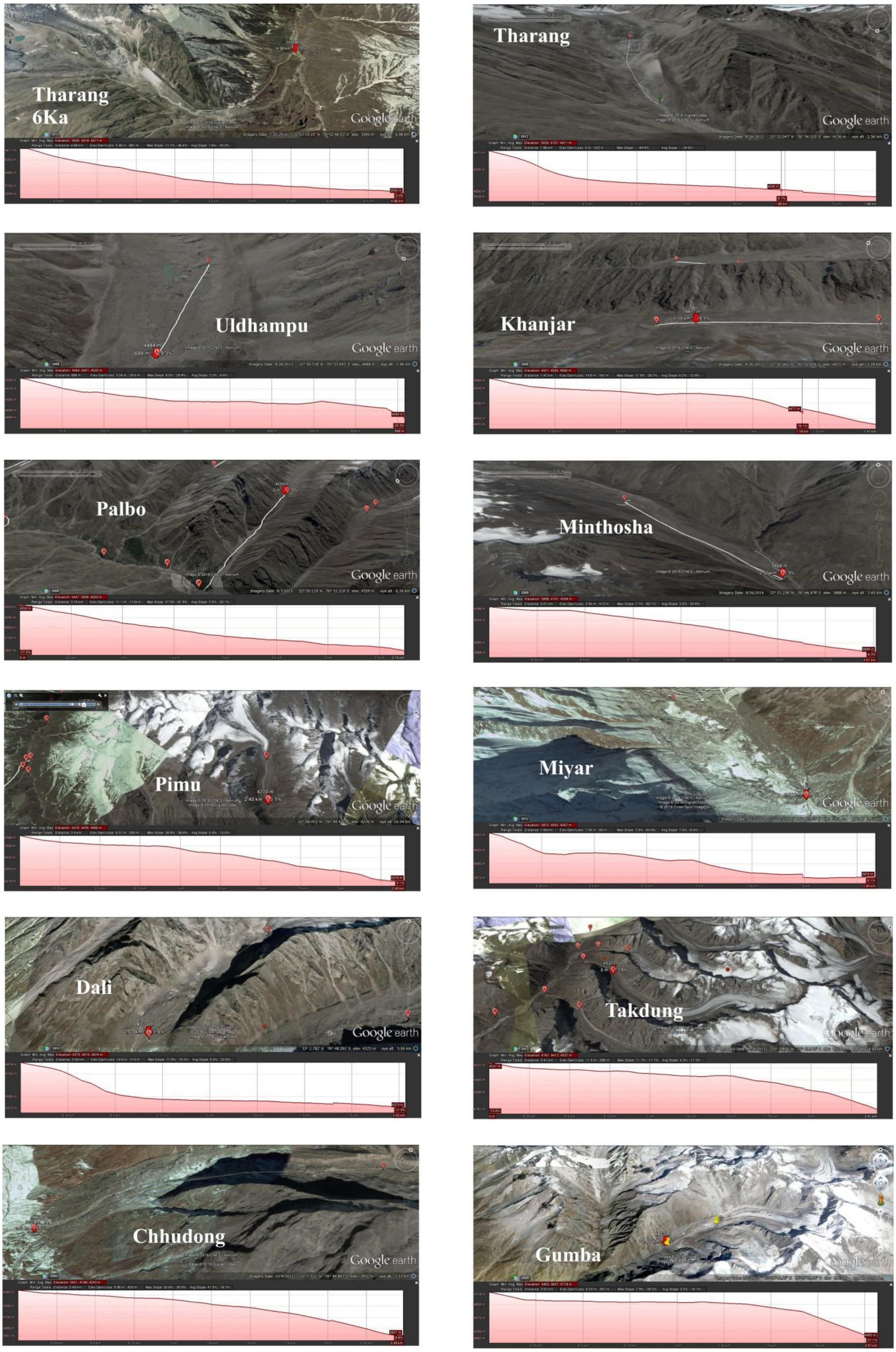

Fig. 4.8 Profile change of major glaciers during the late Little Ice Age (early19th century) and Mid Holocene (marked as 8Ka) advance in the *Miyar* basin.

(ELA, Table 4.3). The glaciers which experienced higher rate of ELA change (>250m) includes Karpat, Darjeyang, Tharang, Menthosa and Dali glacier with 375, 299, 275, 258, 254m ELA depression, respectively. The glaciers which experienced moderate ELA change (250-150m) are Hulat, Pimu and Palbo with 158, 151 and 139m ELA change, respectively. However, Khanjar, Gumba, Takdung, Chhudong, Miyar, Gangpo and Uldhampu noticed the lowest ELA change with 95, 70, 51, 46, 41, 35 and 18m ELA depression, respectively.

3.4 Conclusions

Keeping in view the absolute and relative geochronology of the glaciations in the basin, this basin experience two major glacier stage and one recent glacier advance, well preserved in the landforms throughout the basin. The available plaeoclimatic records are also in support of our findings of a limited 19th Century advance. However the secular retreat as reported by Mayewski & Jesche (1980) appears to have begun post 1880s. There is reference of Bara Shigri also expanding and blockading the Chandra river in 1860s (Chand et al., 2018). There is no denying that each successive expansion was many degrees smaller than the previous, that helped preserve large number of landforms which otherwise would have obliterated the record, had there been Ice Age of higher magnitude. Landforms in the form of trimlines and shoulders are indicative of the antiquity of the event in the basin and region, which need future attention.

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Chapter V

LATE HOLOCENE HYDROLOGICAL HISTORY OF THE STUDY AREA

Introduction

The Himalaya is one of the most dynamic and vulnerable regions of the world. The highest mountain ranges constitute a barrier for northward approaching Indian Summer Monsoons (ISM), resulting in a strong moisture gradient of increasing aridity towards north (Bookhagen and Burbank, 2006; Bhutiyani et al., 2007). Observational records suggest that precipitation and temperature varies according to aspect, altitude, and dominance of wind system. Yet, the region is poorly studied because of inaccessibility and sparse meteorological and hydrological data (Bhutiyani et al., 2007). Mutli-proxy studies in parts of the North West Himalaya and surrounding regions reflect varying nature of the Indian Summer Monsoon during the last millennium. Dendro-chronological studies in the north west Himalaya (Uttarakhand) reveal low precipitation during 15th and 16th Centuries AD, with 1410–1510 being the driest period in past 600 years (Singh and Yadav, 2005; Yadav, 2011 a). Similar study in Lahaul & Spiti reveal high magnitude droughts during the 14th and 15th Centuries and increasing wet conditions thereafter (Yadav, 2011b). However, Yadava et al., (2016) have reported decreased precipitation between the 12th to early 16th Century, and then progressive increase between the 16th to 19th Century, with a peak around 1840AD.

Based on speleotherm, Sinha et al. (2011) have suggested a break in the Indian Summer Monsoon during AD 1400 to ~1700, and an increase (active) during AD ~1700 to 2007, whereas, Sanwal et al., (2013) from the Central Kumaun Himalaya reported variability in climate conditions in the last 1800 years. They suggest reduced precipitation towards the end of Medieval Warm Period (~1080-1160 AD) and from

~1210 to 1440 AD, and increased precipitation during the lower part of MWP (830-910 AD), and the middle part of Little Ice Age (1600-1640 AD).

However, Liang et al., (2015) has reported warmer and drier conditions during the Medieval Climate Anomaly (MCA) and also in the post-LIA periods, but cooler and slightly wetter conditions during the Little Ice Age (LIA) which lasted from ~AD 1489-1889, and AD 1450-1820. Studies based on glacial chronological in the northwest Himalaya also suggest varying response of the ISM. Barnard et al., (2004b) had dated Gangotri glacier advance around 200-300 years (CRN) back in Garhwal Himalaya. Barnard et al., (2004a) had also reported Milam glacier advance 400-300 years ago in Gori Ganga basin. Similarly, in parts of Lahaul Himalaya, Owen et al., (2001) suggested that the Sonapani I-II advanced by 800 & 200 years ago. However, Saini et al., (2016) and Deswal et al., (2017) suggested no advance during the LIA peak (1300-1600) in the Miyar basin but recorded glacier advance only in the early 19th Century.

Such ambiguous findings suggest long-term regional precipitation variability in the Himalayas. Current knowledge is too shallow to understand the spatial and temporal variability of precipitation. It is obvious that more information is needed to understand this complex issue. The present study investigated the changes in the major and trace elements in an alpine lacustrine deposits in a rain shadow zone of the ISM at Par got (Than Pattan), Miyar Basin, Lahaul Himalaya, (32°55'54.18"N to 76°53'49.11"E and 3831m a.s.l.) as a palaeo-climatic indicator and proxy. Also proposed is the technique and method to show how the mineralogical chronology concurs with other climatic and glacial proxy records from the North Western Himalaya.

5.2 Site Setting

Par lacustrine deposits (part of the Miyar basin in lower Chandrabhaga valley) lies within the Great Himalayan Tract of the Lahaul and Spiti district of Himachal Pradesh, India (fig.5.1). Topographically, it is located in a rain shadow region of the NW Himalaya; as the lofty Pir Panjal generates a barrier for the northward approaching Indian Summer Monsoon (ISM), resulting in a strong moisture gradient of increasing aridity towards north (Owen et al. 1996; Bhutiyani, et al. 2007).

The exposed Par lacustrine sequence is a part of the Par glacier deposits extended in the main trunk valley of Miyar channel. This lacustrine deposit is located south of the Gumba drumlins (Deswal et al., 2017) and north of Tharang end moraines ruins (Saini et al., 2016). Geomorphologically, the area is dominated by glacial and paraglacial landforms; most common Late Quaternary sediment are characterised by moraines, drumlins and lacustrine plains (Deswal et al., 2017). Optical Stimulated Luminescence (OSL) dating of the moraines and lacustrine deposits at Gumba and Thanpatan suggest an early Holocene (10 ± 1 to 6.6 ± 1.0 ka) glacial advance in the region. This site probably started evolving on initiation of the retreat of glacier from this area, post advances. The sequence is well exposed due to recent channel incision at Par Got, Than Pattan, (fig. 5.1). The main trunk valley (Miyar valley) from here displays an open U shaped cross profile, and is broadest (about 2km) at Gumba (3800m a.s.l.).

Based on the OSL dating of the exposed section, Deswal et al., (2017) has suggested an age of 1ka years. Therefore, the deposit represents the hydrological and depositional history of the last 1 ka years at Par got. This hydrological chronology of

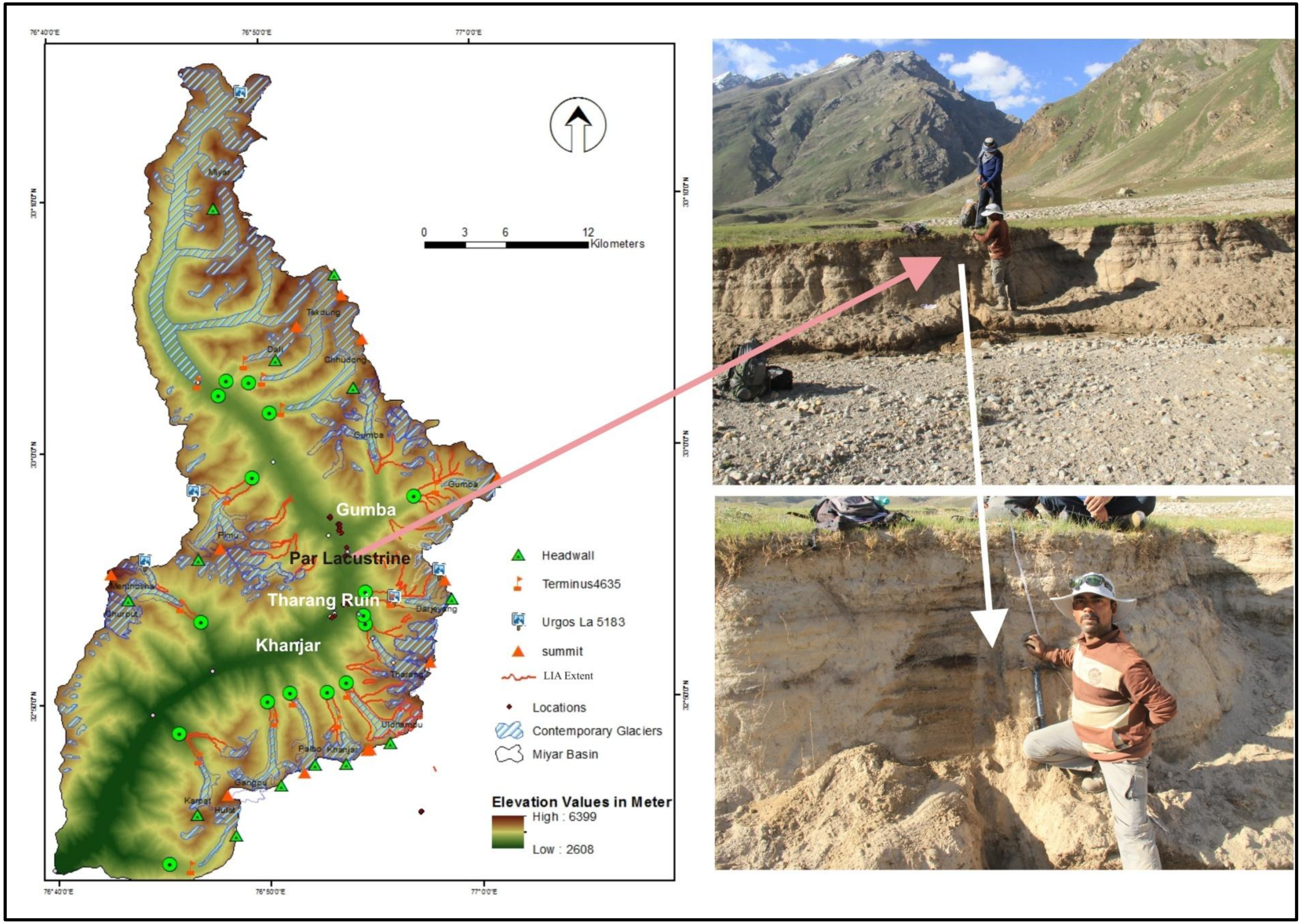

Fig.5.1 Location of the Par lacustrine deposits in Miyar basin, Lahaul Himalaya.

the area has been used to better understand the glacio-archaeological history of Tharang end moraine ruins, discussed earliar.

Geologically, the lacustrine deposit is situated in the High Himalayan Crystalline Zone (HHCZ) complex, which is bounded by Gianbul Dome and Leucogranitic deposits to the north and Khanjar Shear Zone and combro-ordovician deposits to the south (Robyr et al., 2002; 2006a). The Miyar Thrust passes through the Par lacustrine deposit (fig. 2.2). Lithologically, the area is dominated by amphibolite facies and migmatitic paragenesis. The continuous HHCZ is cross cut by numerous leucogranitic dykes and small plutons in the north. These intrusions (Gumburanjun Lecogranites) are most likely related to the early Miocene (26.6 and 19.8 Ma) (Robyr et al., 2006b).

The modern glaciers in the surrounding area are situated as low as 4000m a.s.l. with an average equilibrium line altitude (ELA) of 5150m asl. Observations during the field visits suggest that temperature varies between 35^0 to -4^0 C during day and night. Precipitation and temperature varies according to aspect, altitude, and dominance of wind system (Saini, 2012). The nearest sedentary village is Khanjar, situated almost 7 km down the valley south at 3500m asl (fig.5.1). However, during summer months (June-August), the area is used for seasonal grazing by the transhumance. The modern vegetation in the study area is characterised by desert steppe and alpine steppe plant communities.

5.3 Methods:

5.3.1 Field Sampling

5.3.1.1 Sampling for Sediment Size and Mineralogy Analysis

Stratigraphic analysis of chemicals along with chronology in a lacustrine deposit provides enough information on the lakes history. The interpretation of lake sediments helps to reconstruct the past hydrological conditions and prevailing climate within which the sediments were deposited. The analysis of sediments size and different species of minerals across the lacustrine stratigraphy provides a basis for environmental reconstructions (Phartiyal et al., 2009; Mishra, et al., 2014; Bali et al., 2017). Although, sediment deposited in a lake profile notice large changes due to internal chemical reactions, production area lithology and physical changes. In spite of such complexities, attempt has been made to understand the stratigraphic variation in lacustrine deposits for past hydrological and climatic reconstructions (Taylor, 1951; Basavaiah et al., 2004; Li et al., 2008; Phartiyal et al., 2009; Mishra, et al., 2014; Rawat et al., 2015; Bali et al., 2017). To analyse the sediment size and mineralogical components of the Par lacustrine deposits, 10 sediment samples were retrieved from the 1.6m exposed section of the lacustrine deposits at Par Got, during the field expedition in July 2016. The lacustrine section was properly exposed, and enough materials were removed from the section to avoid any surficial intrusions (fig.5.1). The samples were extracted on an equal interval of 15-16 cm, covering the profile (1.6m) from top to bottom.

5.3.1.2 Sampling for Chronology

Keeping in view the dark texture of the soil within the exposed section, one sample for radiocarbon was taken from the section (plate5.1). However, the WD XRF results suggested no carbon content. In the absence of the organic material we depended on the OSL. Four samples were collected using 30×6 cm iron tubes from the 1.6 meter Than Pattan lacustrine exposed section (Table2). The samples were properly sealed and marked with location characteristics (Than Patten Lacustrine I, II, III, and IV) and kept in thick black poly bags to avoid any exposure.

5.3.2 Laboratory Methods

5.3.2.1 Grain Size Analysis

The grain size distribution of 10 samples from the lacustrine sediment was determined using Retsch AS 200 sieving machine. The samples were dried at room temperature and were sieved with 10 minute run with 50mm/gm supply in the sieving machine. The grain size distribution of the sample measured at particle from >1mm, 1mm-500µm, 500µm-250µm, 250µm-125µm, 125µm-90µm, 90µm-63µm, 63µm-32µm, 32µm -16µm and <16 µm. The samples were re-classed into sand (0.5-2 mm), silt (0.002-0.05 mm) and clay (<0.002 mm). For mineralogical analysis these samples were processed for quantitative X-ray Fluorescence (XRF) test. Initially the extracted samples were dried at room temperature. The vegetation roots were removed from the sample. At later stage, the sample was crushed for powder in Miller Mill and sieved at < 75 um. The powder sample dried at 80^0 C for 2 hours. A homogenous amount of the sample was taken while ensuring that the powder represents the complete deposit. Thereafter, 2mg Boric Acid (BH_3O_3) was added in 2gm sample as a binder additive. The sample was prepared for pressed pallet by pressing the mixture between 10 – 20 T with Hydraulic Press.

5.3.2.2 Mineralogical Analysis

The powder samples were exposed to X-ray beam (with wavelength of 0.01 to 10 nm, corresponds to energies in the range from 0.125 to 125 Kev.) in Bruker S4 PIONEER Wavelength Dispersive X-ray Fluorescence (WDXRF) Spectrometer. XRF works on the principle that when an element is exposed to X-ray beam electron, transition takes place and an electron drops from a higher to a lower energy atomic shell to fill the vacancy. The difference in energy is released as X-ray fluorescence radiation. The characteristics fluorescence of the samples were measured and analysed in the Integrated Analytical Intelligence (IAI) of the analytical X-ray fluorescence (XRF) software. The integrated standardless evaluation for minerals allowed the fast and easy determination of element concentrations from 100 % down to the ppm-level without performing a calibration.

5.3.2.3 OSL Dating

Four samples were processed in OSL laboratory at Center for the Study of Regional Development, Jawaharlal Nehru University, New Delhi. The samples were processed at two stages; treatment stage and measurement of age in LexygSmart Luminescence Reader.

Treatment Stage

The samples were opened in dry room of the laboratory in led red light environment (620 nm) non sensitive to sample. The top 20% (6cm) from both sides of the sample were separated from the main sample assuming that it may have bleached during sampling in the field. The separated samples were considered for the measurements of moisture present in the sample. It has been weighted and kept in oven overnight to dry then its weight has been re-measured; the loss of weight indicated the moisture level of the sample. The main portion of the sample were kept in a separate beaker and treated with 1N HCl (Hydrochloric acid) to remove carbonates from the sediment. The sample was dipped into the chemical for 8 hrs and when no reaction noticed we moved to next step. The sample treated with concentrated hydrogen peroxide (H_2O_2) 30% to remove organics from the sediment. The sample dipped into it for 12 hours till the reaction is over.

5.4 Results

5.4.1 Lithostratigraphy

The Par lacustrine sediment can be broadly divided into four dominant litho-units (Table 5.1,fig. 5.2). The bottom (160-128 cm) of the exposed section is dominated by clay loam with a thin section of loam, and is overlain by sandy clay loam (128-96 cm). The remaining part of the exposed section (96-0 cm) is dominated by clay and clay loam mixed with silt loam and sandy loam.

Table 5.1 Litho-units of Par lacustrine deposits based on the size measurements.

Unit	Depth of the Layer from Top	Remarks
LU-I	From Top 0-16cm	dominated by sandy loam
LU-II	(16-80 cm)	this unit is dominated clay and clay loam with silt loam layer between 32-48 cm, discontinuous brown and grey laminations are common features
LU-III	(80-112 cm)	dominated by sandy clay loam with larger contribution from fine sand.
LU-IV	(112-160 cm)	the layer is dominated by clay loam with loam occupying the lowermost part between 144-160 cm

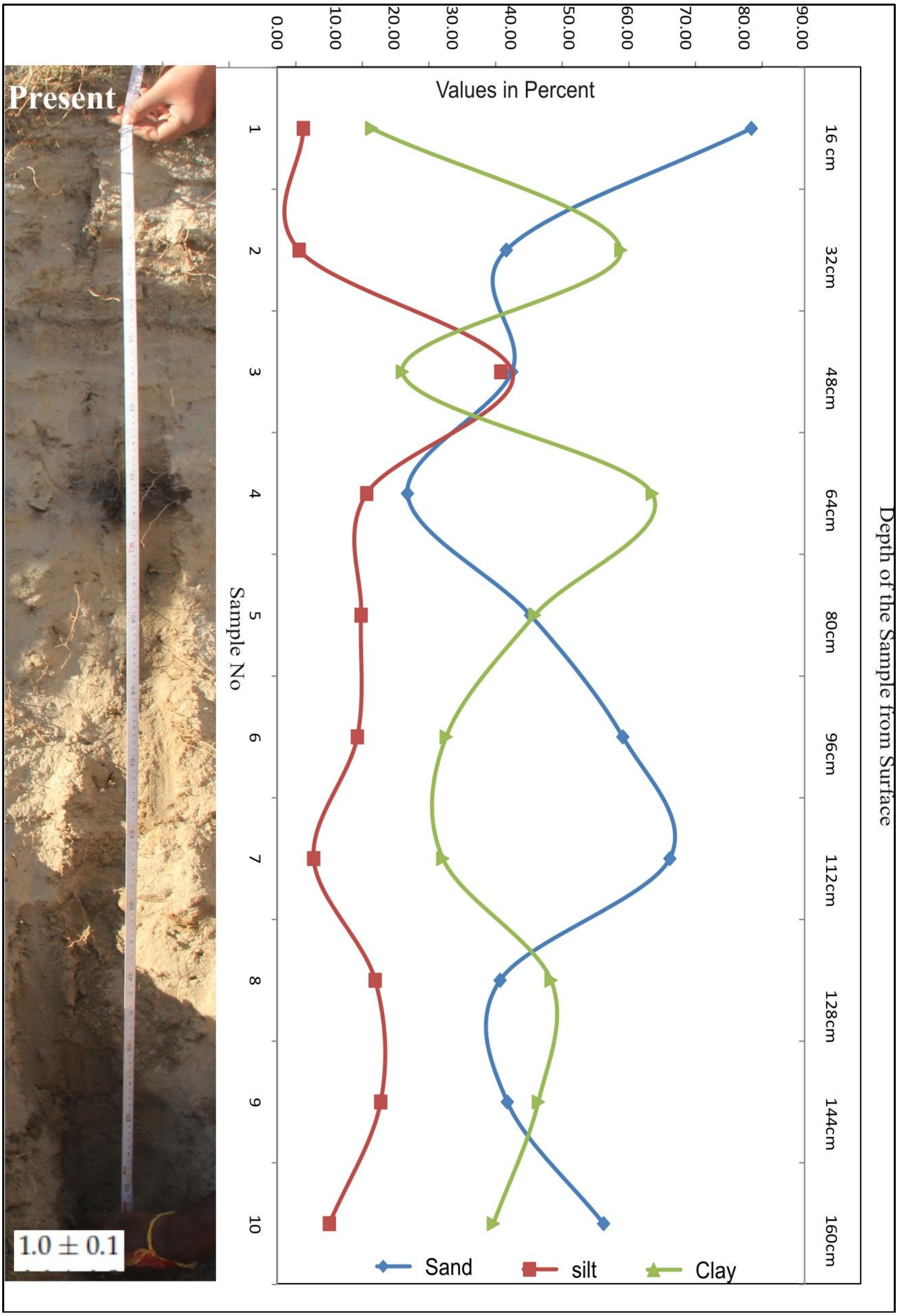

Fig. 5.2 Particle size distribution of sand, silt and clay across the Par lacustrine deposit.

However, based on the degree of particle distribution a more detailed classification into four litho-units (LU) has been made (fig.5.2, Table 5.2).

Tale 5.2 Grain size measurements of the Par lacustrine deposits.

Sample No	Very coarse sand	Coarse sand	Fine sand	Very fine sand	Sand	Silt	Clay
1	45.1	13.7	11.6	6.4	76.8	2.4	15.3
2	9.8	4.3	9.9	8.4	32.4	1.5	48.6
3	9.1	6.9	8.5	5.3	29.8	28.4	15.9
4	5.8	4.2	3.5	10.5	24	14.4	69.1
5	12.9	10.1	22.5	19.8	65.3	18.7	66.4
6	12	19.1	31.3	23.5	85.9	17.1	42
7	55.4	16.3	21.9	19	112.6	7.2	47.5
8	13.8	8.1	16.5	17.2	55.6	21.6	68.3
9	5.9	5.4	11.7	26.7	49.7	19.9	56.4
10	15.1	3.9	22.6	28	69.6	8.7	46.1

5.4.2 Chronology of the Par Lacustrine Deposits

The radiocarbon samples did not record any carbon content and hence could not result into the age. The OSL samples were processed up to treatment stage and still in queue for the measurement of age in LexygSmart Luminescence Reader at CSRD/SSS III, JNU Laboratory, New Delhi. However, Deswal et al., (2017) dated the lacustrine section and obtained the 1± .01ka old date for the lower most layer of the section (1.6m). Hence the section describes the hydrological and depositional history of the last 1000 years for the Par glacier.

5.4.3 Carbonate Distribution in the Par Lacustrine Deposits:

Figure 5.3 indicates two contrasting trend in the carbonate deposition. While the overall concentration of rubidium (Rb) across the profile from top to bottom increases, the strontium (Sr) and zircon (Zr) decrease all together. However the fluctuations are high, as initially the Rb concentration from sample1 to 3 decreases but regains at sample4 and attains highest concentration at sample5, again in sample6 the concentration decrease but maintains the level more than the sample1, between samples 6-10 the Rb concentration remains almost constant with small changes.

In terms of Sr concentration, the values fall rapidly from sample1 to 2 and maintain similar level up to sample4, with minute changes. The concentration gradually increases there onwards and maintains a peak at sample7 but less than sample1. The level continues up to the lowest part of the profile (sample10). The profile of Zr concentration shows similar trend that of Sr. Concentration values decrease from sample 1 to sample 3. Thereafter, it slightly increases up to sample 5 but drops back at sample6. Suddenly, at sample7 it noticed its highest level and drops back at sample8 and maintains the same level up to lowest part of the profile (sample10).

The variations of carbonates across the profile show that between samples 5-7, the depositional conditions were oscillating. On the other hand, between samples 1-4 and 7-10 the conditions were as of almost today. It indicates that present environmental conditions in the study area are as similar to 1Ka years ago. Climatically and hydrologically, we suggest that similar to present, climate was dry and summer conditions hot in this part of the Himalaya. The increased level of the carbonates between sample 5-7 point towards the

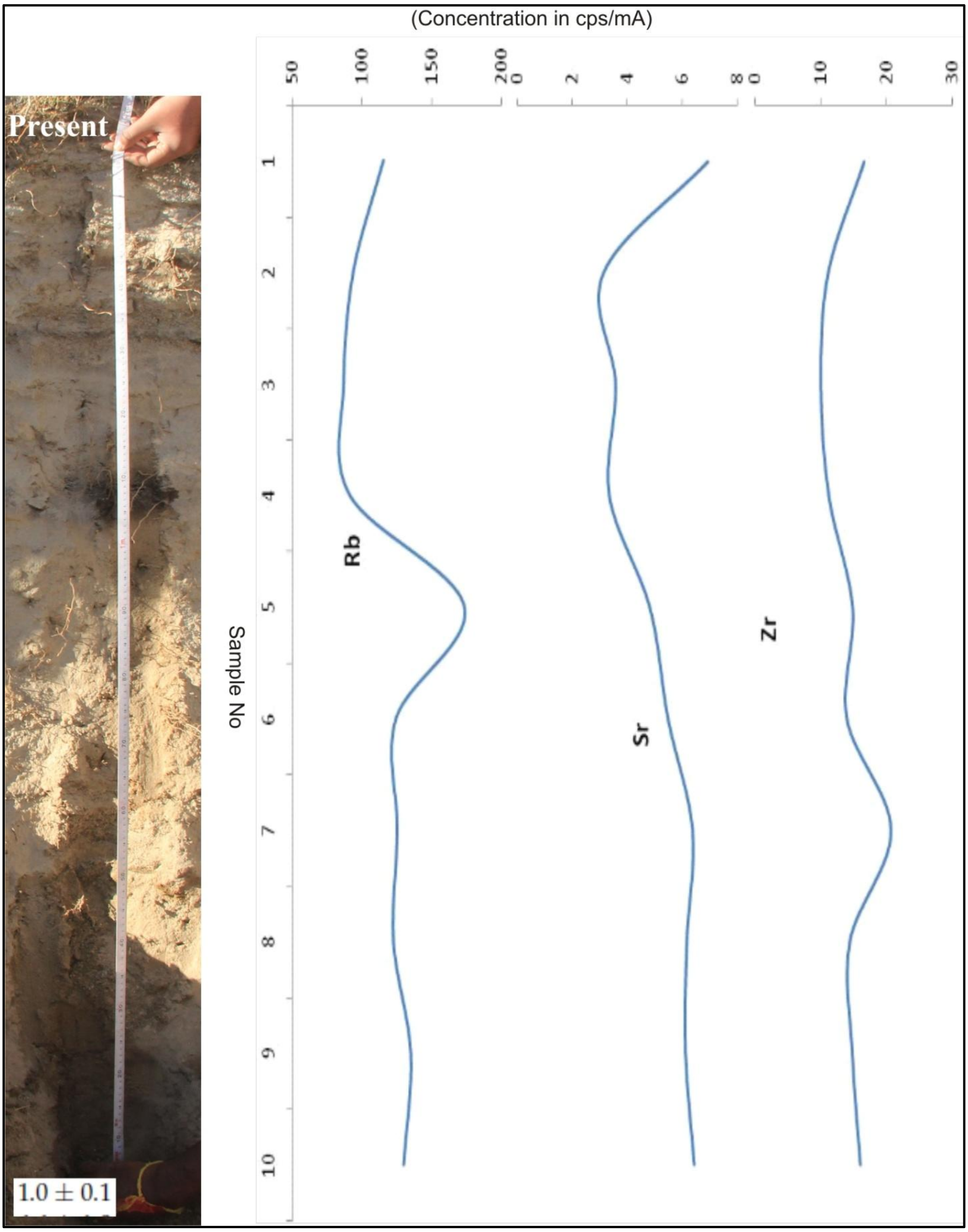

Fig.5.3 Concentration of carbonates in the lacustrine profile at Than Pattan.

increased precipitation conditions relative to the previous and after conditions. Similar conditions have been drawn on the high concentration of carbonates indicating rise in precipitation in the catchment (Zhang et al., 2012)

5.4.4 Oxides Distribution in the Par Lacustrine Deposits:

The oxides concentration change in the profile shows two major groups (fig.5.4). While the calcium oxides (CaO) and silicon oxides (SiO_2) maintain dynamic concentration across the profile with highest concentration at sample 1 (16cm from surface) representing present conditions, all other oxide compounds (Al_2O_3, Fe_2O_3, K_2O, MgO, MnO, TiO_2) shows a opposite distribution; increasing from the sample 1 to sample 10. The silicon oxides are commonly found in the quartz as sand particles. Whereas the aluminium oxides (Al_2O_3) are naturally found in crystals easily insoluble in the water and maintain a high melting point.

The Iron oxide or ferric oxide (Fe_2O_3) is the main inorganic compound of iron and it naturally occurs in magnetite rocks. It is produced through thermal decomposition as well as through precipitation. The Potassium oxide (K_2O) is a highly reactive compound. The oxide deposits show that around sample 5, concentration suddenly increase in the profile and retreat thereafter to the same level. This indicates that during this time, the sediment depositing process and enforcing environmental conditions were oscillated periodically; and resumed thereafter to the gradual level (fig. 5.4, Table 5.3). This could be result of the abnormal discharge in the Par glacier melt channel due to increased precipitation or may be due to increased ablation . The increased concentration of carbonates and oxides altogether indicate that the watershed experienced increased pluvial conditions by which the lacustrine deposit had abnormal rise in the level of oxides as well as in the carbonates. .

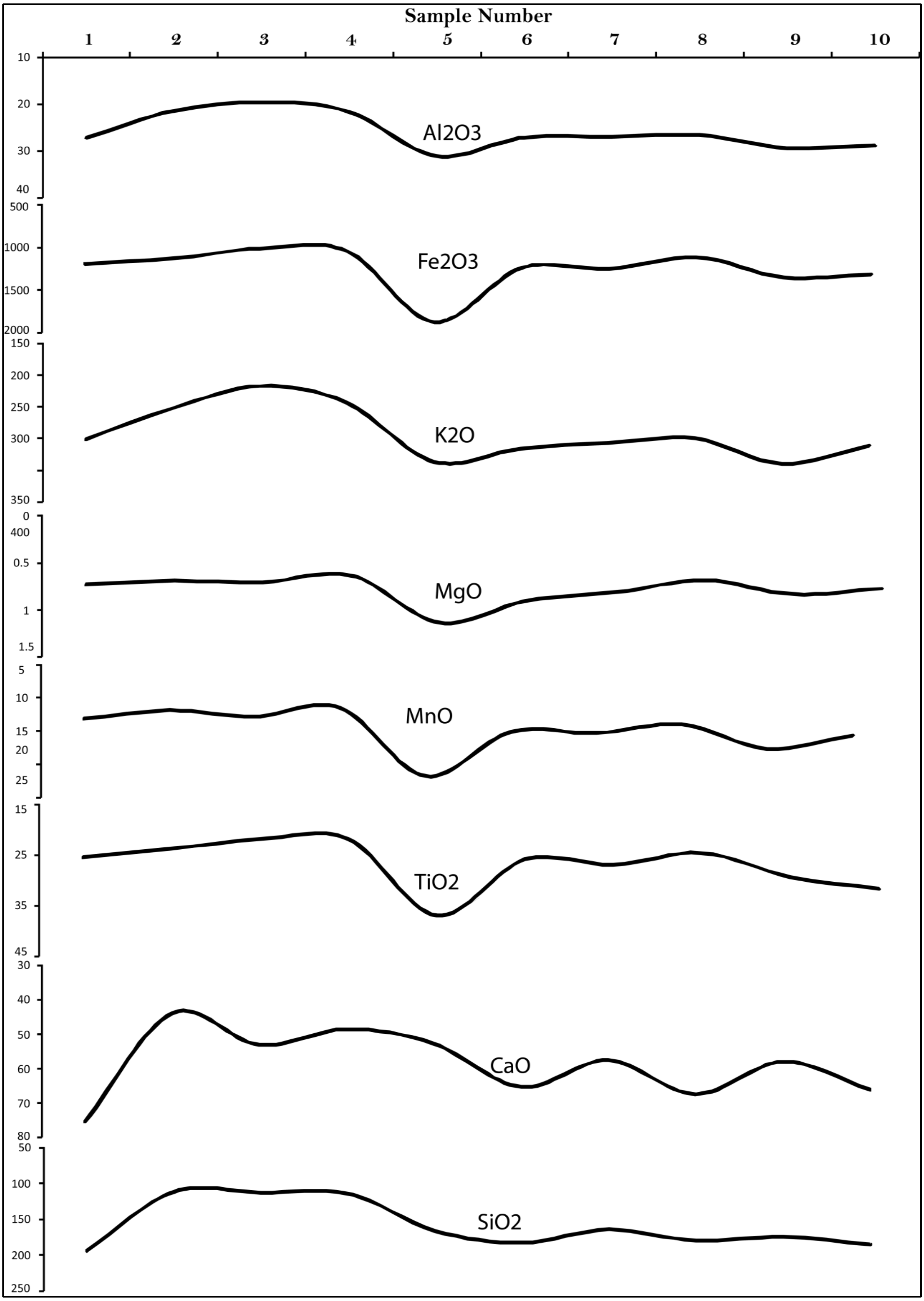

Fig.5.4 Distribution of the major oxides in the Par lacustrine deposit.

Table 5.3 Distribution of major compounds measured for the Par lacustrine deposit.

Sample No	1	2	3	4	5	6	7	8	9	10	Unit
Al2O3	27.328	21.451	19.589	21.63	31.192	27.171	27.076	26.729	29.443	28.956	%
SiO2	194.932	111.705	113.309	114.272	166.905	183.747	165.168	180.548	175.36	186.128	%
As	1.261	0.942	0.956	0.754	2.203	0.656	0.995	0.839	0.769	1.561	ppm
Ba	123.565	69.727	61.601	72.581	127.798	94.382	102.316	105.842	115.762	106.423	ppm
CaO	75.528	44.149	53.321	48.72	52.931	65.477	57.732	67.546	58.161	66.157	%
Ce	22.985	16.741	17.764	18.005	20.703	19.131	26.143	21.575	16.118	22.816	ppm
Cu	2.619	1.93	2.589	1.859	5.271	1.116	1.176	1.076	1.5	2.232	ppm
Fe2O3	1193.55	1134.152	1013.851	1045.412	1880.188	1243.203	1253.502	1118.514	1354.202	1321.36	%
Ga	2.712	1.81	1.597	2.111	2.499	2.488	2.682	2.433	2.609	2.68	ppm
K2O	301.876	253.14	218.341	244.636	337.729	316.74	308.467	300.828	341.055	312.623	ppm
MgO	0.729	0.692	0.710	0.635	1.136	0.9	0.814	0.685	0.835	0.775	%
MnO	13.263	11.986	12.929	11.641	21.832	15.194	15.405	14.118	17.742	15.773	ppm
Nb	1.673	1.499	1.213	1.52	2.691	1.993	1.963	1.69	2.325	1.869	ppm
Pb	2.878		1.835	2.061	2.84	2.709	2.976	2.987	2.721	3.069	ppm
Rb	115.094	93.415	86.526	90.947	173.205	124.128	125.095	122.282	134.691	129.642	ppm
Sr	6.927	3.129	3.576	3.346	4.819	5.48	6.373	6.162	6.114	6.435	ppm
TiO2	25.58	23.88	22.079	21.963	36.964	25.997	27.049	24.721	29.416	31.734	%
W	6.398	5.481	5.632	5.725	6.028	6.567	6.479	6.693	6.417	6.572	ppm
Y	1.708	0.952	1.117	1.192	1.563	1.119	2.498	1.516	1.757	1.51	ppm
Zn	4.535	4.276	4.633	4.612	8.733	4.777	5.237	4.186	5.593	5.307	ppm
Zr	16.562	11.058	9.959	11.16	14.793	13.911	20.646	14.365	14.742	15.977	ppm

Table 5.3 shows the oxides domination in the profile of the Par lacustrine deposits and point towards relatively warm and dry conditions during the deposition. The concentration of oxides and carbonates (fig. 5.2, 5.3), relative to the present conditions (sample 1) suggest that at the sample 5, the depositing conditions oscillated and returned to the normal dry and warm episode in the catchment.

Available dendrochronology based annual (August-July) precipitation data since AD 1330, using a tree ring data network of the Himalayan cedar (Cedrus deodara) for the Lahaul-Spiti region suggest multi-decadal droughts during the 14th and 15th centuries and thereafter a gradual increase in the precipitation. Similar precipitation pattern has been suggested back to AD 1410 for the western Himalaya Kinnaur (Yadav, 2011). The study suggest extended period of drought in the 15th and 16th Centuries and increasingly pluvial conditions between 18th Century, with the highest precipitation in the early part of the 19th Century and the decreasing trend in the last decade of the twentieth century.

5.5 Conclusions

Based on the oxides and carbonates distribution of the Par lacustrine deposit and available precipitation records of the region it is found that the area remain dry and warm throughout the last 1000 years, except with one episode of increased wet conditions in between the sample 5 to 7 (80-112 cm from the top surface). The timing based on the precipitation records of the region is in between to the late 17th to early 19th century. However, we need more detail work on the part of the chronology of the layers so that the exact possible time can be determined as the chronology of the Par lacustrine deposit depend upon 1 OSL sample only and only describe the lower limit of the deposit, the beginning of the deposition.

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Chapter VI

Summary, Synthesis and Conclusion

6.1 Summary

The main focus of the research was to work out the nature and timing of the Tharang end moraine ruins and its concurrence with the other palaeo-climatic proxies in the region. The study begins with evaluating the available glacial, dendro-record, lake and speleotherm chronology in the region. Available glacial chronology suggest that the style and timing of past glacier fluctuations in the Himalayas is widely contested. The late Quaternary maximum glacier expansion in the Himalaya has been asynchronous with the global Last Glacial Maximum and the timing and extent of the Holocene glacial fluctuations in the Himalaya differ notably from the northern latitudes. Little is known about the recent glacial fluctuations that occurred in the last millennium. In the absence of glacial chronology for the last millennium in the region, the relative size and extent of the Himalayan moraines were compared with that of the LIA glaciers in Europe. Although the recent studies have attempted to generate the glacial chronological of the last two millennium but careful observation of the available 1k glacial chronology suggest variation in timing and extent of glacial advance, and are mostly based on relative rather than absolute chronologies. Wherever the numerical dating technique has been applied, a limited number of dates are given (≤ 2). Areas which have been historically accessible such as Khumbu (Everest) and Garhwal provide the most dates. Uncertainties often persist because of the absence of the suitable organic other datable material for constraining the timing of the glacial expansions.

It is a matter of concern that the last millennial was the most explorative time period of the human generations. But little is known as to why people moved away from their indigenous locations. Such scenario invited more studies from the inner parts of the Himalaya for the robust glacial chronology of the period at least in the region, being the water supply/store region to the foreland areas. Plaeoclimatic observation, based on high resolution climate records from caves, tree rings, lake deposits, ice cores and glacial landforms suggest large variability in precipitation and temperature across the Himalayas on a millennial scale.

The study focused on the analysis of the environmental setting of the study area, for which different raster datasets along with field inputs were analysed in Chapter II. Observations suggest that topographically & climatically the study area is located in a very dynamic environment. The Pir Panjal acts as a barrier for northward approaching Indian Summer Monsoon (ISM), thus resulting in a strong moisture gradient of increasing aridity towards north. Physiographically, this area is confined in the form of a narrow valley; relatively, the upper reaches are broad due to the dominance of glacial process. The paraglacial and periglacial processes dominate the valley fill including, debris fan, rock avalanche, solifluction lobes and pattern ground. The trunk valley (main Miyar Valley) above 3200m displays an open U shaped cross profile, with a valley floor filled with glacial sediments, providing abundant scope for dating and understanding the glacial dynamics of the region.

All the permanent villages (12 inhabited), including Khanjar, which is the highest sedentary village, in the basin are located below 3500m. The modern vegetation in the study area is characterised by desert steppe and alpine steppe plant communities. Tree line in the basin is found up to 3500m. Ground record and oral history observations suggest that the basin compasses several sites of completely dilapidated ruins between Khanjar (the last sedentary village in the main trunk valley at 3500m) and Gumba; the prominent being Tharang, Phundang and Patam within the Tharang moraine complex. These remains hold much significance for palaeoclimatic reconstructions, given that under the modern climatic conditions, permanent habitation and agriculture are confined in areas below ~3500 m a.s.l. The presence of large number of ruins at an elevation of ~3710 m a.s.l., added with organized irrigation system and identifiable fields suggest that during the time of human habitation, climatic conditions may have been conducive for such activities or the crops would have failed given the duration of cropping season.

Importantly, the basin has recorded little anthropogenic modification of these landforms or settlements, and the bounded fields, an important parameters to reconstruct the glacio-archaeological history of the region. Little is known about the LIA glacio-archaeological history of this region.

The archaeological reconstruction of the Tharang end moraine ruins is addressed where the study depended on extensive field mapping, Radiocarbon (^{14}C) dating, compilation from historical map records and other plaeo-climatic proxies of the region. The study is based on the mapping of the ruins identified three abandoned village sites namely; *Tharang*, *Phundang* and *Patam* within the Tharang end moraines. Further analysis suggest that the *Tharang* was the largest village (with a group of ~50 rooms spread in ~1700 m^2) (fig.3.2), followed by *Patam (*5 separate group of settlements having 6 rooms on an average) and *Phundang (*3 separate settlements having 7 rooms on an average). Their migration from here has remained a mystery until now.

The study depended on fourteen (2 charcoal, 7 wood, 1 horn, 2 bone and 2 soil) radiocarbon samples to establish the chronology of artefacts and its analysis suggest that the ruins remained inhabited in the end moraine complex of the *Tharang* glacier during 980-1840 AD, a part of the peak of the Little Ice Age (1300-1600 AD) period in other parts of the Himalaya (Xu and Yi, 2014; Rowan, 2016). Therefore, for further confirmation the study analysed the available plaeoclimatic proxies of the region. Records suggest that the available temperature (fig. 6.1,Yadav et al. 2009) and snowfall (Yadav and Bhutiyani, 2013) proxies of the last millennium for the region are in consonance with the timing of the settlements. The LIA period in the region was relatively warm and only by the late 18th and early 19th centuries the region experienced the coldest interval of the last millennium, along with increased snowfall. The reliability of the proxies for the region is such that the snowfall proxy is based on the dendrochronological studies sampled in the lower parts of the study area, i.e. Kukumseri, Udaipur, Madgram, Ratoli, Khursad and Tindi (fig. 6.2). In view of the radiocarbon dates (Table 3.1, fig. 3.4) and available temperture and snowfall proxies of the region it is infered that these settlements were finally abandoned at the end of 18th or early 19th century.

The Great Trigonometric Survey map (1860-70) of the basin (fig.3.5) also supports these results as the map marks the *Tharang* end moraine complex as ruins by 1850s. We suggest that at the time of GTS survey 1850-60 the area was already abandoned probably due to cooling and advancing glaciers. Glaciers from other parts of Himalaya & Tibetan Plateau are also reported to have advanced during this period (Xu and Yi 2014).

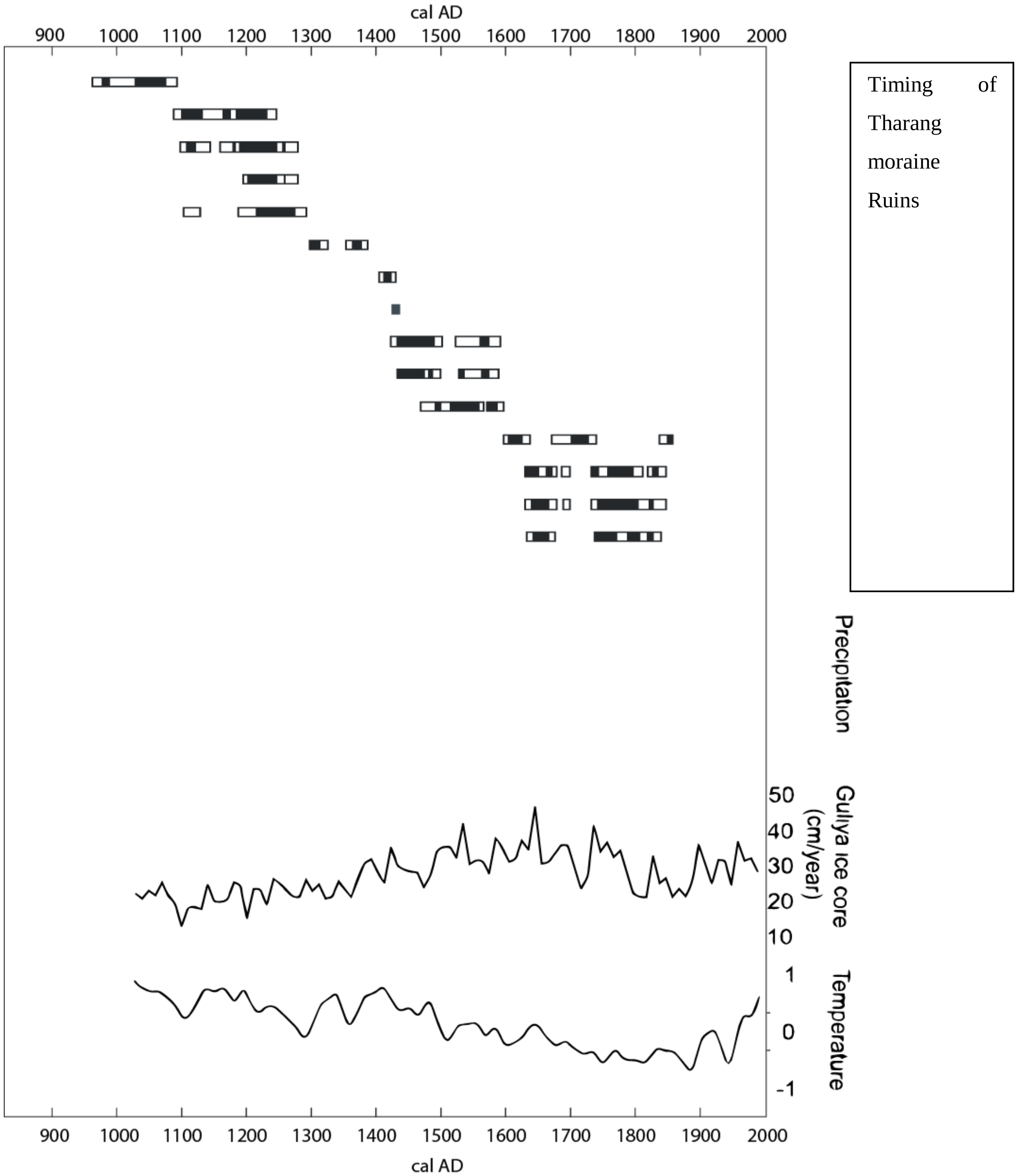

Fig.6.1 Calibrated Radiocarbon (14C) chronology of the artefacts (this study) compared with adjacent palaeo environmental chronologies. Guliya accumulation (Thompson et al., 1997), Temperature record of NW Himalaya (Yadav, et al., 2009).

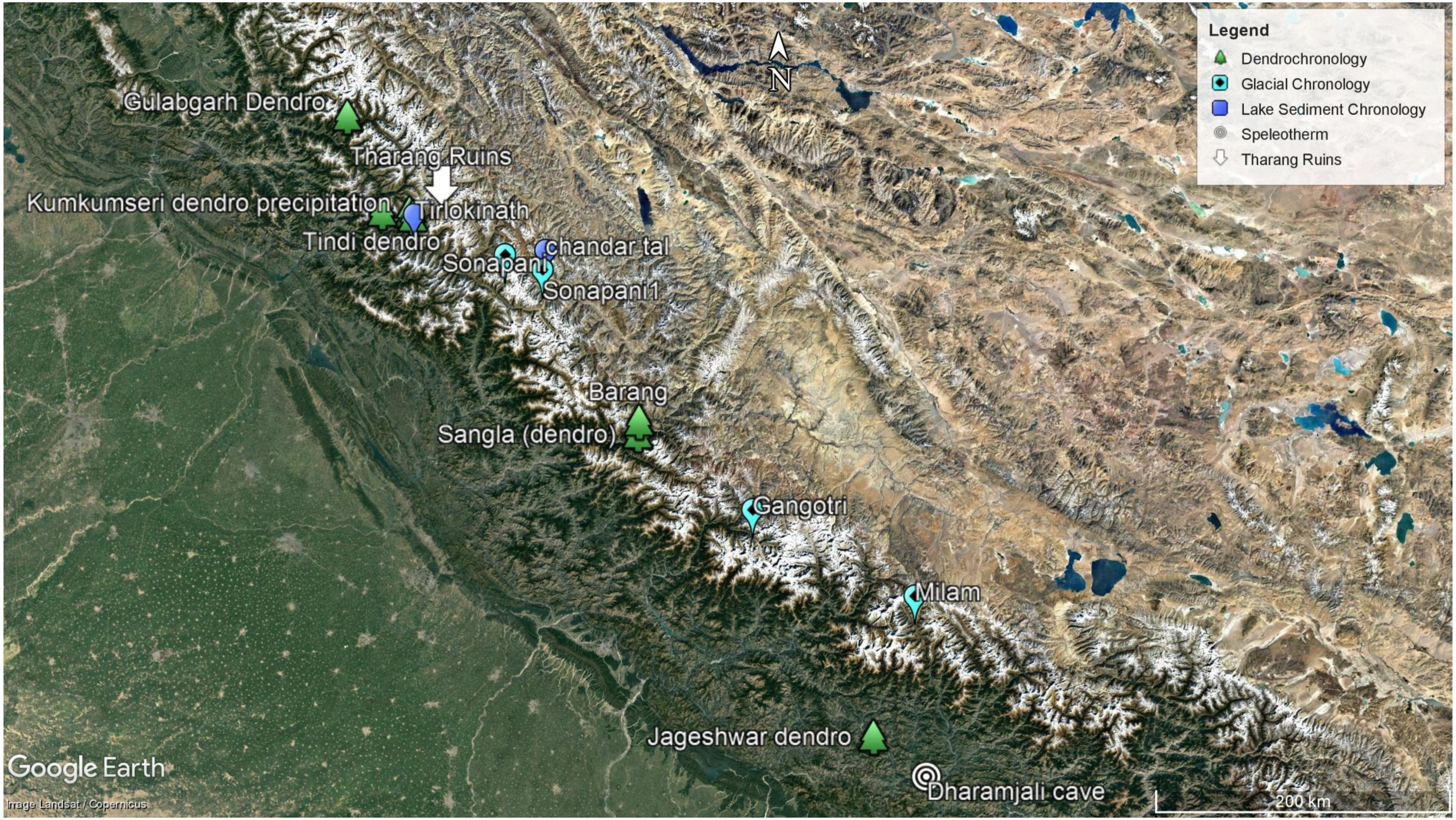

Fig. 6.2 Locations of the reconstructed palaeo-climatic proxies of the NW Himalayas.

The GTS map (1860-70) also shows advanced positions of at least *Tharang* glacier that correlates with the snowfall data reported by Yadav and Bhutiyani (2013) and other precipitation records from similar moisture stressed settings in north west Himalaya (Yadav, 2011a; Yadava et al., 2016).

In order to generate the palaeo-glacial fluctuations in the basin this study assessed the palaeo- Equilibrium Line Altitudes (ELA), landforms, historical maps and other proxies. Keeping in view the absolute and relative geochronology of the glaciations in the basin, this basin certainly experience two major glacier stage (Miyar Stage and Khanjar Stage) and one minor recent glacier advance (late 18^{th} and early 19^{th} Century).

The Miyar glacial stage is associated with the local Last Glacial Maximum (Plate 4.2) when Miyar, the largest glacier in the basin, coalesced with the tributary glaciers, expanding down-valley by ~35 km to reach Karpat, with an ELA depression of ~530 m relative to contemporary ELA at 5000 m. This most extensive glacial advance in the basin is recorded as a large U-shaped trunk as well as tributary valleys, scoured shoulders and bedrock walls, along with truncated spurs. This stage still remains to be dated however, considering the size and extent of the glacial landforms and features, this stage is proposed to be contemporaneous with the Chandra Stage in the eastern part.

The Khanjar stage is constrained within 10-8 ka (OSL), where sharply crested lateral moraines of tributary glaciers descend from ~4600 m a.s.l. to ~3000 m a.s.l. within a short distance of 3.7 to 5.4 km, controlled strongly by slope characteristics. During this stage, ELA probably fluctuated between 4405-4949m with a basin average of 4652m, with ∆ELA of 423 m asl from present to Holocene. During this expansion, the tributary glaciers chocked main trunk valley at many places. This resulted into a considerable length of blockade of the main trunk river, thus filling the valley with large and thick lacustrine fills prominently at Gumba and Than Pattan. During this stage, Tharang glacier descended to ~3595 m in comparison to its present terminus position at ~4471m, a vertical drop of ~880 m in a distance of ~4.96 km and produced the highest existing lateral moraine of the Tharang complex on the either flank.

Following the Holocene glacial advance, recent glacier advance (late 18th and early 19th Century) was identified based on fresh sediments and landforms assemblage within two kilometres from the present glacier terminus and the extent marked on available historical GTS map. The available plaeoclimatic proxies of the region are in consonance with the timing of this minor expansion. There is no denying that each successive expansion was many degrees smaller than the previous that helped preserve large number of landforms which otherwise would have obliterated the record, had there been an Ice Age of higher magnitude. Landforms in the form of trimlines and shoulders are indicative of the antiquity of the event in the basin and region, which need future exploration.

In order to understand the hydrological history of the study area the study investigated the changes in the major and trace elements in alpine lacustrine deposits at Par Got. Based on the oxides and carbonates distribution in the Par lacustrine deposit and available precipitation records of the region it is suggested that the area remained dry and warm throughout the last 1000 years, except with one episode of increased wet conditions in between the sample 5 to 7 (80-112 cm from the top surface). The timing based on the precipitation records of the region is between the late 17th to early 19th Century. However, we need more detailed work on the part of the chronology of the layers so that the exact possible time can be determined as the chronology of the Par lacustrine deposit depend upon one OSL sample that provide the lower limit of the deposit, the beginning of the deposition.

6.2 Linkages between Tharang ruins and LIA glacier advance

Chronology of Tharang end moraine ruins and landforms (Table 3.1 and fig.3.1) are the key factors in understanding the LIA climate, glacier fluctuations and settlement patterns in the basin; as under the modern climatic conditions, habitation and agriculture are confined to areas below ~3500 m a.s.l. The continuation of a settled economy with multiple house structure and robust irrigation system within the *Tharang* end-moraine complex (at an elevation of ~3710 m a.s.l.) suggest that during the timing of these settlements, climatic conditions were favourable. These land use and climatic inferences suggested that the basin experienced no glacial advance during the peak of the LIA (1300-1600AD), except during the late LIA advance (Late 18th to early 19th century). The available temperature (Yadav, et al. 2009) and precipitation (Yadav 2011b; Yadav et al. 2014; Yadava et al. 2016) proxies for the last millennium of the north west Himalaya support the timing of these settlements and associated irrigation practices. The sedentary villages in such high altitude environment usually prefer to colonize in relatively stable, ice and avalanche free landscape, with life supporting conditions (Meyer et al., 2009). The 600 years old (1460-2008) snow fall data by Yadav and Bhutiyani (2013) further support the timing as the time existence of the settlements indicate relatively low snowfall. The occurrence of late LIA glacial advance in the late 18th and early 19th century is consistent with the view that plentiful precipitation is required for glacial expansion (Owen, et al. 2002), along with low temperature (Yadav, et al. 2009). The increased precipitation along with the lowest temperature during the late LIA period had resulted into the glacier advance. The subsequent conditions might have lead to a cool conditions at 3700m asl; resulting into inhospitable climatic at this altitude, and subsequently abandoning the site.

The temperature record by Yadav, et al. (2009) also supports this explanation as lowest temperature has been reported for the 18th and 19th centuries in the last millennium. The climate-induced migrants from *Tharang* are settled at *Tingrit* (3225 m) and *Urgos* (3300 m), ~10 km down valley, as *Phun Phundang Pa* and *Chhe Chung Garad*, who trace their family genealogy for six generations to these sites. The reason for migration to lower altitudes, as sited by these families, happens to repeated crop failure at these sites. The comparatively increased temperature during 10th to17th century AD (Yadav, et al. 2009) in the western Himalaya and relatively reduced and dynamic snowfall during the 1450-1780 AD (Yadav and Bhutiyani, 2013) for the lower part of the basin, would certainly have restricted the glacier in the study area during the peak of LIA, which allowed people to survive at this altitude, next to the glacier. Such peculiar pattern in terms of limited glacier extent during peak of LIA can be understood by the glacial expansion of the last two millennium (fig.1.1). Figure 1.1 shows that the monsoon dominated region of the Eastern and Central Himalaya did not experience the late LIA advance during the 19th century AD, whereas, it was common phenomena in the Western Himalaya, Karakoram and further North West. This suggests spatial and temporal variability in terms of LIA glacial expansion. Such asynchronous behaviour within the Himalayas may be a result of topographic characterstics, as the towering relief plays a dominating role in controlling the climate (since elevation-related precipitation and temperature gradient are notable fig.2.1a) in the Himalaya (Lehmkuhl and Owen, 2005; Owen et al., 2005; Bookhagen and Burbank, 2006; Staubwasser, 2006; Chen et al., 2008). During the majority of the LIA, this area had restricted glacier, i.e., *Tharang* glacier terminated up-valley beyond the moraine complex to have people draw waters for irrigation through three sets of *Kuhls* from the flowing rivulet (fig. 3.1, 3.2, 3.3 and Plate3.2). In addition, *Tharang* glacier fore-field is marked as ruins, along with glacier marked on the GTS map of 1874 (fig. 3.5); suggesting that these were abandoned due to glacier advance and deteriorating climatic conditions.

The evidence provided by Sinha et al. (2011) scientifically supports this timing and explanation, where they have suggested a break in the Indian Summer Monsoon during AD 1400 to ~1700 and an increase (active) during AD ~1700 to 2007. Similar records were reported by Thompson et al., (2000) from Dasuopu Ice cores, along with hordes of additional research which support the glacial advance during the late 18th to early 19th centuries (Rowan, 2016; Xu and Yi, 2014). The mineralogical data (fig5.2, 5.3, 5.4) also shows that relative to present conditions the climate was dry and warm for the last 1000 years in the basin.

Based on the changes in the major and trace elements in the Par lacustrine deposits, the study suggest that hydrologically the area remained dry and warm throughout the last 1000 years, except with one episode of increased wet conditions. However, the available precipitation records from the NW Himalaya (Singh and Yadav, 2005;

Yadav, 2011a; 2011b; Yadav and Bhutiyani, 2013; Yadava et al., 2016; Yadav et al., 2017) suggest an increased pluvial conditions by the late 17th Century, with a dominance by late 18th and early 19th century. We propose that the sudden increase of carbonate and oxides in the Par lacustrine profile is result of the increased precipitation in the reason.

In a brief, the chronology of the ruins, timings of the late LIA glacial expansion and hydrological history of the study area is in consonance with the available climatic proxies of the region. Climatically the region between Gulabgarh-Kumkumseri-Barang (fig. 6.2) experienced dry and warm conditions during the peak of LIA (1300-1600) in the higher latitudes (Europe), but the later part of the LIA (late 18th to early 19th Century) is found to be coldest and wetter in the last millennial. This probably resulted into creating hospitable conditions within the Tharang moraine complex where population thrived here between 980-1768AD; for almost 800 years.

Future investigations with robust additional dates would help in understanding such events in this area as well as other parts of the Himalayas.

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Annexure 1 Radiocarbon samples and obtained dates.

Lab Code	Material Type	Latitude	Longitude	Altitude (m)	Site Location	14C age	lower cal range AD	upper cal range AD	relative area	lower cal range AD	upper cal range AD	relative area	lower cal range AD	upper cal range AD	relative area	lower cal range AD	upper cal range AD	relative area	median Age AD
UBA-30075	Wood/charcoal (Hearth)	32°53.750'N	76°53.201'E	3739	Tharang	838±28	1159	1260	1										1206
UBA-30064	Charcoal (Hearth)	32°53.342'N	76°52.969'E	3681	Patam	654±21	1283	1317	0.462843	1353	1390	0.537157							1358
UBA-30076	Soil (Hearth)	32°53.753'N	76°53.196'E	3731	Tharang	489±22	1412	1444	1										1429
UBA-30077	Soil (Cattle shed)	32°53.760'N	76°53.195'E	3734	Tharang	378±27	1446	1524	0.658401	1559	1564	0.013336	1569	1631	0.328263				1501
UBA-30074	Wood (hearth)	32°53.756'N	76°53.197'E	3730	Tharang	327±21	1488	1603	0.792136	1610	1641	0.207864							1565
UBA-30078	Horn	32°53.849'N	76°53.210'E	3739	Tharang	212±34	1641	1690	0.337825	1729	1810	0.532033	1925	1949	0.130142				1768
UBA-30069	Wood (hearth)	32°53.792'N	76°53.197'E	3729	Tharang	123±22	1681	1739	0.294694	1750	1762	0.024585	1802	1894	0.52991	1905	1938	0.15081	1836
UBA-30072	Bone (Hearth)	32°53.735'N	76°53.189'E	3735	Tharang	108±32	1693	1727	0.272913	1812	1891	0.644928	1908	1919	0.082159				1836
UBA-30065	Bone (Hearth)	32°53.499'N	76°53.208'E	3699	Phundang	101±27	1684	1734	0.282198	1806	1929	0.717802							1840
THMCS02	Pine Wood	32°53.342'N	76°52.970'E	3681	Patam	393±41	1462	1642	1										1556
THMCS03	Pine Wood	32°53.342'N	76°52.975'E	3681	Patam	860±42	1044	1101	0.188	1119	1261	0.812							1179
THMCS04	Pine Wood	32°53.845'N	76°53.210'E	3738	Tharang	892±42	1032	1221	1										1133
THMCS05	Pine Wood	32°53.848'N	76°53.210'E	3737	Tharang	826±42	1052	1080	0.042	1152	1276	0.958							1212
THMCS06	Pine Wood	32°53.850'N	76°53.210'E	3738	Tharang	1058±44	885	1040	1										980

Calibration of the CRA is based on Oxcal 4.3 (online) RADIOCARBON CALIBRATION PROGRAM 1986-2017 using IntCal13 calibration curves NH2 (after P. Reimer 2013). The uncertainties for the calibrated ages are given up to 2σ.

Note: The samples were superficial covered with shattered stone and has been dug out after removal of the same. For hearth based samples, the soil profile of the hearth dugout around 1 foot. However, horns sample was open exposed on the animal sacrifice point.

The UBA samples were processed at 14CHRONO Centre of Queen’s University Belfast, Northern Ireland, United Kingdom whereas the THMCS were processed at Inter-University Accelerator Centre (IUAC), New Delhi.

APPENDIX-I

Summary of Publications

Following is a list of the research papers and abstract published by the author during the course of the PhD thesis. The relevant papers have been well cited in the thesis as well and may appear in the References.

Journal Papers (Peer Reviewed)

1. Kathleen D. Morrison1, E. Hammer, L. Popova, M. Madella, N. Whitehouse5, M-J Gaillard, **Rakesh Saini** and LandCover6k Land-Use Group Members (2018) Global-scale comparisons of human land use: developing shared terminology for land-use practices for global change, *Past Global Changes Magazine*, Vol. 26(1), 8-9, 2018, doi.org/10.22498/pages.26.1.8
2. Deswal, S.; Sharma, M.C.; **Saini, Rakesh**; Chand, P; Juyal, N; Singh, I; Srivastava, P; Ajai and Bahuguna, I.M. (2017) Late Holocene Glacier Dynamics in the Miyar Basin, Lahaul Himalaya, India, *Geosciences* (**2017)**, *7*(3), 64; doi:10.3390/geosciences7030064.
3. **Saini, Rakesh**; Sharma, M.C.; Deswal, S.; Barr, I.D.; Kumar, P (**20016**) Glacio-archaeological evidence of warmer climate during the Little Ice Age in the Miyar basin, Lahul Himalaya, India, Clim. Past Discuss., doi:10.5194/cp-2016-101, 2016

Books & Policy Documents

1. Saraswat et al. (2016) Monitoring Snow and Glaciers of Himalayan Region, Space Applications Centre, ISRO, Ahmedabad, India, 413 pages, ISBN: 978 – 93 – 82760 – 24 – 5.
2. **Rakesh Saini** (2012) *Climate Change & Glacier Dynamics in Lahaul Himalayas: Present & Palaeo Glacial Fluctuations of Lahaul Himalaya*, **Publisher:** LAP LAMBERT Academic Publishing.
3. Ajai et al. (2010) Snow and Glaciers of the Himalayas**,** Space Applications Centre, ISRO, Ahmedabad, India, 290 pages, ISBN 978-81-909978-7-4**.**

Peer Reviewed Conference Abstract/ Presentation/ Invited Lectures

1. 26 Feb to 4 March, 2016 in Science Fair & National Science Day held at Dr. Harisingh Gour Central University, Sagar, delivered an invited lecture on Application of GPS, GIS and Remote Sensing.
2. March 18-20, 2016 9th International Geographical Union (Igu) Conference On Land Use Change, Climate Extremes and Disaster Risk Reduction, Shaheed Bhagat Singh College, University of Delhi, Delhi: **"Little Ice Age in Himalaya and Spatio-temporal Variability".**
3. 28-30 April, 2016 International Conference on Quaternary Climate: Recent Findings and Future Challenges **,** CSIR-National Institute of Oceanography, Dona Paula, Goa, India **"Geo-archeological evidences of Holocene variability and little ice age warm from Miyar basin, Lahul Himalaya".**
4. 22.-23 October, 2015 PAGES Working Group Land Cover6K Meeting at Chicago University Centre in Paris, France for **Landuse 6K:Putting History to Work on Climate Change**,
5. 6-8 November 2015in international conference on Global Environmental Change in the Himalayan Region controversies impacts futures, , Venue: Gulmohar auditorium, India Habitat Centre, Lodhi Road, New Delhi **Geomorphological and Chronological Evidence for Holocene Glacier Dynamics in the Miyar Basin, Lahul Himalaya, India.**
6. 3-4 October 2013 *1st International Conference of Association of Punjab Geographers* on Disasters, Natural Resource Management and Socio-economic Development organized by Department of Geography, Kurukshetra University, Kurukshetra. "**Reconstructing Quaternary Glacier Fluctuations in the Miyar Watershed, Lahul Himalaya, H P, India.**
7. December, 2013, 35th *Indian Geography Congress*, Chennai: "**Assessing Glacier Changes During Past 150 Years: A Case of Miyar Basin, Lahul Himalaya,** ***India***.