Soil Formation in the foreland of Bhimthang Glacier, Manang, Central Nepal

A Dissertation Submitted for the Partial Fulfillment of Masters' Degree of Science in Botany (Plant Ecology and Resource Management)

Submitted by

Mahendra Gahatraj
Plant Ecology and Resources Management Unit
Exam Roll No.: Bot.313/072
T.U. Regd. No.: 5-1-33-512-2006
Batch: 2072/074

Central Department of Botany
Tribhuvan University, Kirtipur
Kathmandu, Nepal
December, 2019

RECOMMENDATION

This is to certify that the M. Sc. dissertation work entitled "**Soil formation in the foreland of Bhimthang Glacier, Manang, Central Nepal**" was carried out by Mr. Mahendra Gahatraj under my supervision. This work is primarily based on his own research work and has not been submitted for any award of an academic degree.

I, therefore recommend this dissertation to be accepted for the partial fulfillment of Masters' Degree of Science in Botany (Plant Ecology and Resource Management Unit) at Institute of Science and Technology Tribhuvan University, Kirtipur.

……………………………

(Supervisor)

Chitra Bahadur Baniya, PhD.

Associate Professor

Central Department of Botany

Tribhuvan University, Nepal

Date: 17, December 2019

LETTER OF APPROVAL

The M.Sc. dissertation entitled "**Soil formation in the foreland of Bhimthang Glacier, Manang, Central Nepal**" was carried out by Mr. Mahendra Gahatraj and submitted to the Central Department of Botany, Tribhuvan University has been accepted for the partial fulfillment of requirement for Masters' of Science in Botany (Plant Ecology and Resource Management Unit).

Examination committee:

…………………………………

(**Supervisor**)

Chitra Bahadur Baniya, PhD

Associate Professor

Central Department of Botany

Tribhuvan University, Nepal

…………………………………

(**Head of Department**)

Ram Kailash Prasad Yadav, PhD

Professor

Central Department of Botany

Tribhuvan University, Nepal

…………………………………

(**External Examiner**)

Sudeep Thakuri, PhD

Associate Professor

Central Department of Environment Sciences

Tribhuvan University, Nepal

…………………………………

(**Internal Examiner**)

Giri Prasad Joshi, PhD

Associate Professor

Central Department of Botany

Tribhuvan University, Nepal

Date: 17, December 2019

ACKNOWLEDGMENTS

I am greatly indebted to my supervisor Dr. Chitra Bahadur Baniya, Associate Professor of Central Department of Botany, Tribhuvan University, for his countless hours of patience, guidance and skillful supervision to carry out this work smoothly.

I take this opportunity to express my sincere gratitude to Prof. Dr. Ram Kailash Prasad Yadav, Head of Department, Central Department of Botany for his continuous support and encouragement throughout the study period. I am also thankful to Prof. Dr.Mohan Siwakoti, Former Head of Department and Prof. Dr. Mohan Prasad Panthi, Former Head of Department, Central Department of Botany for their continuous support during the commencement of this work.

I am very much pleased and thankful to my friend Ms. Priti Dhakal for her valuable support and priceless help and courage for dealing with difficult situation in each and every moments throughout this research work. I would like to thanks to Mr. Surya Prakash Sharma, Mr. Benup Raj Adhikari and all my junior friends of BEM 2075 batch for their support during my field work. I am extremely grateful to Mr. Raju Chauhan, Lecturer of Amrit Science Campus, Tribhuvan University.

Thanks also goes to all the teaching and non-teaching as well as administrative and non-administrative staffs and colleagues of Central Department of Botany, Tribhuvan University for their direct and indirect support and help.

I would like to pay special thanks and my due respect to the local people, especially of Nasong- 6, RM, Manang for sharing their experiences and knowledge. Special thanks goes to Chairperson, Mr. Dhan Bahadur Gurung for sharing his practical knowledge and experiences and all his warm hospitality and tremendous support during the entire study period. I am very much thankful to Department of Hydrology and Metrology, Babar Mahal, Kathmandu for providing climatic data.

My families, friends and seniors have been a great part of my success, as they are the ones to drive me to be the best that I can be. Finally, I would like to express my love and dedicate this research work to my parents Hira Bahadur Gahatraj and Mani Kumari

Gahatraj as well my maternal uncle, Mr. Lok Bahadur Baral (Lecturer, Amrit Science Campus), T.U. all family members and relatives who developed a never ending strength and patience in me to go behind something which seem too farfetched.

……………………..

Mahendra Gahatraj

Date: 17, December 2019

ABSTRACT

Glacier forelands is considered as a unique field laboratory and the most sensitive and highly-confident indicators of climatic variation. Glacier forelands after retreat of glacier expose new sites to understand soil development through mechanical and chemical weathering, as well as biological i.e. due to vegetation and microbial colonization. The present study attempts to understand the variation in soil development through time and space and status of Bhimthang glacier foreland in Manang district of Central Nepal. Five transects were laid on the south-west aspect of foreland. The transects line were placed parallelly at the distance of 50m from each other. Along each transect, 12 quadrats of 2 m × 2 m each were laid down at an interval of 30 m. Result shows that the soil nutrient contents (SOC, N, P and K) increases with increased distance from glacier toe and the other physical as well as chemical properties (Soil depth, bulk density, pH, RRI, open space, vegetation cover and rock cover) also varied between newly formed soil and old aged soil along the glacier foreland. The study also explains the chrono sequential changes of glacier foreland soil through spatio- temporal scale. The area close to the glacier toe is regarded as young soil and farther from glacier as old soil. Bhimthang glacier was found to be continuously retreating from 1988 to 2018. Glacier foreland represents a unique platform for research on the study of chrono sequential changes of the ecosystems and soil development pattern during primary succession.

Key word: Climate change, Chronosequence, Physico-chemical parameters, Glacier retreat

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS AND ACRONYMS

CBS	Central Bureau of Statistics
GEN	Glaciological Expedition in Nepal
GPS	Global Positioning System
ICIMOD	International Centre for Integrated Mountain Development
K	Potassium
kg/ha	Kilogram per hacter
LIA	Little Ice Age
N	Nitrogen
P	Phosphorus
PCA	Principal Component Analysis
ppm	Parts per million
RRI	Relative Radiation Index
SOC	Soil Organic Carbon
USGS	United States Geological Survey
WGMS	World Glacier Monitoring Service
WWF	World Wide Fund

1. INTRODUCTION

1.1 Background

Glaciers are sensitive and 'high-confident' indicators of climate change (Zemp *et al*., 2008; Armstrong, 2010). They respond to changes in temperature and snowfall. Glacial length change indicates an indirect and delayed response to climate change, while glacier mass balance indicates a direct and un-delayed response to the climate (Haeberli, 1995). The Himalayan regions have experienced numerous glaciations during the late Quaternary (Owen *et al*., 2002; Richards *et al*., 2008). Glacial advances, i.e. glaciations, occur in cycles with interglacial periods when glacial ice retreats due to global warming; the interglacial typically occurs for about 10,000 years before the next glaciation (Gaudie, 1983).

Glacier forelands are considered a unique type of the field laboratory. A glacier foreland is the area of newly-exposed landscape in front of glacier, which was recently ice-covered but has been exposed by glacier retreat (Matthew, 1992). Retreating glaciers or the glacier forelands expose new sites for soil development through processes of chemical weathering, as well as vegetation and microbial colonization (Haugland, 2006). A retreating glacier presents a temporal sequence (chronosequence) in ecosystem development: the further the distance from the retreating glacier, the older site and hence the longer the period for plant succession to occur (Matthews, 1992). Climate change influences glacial ecosystems by affecting the advance and retreat of glaciers. Since the end of the Little Ice Age (LIA), glaciers have extensively retreated, and glacier foreland area has extended in the circumpolar region (Serreze *et al*., 2000).

Glacier foreland provides great opportunities to study chrono sequential changes through space-for-time substitutions; since the distance from the glacier terminus is a proxy for soil age, the area close to the glacier edge is regarded as young soil and vice versa (Huggett, 1998; Walker *et al*., 2010). The concept of chronosequence as a spatial representation of a temporal sequence has been systematized by Jenny (1941) in the concept of soil development as mentioned by Matthew (1992). By substituting space for time, Coaz (1887) and later researchers realized that increasing distance from the margin of a retreating glacier could be interpreted as representing a temporal sequence (chronosequence) in an ecosystem development. According to Matthew (1992), chronosequence are spatial sequence in which environmental factors other than time are considered to be unimportant either because they are invariant or because they are relatively ineffective.

The pedogenic process in glacier foreland is a function of various variables including temperature and moisture regimes (Hall and Walton, 1992), time since exposure and topography (Darmody *et al*., 2005). Jenny (1941) explained soil as the pioneer building block of ecosystem that is the mixture of fragmented and partly or wholly weathered rocks and minerals, organic matter, water, air in varying proportion and differentiated into horizons.

The deglaciation facilitates biogeochemical processes on glacial deposits with initiating soil formation as an important driver of evolving ecosystems (Schweizer *et al*., 2018). Bare rocks and gravels exposed in the glacier retreat site are subjected to weathering and pedogenesis respectively. Rowell (2014) explained the rocky surface exposed after glacier retreat undergoes weathering along with erosion and pedogenesis over a long period of time which constantly lead to the formation of soil profile with different soil horizons each with distinct texture, structure, colour and other physico-chemical properties. A general pattern of soil development can be studied through the soil physico-chemical properties along spatio-temporal gradient although the extent of soil development greatly varies on pro-glacier areas like glacier foreland (Matthews, 1992).

Pedogenesis affects various soil physical properties including bulk density, texture, and soil depth as well as different soil chemical properties (Gurung and Bajracharya, 2012). Soil organic matter is also an important component of the soil system. It performs numerous functions that determine soil productivity: soil aggregation is promoted by organic matter; decomposition of soil organic matter releases plant nutrients; soil cation exchange capacity and hence affects nutrient availability; and enhances the availability of phosphorus in acidic or basic soils (Stevenson, 1994). The young soils characterizing glacier forefields are generally scarcely vegetated and low in nutrients such as C, N, P and S. Bedrock properties determine the physico-chemical properties of the corresponding soils such as texture, pH, nutrient concentrations, heat and humidity retention, water and gas fluxes (Miniaci *et al*., 2007).

During the primary succession, not only the plants but also the soil undergoes remarkable changes such as soil accumulation, organic matter added by the vegetation, increase in water holding capacity, increase in soil aeration and porosity, decrease in bulk density, decrease in water runoff and other soil quality development (Singh *et al*., 2008). Plants have good connection with microbes and soil (Schmidt *et al*., 2014) as soil microbes carry out key processes in the soil development, biogeochemical cycling and facilitating the plant colonization by nitrogen fixation and carbon sequestration (Schutte *et al*., 2009).

1.2 Rationale of the Study

The effects of climate change on Himalayan soil and vegetation dynamics should be understood so that it will help for assessing impacts on mountain livelihoods, as well as for implementing effective conservation strategies. Due to the climate change and global warming, glaciers in the mountain are continuously melting and retreating than the normal range. Nepal being the land- locked and mountainous country, people here substantially depend upon the water from glaciers and mountain for their economy and livelihood (Shrestha and Aryal, 2011).

Glacier foreland represents a unique platform for research on primary productivity and ecosystem development. The exposed glacier foreland is an ideal place to study chronosequential changes in ecosystems and soil development pattern during primary succession. Although, vegetation succession in the glacier forelands has been studied intensively, little is known about the soil development pattern and variation in soil nutrient content in these environments. Despite of abundant literature on Himalayan glaciations and glaciers, including glacier retreat, information on soil development and plant succession in deglaciated Himalayan terrain in context to Nepal is still insufficient.

The present research work is expected to fulfill the significant gap in knowledge regarding the soil properties along the spatio-temporal gradient along glacier foreland of Bhimthang, Manang, Central Nepal. Such studies in the glacier forelands give the empirical data for understanding the pattern and process of soil development along the glaciers forelands of Nepalese Himalaya.

1.3 Hypothesis

The hypothesis of this study is “Soil physico-chemical properties steadily developing on the glacier foreland shows a linear relationship i.e. increases with the increasing distance away from the glacier terminus or toe”.

1.4 Objectives

The general objective is to determine the change in soil nutrients along the spatio-temporal gradient in the foreland of Bhimthang glacier.

The specific objectives of the study are as follows:

- To explore the variation in soil physico-chemical parameters along glacier foreland.
- To investigate the retreat of glacier along spatio-temporal gradient in chronosequence order.

1.5 Limitations

The increase in rate of deglaciation in response of climate change need to be studied in long geological time periods from Little Ice Age, but deglaciation of Bhimthang glacier, Manang has not been investigated since the Little Ice Age (LIA). Thus, an actual 'chronosequence' in a deglaciated foreland could not be used and comparisons are to be subsequently made only on basis of soil properties change. Only a short gradient which covers the glacier foreland starting from 3700 to 3450 m asl has been taken in this study.

2. LITERATURE REVIEW

2.1 Glacial retreat

Glaciers cover in the Himalayas represents 28.8% of glaciers in Central Asia and 4.8% of glaciers and ice-caps in the world (Gurung *et al*., 2012). WWF Nepal Program (2005) reported that there are 3,252 glaciers and 2,323 lakes covering an area of 5,323 km2 with an estimated ice reserve of 481 km3 in the Nepal Himalayas which are above 3,500 m asl. In 2010, a total of 3,808 glaciers were identified with a total area of 3,902 km^2 and estimated ice reserves of 312 km^3 (Bajracharya *et al*., 2014). The decadal mapping of glacial lakes across the Nepal Himalaya revealed that there is an increase in the number and area of lakes from 1977 to 2017, with 606 (55.53 ± 16.52 km^2), 1137 (64.56 ± 11.64 km^2), 1228 (68.87 ± 12.18 km^2), 1489 (74.2 ± 14.22 km^2), and 1541 (80.95 ± 15.25 km^2) in 1977, 1987, 1997, 2007, and 2017 respectively (Khadka *et al.*, 2018). Glaciers are important as indicators of climate change because physical changes in glaciers whether glaciation or deglaciation, provide visible evidence of changes in temperature and precipitation (U.S. Environmental Protection Agency. 2016).

According to IPCC (2014), the amount of snow and ice on the Polar region and mountain are diminishing due to increasing global warming. In context of Nepal, the average maximum temperature has been increasing at the rate of 0.056°C/annum and minimum temperature by 0.002°C/annum since 1971 (DHM, 2017). The formation of glacier forelands, along with increase in temperatures, present new scenarios for soil development and plant succession in the Himalaya (Gurung and Bajracharya, 2012). Bajracharya *et al.* (2014) reported that the glacier area of Nepal is decreasing 30 km^2/year since 1970s and glaciers of Nepal will disappear by 2100 A.D. if this trend continues.

Himalayas are the most vulnerable to climate change as temperature is the significant limiting factor. Glacial ice are retreating due to increasing rate of global warming and the loss in glacier mass is recorded maximum during period of 2002-2011 than 1992-2002 (IPCC, 2014) . Retreating glaciers expose area of deglaciated foreland as terrestrial ecosystems that have been previously locked under ice for thousands of years where microbes and plants get colonized (Bradley *et al*., 2014).

WWF Nepal Program (2005) reported that regular glacier studies in Nepal began in the early 1970s and some of the studied glaciers are glaciers in the Hidden Valley of Dhaulagiri, Langtang, Khumbu and Kanchenjunga and so on. ICIMOD/UNEP (2001) has published the comprehensive report on inventorying glaciers, glacier lakes and GLOFs in the Himalayas which also provide the baseline information about glaciers of Nepal.

The two renowned university from Japan- Nagoya and Kyoto University attempted the first systematic investigation of Nepalese Himalayan glaciers. The Glaciological Expedition of Nepal (GEN, 2006) lead by Asahi *et al*. (2001) and Kadota *et al.* (1997) found that the glacier are retreating at the rate of 8 m/year and 5-10 m/year in the region of Shorang and Khumbu respectively. They also remarked that the glacier retreat rate accelerated after 1990. Similarly, another Glaciological Expedition to Nepal led by Higuchi (2010) carried out glacier related studies in the region of Khumbu, Shorong, Hink and Hunk regions in Eastern Nepal and the Mukut Himal of the central Nepal from 1973 to 1978.

The process and pattern of biological succession and soil development are well documented in North America, Scandinavia and the European Alps (Gurung, 2012). Gurung (2012) made the first attempt to study the primary colonization and soil development pattern in the Ngozumpa Glacial Valley in the Khumbu Himal region of Eastern Nepal. Similar studies have been carried by Mong and Vetaas (2006) nearby Gangapurna glacier foreland, Baniya *et al*. (2009) along abandoned fields in Manang, King *et al*. (2010) in Annapurna region and Stress *et al.* (2013) in the Sagarmatha region.

Armstrong (2010) reported the glaciers in the east are retreating at higher rate than in the west. Shrestha and Aryal (2011) have reported that the glacier system at the lower elevations, below 4000 m have responded significantly to recent global warming.

According to Bajracharya *et al.* (2014), the total glacier area decreased from 191 to 142 km^2 (26%) in Langtang valley with an average rate of loss from 1.49 km^2/year and from 63 to 46 km^2 (27 %) in Imja valley with an average rate of loss of 0.57 km^2/year. They also further explained that Ngozumpa Glacier has reduced from 82.6 km^2 to 80.7 km^2.

Similarly, Thakuri *et al*. (2014) analyzed variations in glacier surface and snowline altitude for the glaciers/ice mass in the Sagarmatha (Mt. Everest) National Park (area: 1148 km^2), using cartography and remote imaging since 1950s to 2011 and uncertainties associated, providing a longest time series of glacier variations in this region. They found that the glacier surface area had loss of 14.3±5.9 % (0.27 % yr-1) from 396.2 km^2 to 339.5 km^2 in 1958 to 2011 with the loss by 0.12 % yr-1 in 1958-75 and 0.70 % yr-1 in recent years.

2.2 Satellite data and mapping of glacier area

Satellite data were first used to map glaciers in the early 1970s, making use of the US Earth Resources Technology Satellite (ERTS), later named Landsat-1. Since then, several studies on glacier mapping have used data from a steadily improving series of satellites launched by the different world's space agencies (Bajracharya *et al*., 2014). ICIMOD undertook the first ever attempt to carry out systematic study of glaciers and glacial lakes throughout Nepal in 2001 and the study provide baseline information (Bajracharya *et al*., 2007). A new inventory of glacial lakes was published by ICIMOD in 2011 based on an analysis of Landsat satellite images from 2005/6 by which 1,466 lakes were identified with a total area of 65 km^2 (ICIMOD, 2011).

2.3 Soil development and its physico-chemical properties along glacier foreland

Burga *et al*. (2010) reported that soil grain decreased with along the temporal gradient as a result of weathering, but there was negligible signs of chemical weathering and alteration products in the youngest soils near the Morteratsch glacier foreland, Switzerland. Soils in the glacier foreland are weakly developed, but development of soil increased with distance from the glacier terminus (Burga *et al*. 2010; Baniya *et al*. 2012; Gurung 2012).

Schulz *et al*. (2013) and Whelan (2013) explained that the soil nearby the glacier terminus is deprived of vegetation at all and comprised of well heterogeneous and distinct morphophytes such as moraines, rock fields, flood plains, sand hills, erosion channels and mud slides thereby serving as parent materials. In the earliest stages of deglaciation, the soil profile shows irregular variation with depth as the soils are merely disorganized accumulations of morainic debris but with the deposition of more and more debris and microbial activities with time, climate and vegetation begin to modify the soils giving the special characteristics for colonization (Crocker *et.al*, 2013; Vilmundardottir *et al*., 2015).

The youngest soil profile shows the irregular variation with depth as the soil materials are merely disorganized and undifferentiated accumulation of moraines and debris ((Hodkinson *et al*., 2003). Studies on soil properties carried out by He and Tang (2008) along Hailuogou glacier found that bulk density (BD) generally decrease with the timespan. This trend is due to increase in rate of biological weathering and leaching of organic acids by decayed plant detritus.

Soil pH is negatively correlated with increase in distance from glacier foreland (Jones and del Moral, 2005; Baniya *et al.*, 2012), but positively correlated to soil depth (Gurung, 2012). Matthews (1992) also explained that a decline in soil pH with increasing distance from glacier terminus is a universal characteristic of glacier foreland chronosequence. Soil pH in the Ngozumpa glacier foreland ranged from 6.0 to 8.1 which was less acidic than in the soil of outline valley ranging 4.5 to 5.6 (Gurung, 2012). Further, soil pH also increased with depth within the profile (He and Tang, 2008).

The soil organic carbon (SOC) or nutrient contents also increased with increase in soil developments (Jones and del Moral, 2005; Bardgett *et al*., 2007; Gurung 2012). Little carbon present in recently exposed glacial substrates supported a functioning microbial community, but the young site was greatly abundant by the bacteria than the fungi (Bardgett *et al*., 2007). Gurung (2012) reported that the mean SOC and mean total nitrogen concentrations ranged from 7.9 to 38.0 g/kg of soil and 3.4 to 23.9 g/ kg of soil respectively in the 0-10cm soil depth. Vilmundadottir *et al*. (2014) explained that the concentration of SOC and Total nitrogen (TN) increased with soil age. With time, biological activities, climate and vegetation modify the soils giving the special characteristics for biological colonization (Vilmundardottir *et al.*, 2015).

Despite of abundant literature, the research and studies regarding the biological succession, soil formation along the glacier foreland and alpine ecosystem is still lacking. This research is expected to fulfill the research gaps in the Bhimthang region of Manang, Nepal regarding the study of soil properties along the glacier foreland of that area.

3. MATERIALS AND METHODS

3.1 Study area

3.1.1 Geography

The study site, Bhimthang is located in lower valley of Manang district, Central Nepal with the co-ordinate ranging between 28º 27' to 28º 46.35' N latitude and 84º 10.44' to 84º 30' E longitude (Figure 1)

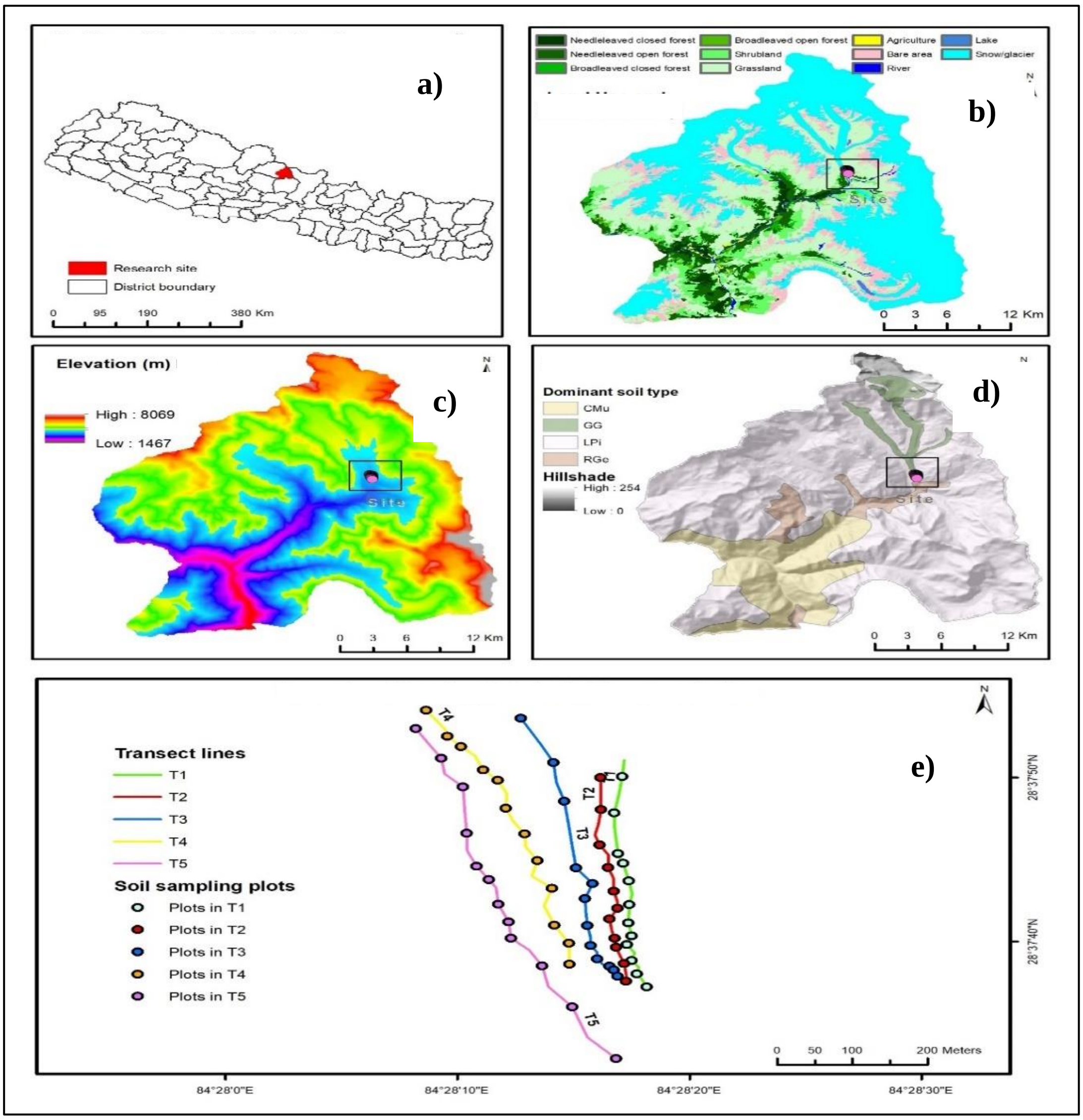


Figure 1: Map of the study area (Bhimthang) (a) Location of Manang district in map of Nepal (b) Land use and land cover of Manang district (c) Elevation map of Manang district (d) Soil types and (e) Study area with distribution of sample plots.

The area is characterized by the high altitude, cold climate, and semi-desert environment with snow fall in winter. Moisture decreases from east to west in the Manang valley, and the south-facing slopes are significantly drier and warmer than those facing north. Thus, dense vegetation can be seen in the North slopes in which soil moisture is maintained by the snow melt (Figure 2)

Figure 2(a): Photograph of study area showing temporary settlement in Bhimthang, Manang.

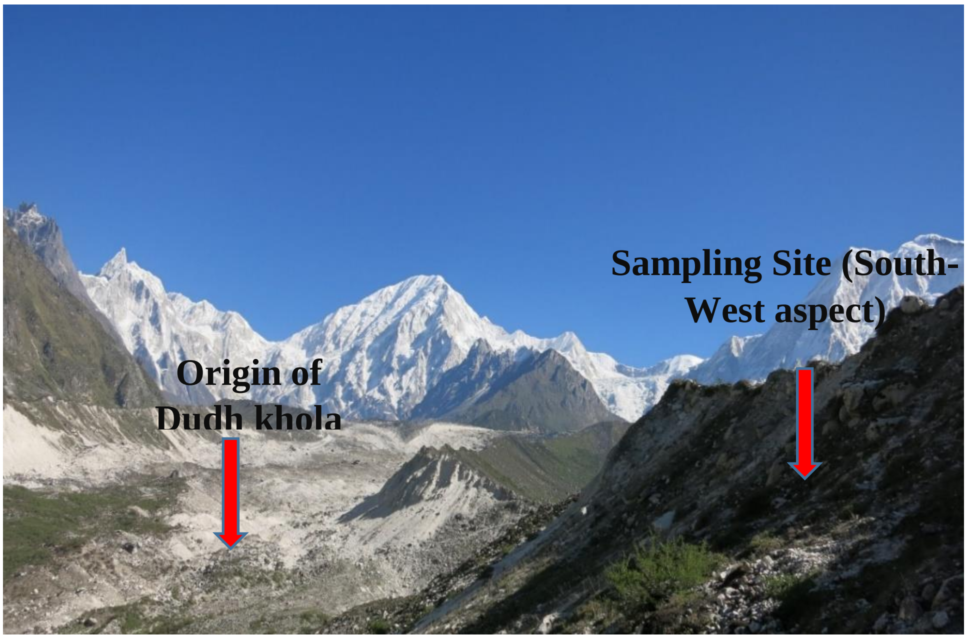


Figure 2(b): Lateral moraine of Bhimthang glacier

3.1.2 Climate

The thirty years of climatic data (temperature and precipitation) were taken from Department of Hydrology and Meteorology, Government of Nepal, Jomsom, the nearby meteorological reference point. As per the Climatic data from 1987-2018 A.D, the average temperature ranged between -0.78 to13.39°C during winter and 12.13 to 24.41°C in summer **(**Figure 3). The mean annual rainfall in the study area was 972.08 mm with the highest monthly rainfall in July (1622.4 mm) and the lowest in November (138.5 mm). The dry month in the study area falls between November to February although the occasional rainfall occurs throughout the year. The study site has typically sub-alpine type of climate and snow fall occurs in most periods throughout the year.

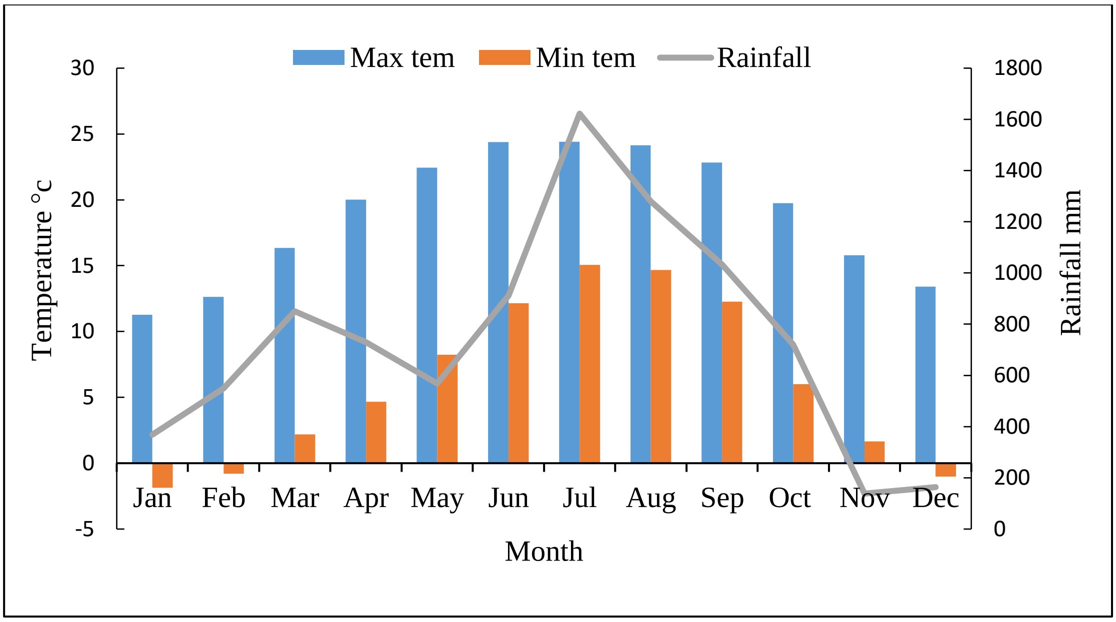


Figure 3: Ombrothermic graph representing the monthly mean maximum and minimum temperature and precipitation trend of Bhimthang, Manang district, Jomsom as meteorological reference point (as per the climatic data of 1987- 2018) (Data Source: Department of Hydrology and Meteorology, Government of Nepal).

In Manang, the humid monsoonal air passes from the south east is shielded by the mountain ranges of Annapurna (>7500 m asl), Lamjung (6932 m asl) and Manaslu (8163 m asl) etc. So the effect of monsoon is greatly reduced (Pohle, 1990). Monsoon enters from south-east, resulting a decreasing moisture from east to west in Manang valley, thus, the south-facing slopes are significantly drier and warmer than those facing north (Baniya *et al*., 2009).

3.1.3 Phytogeography and vegetation

The study site, Bhimthang is situated in lower part of Manang district. The geographical region here is characterized by the arid zone northward of the massif Himalayas, thus the vegetation of the study area is quite similar to that of Tibetan Plateau (Chaudhary, 1998). Bhimthang is a part of Gyasumdo valley, which is glacially formed, U-shaped valley traversed by the Dudh khola and surrounded by high mountains. It is located in north-eastern part of Gyasumdo valley in Manang district between the boundary of Annapurna Conservation Area (ACA), Nepal and Manaslu Conservation Area (MCA), Nepal.

Bhimthang Valley comprises two major succession namely Higher Himalayan rocks and Tibetan Tethys rocks. Higher Himalayan Granite covers most part of the study area as bedrocks of surrounding hills whereas the north east peaks shows bands of sedimentary succession of Tibetan Tethys rocks. Soil is composed of sand, boulders, clays, moraines, lime, etc. which are formed by a long time of deglaciation followed by weathering and pedogenesis process. The dominated soil types are *CMu:-Humic Cambisols, GG:-Glacier Dominant soils, LPi:-Gelic Leptosols, RGe:-Eutric Regosols* as explained in dominant soil type map in the study area (Figure 1 d).

The dominant tree species around the studied area were *Abies spectabilis, Taxus wallichiana, Tsuga dumosa* and *Pinus wallichiana* with scattered trees of *Betula utilis* and *Acer pectinatum* with some patches of Rhododendron forests under open canopy. The dominant shrubby vegetation patches of *Rhododendron lepidotum, Cotoneaster microphyllus, Lonicera spinosa, Salix lindleyana, Gaultheria tricophylla and Potentilla fruticosa* etc were found towards southern slopes whereas towards the northern slopes, the vegetation consists of shrubby bushes of *Rhododendron anthopogon, Salix calyculata, S. lindleyana* and *Rheum australis*. The alpine meadows, mainly on exposed slopes are dominated by *Potentilla spp, Aster spp, Erigeron multiradiatus, Taraxacum eriopodum, Dactylorhiza hatagirea, Primula capitate, Bistorta vivipara, Selinum wallichianum, Anaphalis royleana, Gentiana depressa, Kobresia pygmaea, Saxifraga parnassifolia,* and *Pedicularis spp.*

3.1.4 Socio-economy and culture

According to the population census from Central Bureau of statistics (CBS, 2012), Manang is one of the districts with the least population, i.e. 6538 and 1480 households and population density of 3 individual/km^2. Majority of the inhabitants are Gurung, however, people of Tibetan ethnic origin have also been residing in this valley since a long period of time. They are called "Gyasumdopas" or "Lamas" in their local language, as their lifestyle, food habit, custom and culture resemble to those of Tibetans Lamas (Shrestha *et al*. 1995). Majority of them practice Buddhist culture and speak Tibeto-Burman language.

Tourism industry and hotel business, porter, traditional agriculture, animal husbandry, trade of wild vegetables and medicinal herbs were major income source of the local people. The highest temporary settlement exists at Bhimthang (3700 m asl.) where almost all the people are involved in hotel business. Glaciers are very close to the village.

3.2 Data source and Data collection Method

3.2.1 Field sampling

The actual sampling location, lies adjacent to the Bhimthang glacier, which is formed by the union of three glaciers; Ponker glacier, Salpudada glacier and Kechakyu Khola glacier. The sampling site incorporates lower moraine part of Bhimthang glacier.

The foreland on the either side of Dudh khola represents a spatio-temporal gradient. The terminal moraine of the foreland is represented by origin of Dudh Khola River. The exact age of the foreland is not known as there is paucity of well documented information on the history of glacier advance and retreat. The sampling site was selected in south-west aspect of lateral moraine of glacier and was dominantly colonized by shrubs. Five transects, each representing a particular geological time period and stage of soil development were laid on the south-west aspect of the foreland. The perpendicular distance between two transects was 50 m each. Along each transect, a total of 12 plots of 2 m × 2 m each were laid down at an interval of 30 m, so altogether 60 plots were laid in the study site. Each main plot of 2 m × 2 m were then divided into 4 sub-plots of 1 m × 1 m from center of main plot so as to collect soil samples of glacier foreland (**Photo Template 1**). The coordinates, slope, aspects and attitude of transects and plots in study area are (Figure 4) given in Appendix 1.

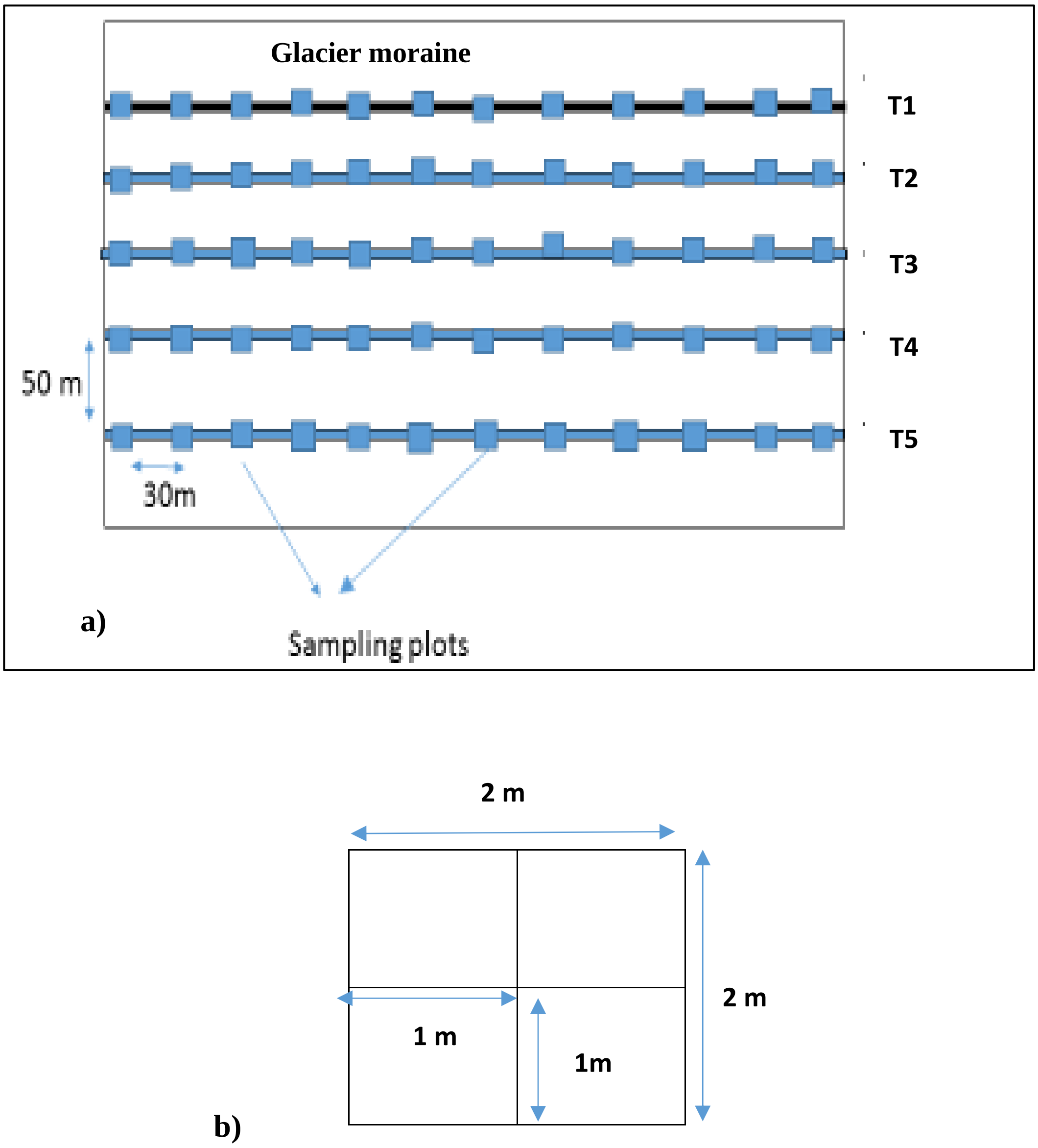


Figure 4: (a) Modified schematic study design showing plot and (b) sub plots in 2 m × 2 m for soil sampling along transect in the study area.

Transect 5, farther from present glacier terminus was considered as the early developed soil or mature and complex stage soil than other transects 4, 3, 2 and 1 which were more progressively nearer to the glacier terminus in chronosequence order.

Geographical location (latitude, longitude and elevation) of each plot (2 m × 2 m) was recorded using Global Positioning System (GPS- *Garmin etrex*) from the center of the plot. Slope and aspect were measured by Clinometer (*Silva 360°*). Ground Vegetation cover for each plot was estimated by visual estimation method from center of each plot.

3.2.2 Soil sample collection

From each plot, 200 g soil samples were collected from various depth (0-10, 10-20 and 10-30 cm) from the center of the plot and were homogenously mixed. To core soil, a digger and soil borer of radius (r) = 20 mm was used and was penetrated to different soil depth as required using hand pressure (Gupta, 2002). A line was marked at different depths of soil taken and was scaled. Then, this length of line in borer was equivalent to soil depth.

The soil samples were air dried in shade for a couple of week, then passed through a sieve wire of 2 mm. These sieved soil through 2mm sieve were again sieved through 0.5 mm mesh for the analysis of soil physico-chemical properties and packed in air tight plastic bags until laboratory analysis.

3.3 Laboratory Analysis

The soil physico-chemical parameters (Soil organic carbon, pH, nitrogen, phosphorous and potassium) were examined during August-6 to September-3, 2019 at soil laboratory of Central Department of botany, T.U (**Photo Template 2**). The laboratory procedure was followed according to Gupta (2002).

3.3.1 Determination of soil pH

Soil pH was determined by using electric pH meter (model-HM-1003). 10 g of soil sample was taken in a beaker and soil solution was prepared by adding 10 ml distilled water to maintain ratio of 1:1. pH meter was allowed to warm for 15 minutes and was calibrated to buffer solution of pH 7.0, 4.0 and 9.2 simultaneously. Then, electrode was immersed in the test-tube containing soil solution and pH meter reading was noted.

3.3.2 Determination of Bulk density

To estimate soil Bulk density, the laboratory procedure by Gupta (2002) was followed. In this method crucible, after weighing was filled with air dried soil samples, flushed up to brim tapping the crucible about 20 times. Then crucible with soil was again weighted. Weight of soil was calculated by subtracting weight of crucible from weight of crucible with soil. Then, soil was removed and the crucible was filled with water using burette. The volume of soil/ the exact volume required to fill the crucible was noted. After that, the bulk density was determined by dividing weight of the soil with volume of the soil.

3.3.3 Determination of soil organic carbon (SOC)

Soil organic carbon was determined by using Walkley-Black Method by Gupta (2002). In this method, 1.0 g air dried soil was taken in a dry conical flask (500 ml). Then 10 ml 1N potassium dichromate ($K_2Cr_2O_7$) was pipetted in and swirled a little. To the mixture 20 ml of concentrated sulphuric acid (Conc. H_2SO4) was added and again swirled a little. The flask was allowed to cool down for 30 minutes and then 200 ml distilled water was added. After that 10 ml orthophosphoric acid and 1 ml diphenylamine indicator were added successively in the conical flask containing the mixture. Finally, the content was titrated with 0.5N ferrous ammonium sulphate (till the colour changed from blue violet to green). A blank solution was also run simultaneously. Then, SOC was calculated using following formula:

$$\text{Soil Organic Carbon (SOC)} = \frac{\text{N(B} - \text{S)} \times 0.003 \times 100}{\text{Mass of dry soil (gm)}}$$

Where, N = Normality of ferrous ammonium sulphate (0.5N).

B = Volume of ferrous ammonium sulphate for blank titration (ml).

S = Volume of ferrous ammonium sulphate for sample titration i.e. soil (ml).

3.3.4 Determination of Total Nitrogen (N)

The soil nitrogen was determined by Micro-Kjeldahl method by Gupta (2002). This method includes the following steps: Digestion, Distillation and Titration.

Digestion: 1.0 g air dried and sieved soil (0.5 mm sieve) was taken in a dry Kjeldahl digestion flask (300 ml). Then 3.5 g potassium sulphate (K_2SO4) and 0.4 g copper sulphate ($CuSO_4.5H_2O$) i.e. catalyst were added to the Kjeldahl flask containing soil. After it, 10 ml conc. sulphuric acid (H_2SO_4) was added to the same flask and mixed with 63 swirling. Then the flask was placed on a pre-heated (30°C) heating mantle for digestion. The temperature was raised to about 300°C (30 min heating). Near the end of digestion process, the color of sample changed from black to brownish and at the end it becomes greenish (turquoise) (45 minutes). Then the flask was removed immediately from the mantle and allowed to cool for 5 min. 50 ml distilled water was added to the digest and the mixture was shaken. A blank without soil was prepared as a reference solution.

Distillation: The diluted digest was transferred to Kjeldahl distillation flask. A beaker (100 ml) with 10 ml boric acid indicator was placed below the nozzle of the condenser in such a way that the end of nozzle dipped into the indicator. After the digest becomes warm, 30 ml 40% NaOH was added. The distillate began to condense and the color of boric acid changed from pink to green. The distillation was continued until the volume of distillate in the beaker reached to about 50 ml.

Titration: The distillate was titrated with 0.1N HCl and the volume of HCl consumed was noted. The volume of acid consumed by blank was also recorded and the total nitrogen content (%) was calculated by using following formula:

$$\text{Soil Total Nitrogen (\%)} = \frac{(\mathrm{T} - \mathrm{B}) \times \mathrm{N} \times 1.401}{\text{weight of soil taken (gm)}}$$

Where, T = Volume of HCl consumed with sample (ml)

B = Volume of HCl consumed with blank (ml)

N = Normality of HCl

In this study TN was understood as Nitrogen (N)

3.3.5 Determination of Soil Available Potassium (K)

The available potassium was determined by flame photometer method. It involves the following process: Ammonium acetate extract of soil and determination of potassium by flame photometer using K filter.

Ammonium acetate extract of soil: It was obtained by shaking followed by filtration. In this method, 2.0 g air dried soil was placed in a 150 ml Erlenmeyer flask and poured 18 ml (1:9 soil to extract) of neutral normal ammonium acetate (1N CH_3COOHN_4) so that volume of solution becomes 20 ml. Then it was shaken for 5 min and immediately filtered through Whatman No. 1 filter paper and collected the filtrate.

Determination of K by flame photometer: K filter was set, started the compressor and lighted the burner of flame photometer. Air pressure was kept at 5 lbs. and adjusted the gas feeder so as to have a blue sharp flame comes. Adjusted the zero reading on the scale by feeding extract solution (CH_3COOHN_4) in the flame photometer. Then, feeded standard KCl solution of the highest value in the standard series (25 ppm K) and adjusted the flame photometer to read full scale i.e. 100 reading. After that, reading was taken for each standard solution (0, 5, 10, 15, 20 and 25 ppm K) which were used for plotting standard curve. Then, extract of sample (filtrate) was feeded in the flame photometer and noted the reading. Similarly, blank reading was also noted and corrected reading was calculated by subtracting blank reading from sample reading. Now, standard curve was plotted between concentration on x-axis and flame photometer readings on y-axis of standard K solution and determined the K content in the sample with the help of standard curve.

$$\text{Soil available potassium (kg/ha)} = \frac{\mathrm{C} \times \mathrm{E}}{\text{weight of soil taken (gm)} \times 2.24}$$

Where, C = ppm of K (obtained from standard curve).

E = Volume of extractant added i.e. CH_3COOHN_4 (ml).

Available potassium was simply defined and taken as potassium (K) by this study.

3.3.6 Determination of Soil Available Phosphorus (P)

Available phosphorus in soil was determined by Olsen's method. In this method, 2.0 g air dried soil sample was taken in a 125 ml Erlenmeyer flask and added a 1.0 g charcoal in it. After it, 40 ml sodium bicarbonate ($NaHCO_3$) solution was added and shaken for 30 min on a reciprocating shaker at 120 strokes per minute. Extract was filtered using Whatman No. 40 filter paper. Pipetted 10 ml aliquot of the extract (filtrate) in a 50 ml volumetric flask and added 10 ml distilled water and one drop of p-nitrophenol indicator. Now content was acidified to pH 5.0 by adding 2.5 M sulphuric acid (H_2SO_4) drop-wise till the colour disappeared. Now added 8.0 ml of Murphy-Riley solution and made the final volume to 50 ml by adding distilled water. After 15 min, intensity of blue color (absorbance) was read on spectrophotometer at 730 nm.

$$\text{Phophorus(kg/ha)} = \mathrm{C} \times \frac{\mathrm{E}}{\mathrm{A}} \times \frac{2.24}{\text{Mass of soil (gm)}}$$

Where, C = μg P in the aliquot [obtained from standard curve plotted between absorbance values and the concentration of P in standards (0, 0.1, 0.2, 0.3, 0.4 and 0.5 μg P/ml or ppm of P)].

E = Volume of extractant added i.e. $NaHCO_3$ (ml).

A = Volume of a liquor of extract (ml).

The laboratory Procedure for reagent preparation for each soil parameter test were presented in Appendix 5.

3.5 Calculation of Relative Radiation Index

Relative radiation index (RRI), which is the relative measure of the substrate's annual exposure to the radiation (the value ranges from -1 to +1) was calculated from the values of aspect (Ω), slope (β) and latitude (Φ).

RRI was calculated using the following formula given by Oke (1987).

$$RRI = \cos(180 - \Omega) \times \sin\beta \times \sin\Phi + \cos\beta \times \cos\Phi$$

3.6 Retreating status of Bhimthang Glacier

The retreating status of the Bhimthang glacier was determined after analyzing the satellite images taken from the same area but different periods and same date. For this study free Landsat and sentinel imagery data (Table1) were downloaded for the periods of 1984 to 2018 A.D. from the United States Geological Survey Department's (USGS) collection. For the period of 2018, Sentinel data for time period 2008/10/28 was chosen to achieve higher resolution. i.e. 10 m.

Table 1: Information of Landsat and Sentinel Imagery data

Satellite	Time zone	Sensor	Total bands	Sun elevation	Path/Row	Spatial resolution(m)
Landsat 5 (1984)	1988/10/19	TM	7	43.69	142/ 40	30
Landsat 7 (1999)	1999/10/10	ETM+	8	49.29	142/ 40	30
Landsat 5 (2008)	2008/10/28	TM	7	46.08	142/40	30

Steps during glacier area extraction.

The glacier area was extracted through Landsat images and sentinel data.

The images were proceeded through Iso cluster Unsupervised classification. Several classes were generated. Then, reclassification was done from which all classes were merged remaining glacier behind. After reclassification of data, the data for the period 2018 was converted from raster to polygon where various polygons resembling glacier area were merged into a single polygon. Through digitization of raster image and merging of polygons, the area of glacier for period 2018 was delineated.

Similarly, Land sat 5 TM was used with false band in order to digitize glacier area. The composite band for Manang district was generated with false bands in order to make clear vision of glacier. The glacier area of 2018 was also taken into consideration. After Iso-cluster unsupervised classification, the glacier area was digitized taking glacier area of 2018 into consideration. For this analysis QGIS was used to finalize the glacier area. Tools like Erase, Identify, Intersect and Union were used to delineate the final area of glacier 1988. The same method was followed for the period of 1999 and 2008.

3.7 Statistical Analysis

A total of 12 variables were analyzed in this research *viz*. altitude, soil depth, soil pH, soil organic carbon, Nitrogen, Phosphorus, Potassium bulk density, vegetation cover, rock cover, open space and Relative Radiation Index. Descriptive statistics was applied to generate mean, range and standard error. Description of each variable was done to discern where significant relationships existed and their strength using R software version 3.5.0 (R Development Core team, 2018). Dependent variables were tested against distance away from glacier terminus (chronosequence) which was represented by 5 transects. All tests were run at 95% confidence level. Correlation coefficient (r^2) was calculated and used to determine the correlation between different variables. Tukey test was used to determine the significant variation of soil physico-chemical properties among transects.

Principal component analysis (PCA) ordination was used to summarize the soil physico-chemical properties by using the *Factoextra* package in R version 1.0.5 (Kassambara and Mundt, 2017). *Factoextra* is an R package making easy to *extract* and *visualize* the output of exploratory multivariate data analyses and produces GGplot2-based elegant data visualization with less typing. Principal Component Analysis (PCA), which was suitable statistical design adopted as it summarizes the information contained in a continuous (i.e., quantitative) multivariate data by reducing the dimensionality of the data without losing important information. Similarly, *Corrplot* package was used to show correlation among different dependent variables such as soil physico-chemical parameters (Relative Radiation Index) RRI, transects and vegetation cover, rock cover and open space. *Corrplot* is a plotting package that makes it simple to create complex plots from data in a data frame. It provides a more programmatic interface for specifying what variables to plot, how they are displayed, and general visual properties.

4. RESULT

4.1 Summary of variable used (Descriptive statistics)

Descriptive of summary of each variable with abbreviation used, nature of data (either qualitative or quantitative), unit of measurement, standard deviation (S.D.) and standard error (S.E.) is tabulated in Table 2

Table 2: Summary of variables used

S.N.	Variables	Abbreviation	Nature	Unit of measurement	Minimum	Mean	Maximum	Standard Deviation (S.D)	Standard Error (S.E)
1	Altitude	Alti	Quantitative	Meter	3613	3676	3754	-	-
2	Soil depth	Soildp	Quantitative	centimeter	5	6.75	30	6.3	0.8
3	pH	pH	Quantitative	pH	4.6	6.5	8.7	0.6	0.07
4	Soil Organic Carbon	SOC	Quantitative	%	0.729	0.85	1.18	0.09	0.012
5	Nitrogen	N	Quantitative	kg/ha	0.3	5.5	133.1	17	2.2
6	Phosphorus	P	Quantitative	kg/ha	4.4	27.6	241.49	35.1	4.53
7	Potassium	K	Quantitative	kg/ha	76.8	229.8	1293.6	215.8	27.9
8	Bulk density	Buld	Quantitative	%	0.53	1.5	1.8	0.25	27.9
9	Veg_Cov(%)	Vegcov	Quantitative	%	1	39.2	100	27.7	3.57
10	Rock cover(%)	Rockov	Quantitative	%	0	24.7	85	22.6	2.9
11	Open space(%)	Opensp	Quantitative	%	0	34.7	90	29.5	3.8

4.2 Ordination of dataset: (Principal component Analysis) PCA

The first axis of PCA diagram (Dim1) explained 32.7 % of the total variance in the environmental dataset. Similarly, Dim2 explained 14.2 % of the total variance in the environmental dataset (Figure 5).

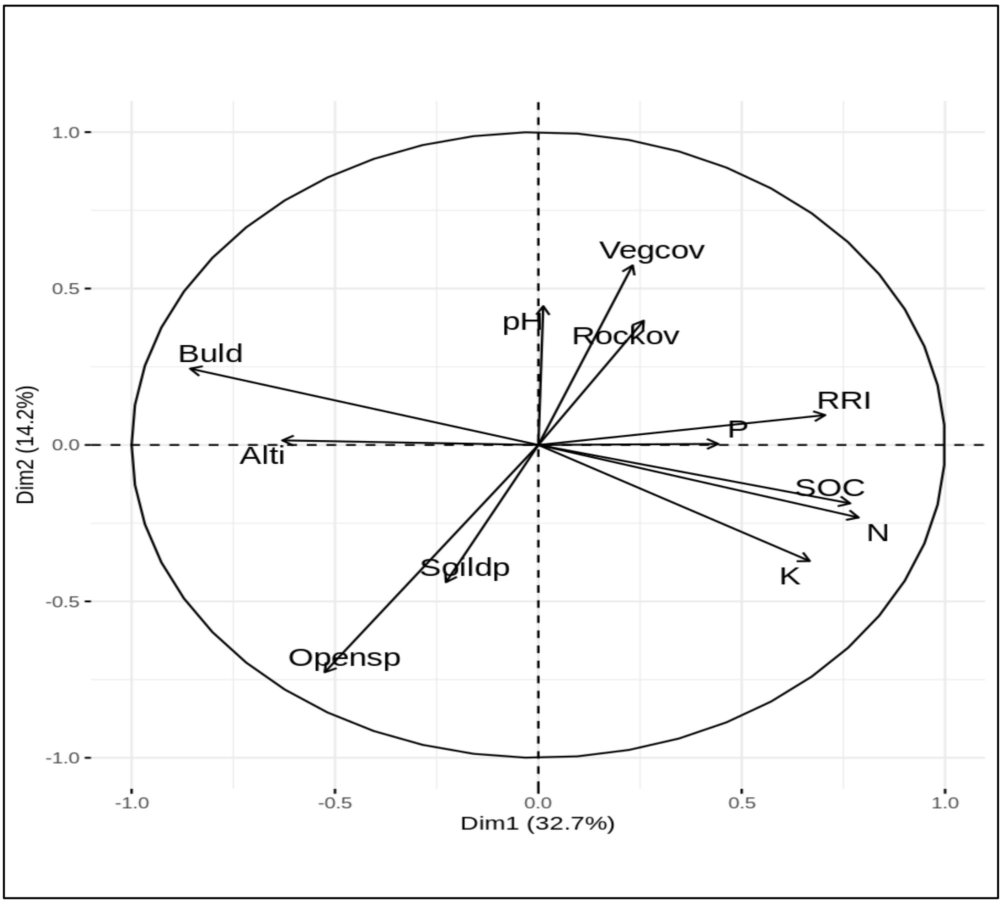


Figure 5: Principle Component Analysis (PCA) of samples by environment dataset from Bhimthang Glacier.

The PCA diagram explained how these environmental variables show affinity among each other. All the soil nutrients, i.e. Nitrogen (N), Phosphorus (P), Potassium (K) and Soil Organic Carbon (SOC) were significantly correlated with each other so there were strong but negative relationship among bulk density (Buld) of soil and altitude (Alti). Similarly, it was found that soil pH (pH), vegetation cover (Vegcov) and rock cover (Rockov) has strong affinity among themselves but negatively correlated with soil depth (Soildp) and open space (Opensp). Relative radiation index (RRI) shows strong and positive affinity with all the soil nutrients i.e. N, P, K and SOC (Figure 5).

4.3 Correlation among soil physico-chemical parameters and other environmental variables

The correlation coefficient among different soil physico-chemical parameters and environmental variables were shown in the following table 3. The color scale on the right explained the strength of each correlation coefficient value between two variables in the matrix in row and column (Table 3).

Table 3: Correlation coefficients matrix among variables studied along Bhimthang glacier foreland. The colour scale in the right explained the strength of each correlation coefficient value.

	Opensp	Alti	Buld	pH	Rockov	Vegcov	P	RRI	K	SOC	N
Soildp	0.22	0.16	0.17	-0.34	-0.25	-0.02	-0.1	-0.02	-0.12	-0.01	-0.11
Opensp		0.23	0.23	-0.06	-0.45	-0.68	-0.14	-0.41	-0.1	-0.27	-0.31
Alti			0.41	-0.05	-0.03	-0.14	-0.3	-0.44	-0.38	-0.38	-0.37
Buld				-0.03	-0.12	-0.04	-0.32	-0.51	-0.65	-0.72	-0.7
pH					0.1	0.05	0.02	0	-0.04	-0.07	-0.12
Rockov						-0.27	0.13	0.27	-0.03	0.13	0.1
Vegcov							0.02	0.18	-0.05	0.15	0.06
P								0.28	0.16	0.28	0.22
RRI									0.4	0.39	0.42
K										0.41	0.54
SOC											0.64

The soil depth showed significant negative correlation with soil pH (r^2= -0.34) The Open space showed strong significant negative correlation with vegetation cover (r^2= -0.68).

Soil pH showed no significant correlation with all soil physico-chemical properties. Soil bulk density showed moderately significant positive correlation with altitude (r^2= 0.41) whereas showed strong negative correlation with N (r^2= -0.7), RRI (r^2= -0.5), SOC (r^2= -0.72) and K (r^2= -0.65).

Rock cover didn't explain significant correlation with other variables except with RRI and vegetation cover. Rock cover showed positive significant correlation (r^2= 0.27) with RRI and negative significant correlation with vegetation cover (r^2= -0.27).

Significant correlation with open space (r^2= -0.68). RRI showed positive significant correlation with N (r^2= 0.42) and K (r^2= 0.4) and negatively correlated with bulk density (r^2= -0.51), altitude (r^2= -0.44) and open space (r^2= -0.41).

The tested soil nutrients, N, P, K showed significant positive correlation with SOC i.e. for K (r^2= 0.69), N (r^2= 0.34) and P (r^2= 0.47)

4.4 Variation of soil physico-chemical parameters along transects (spatio-temporal gradient)

Variation among soil physico-chemical properties with respect to each of the transect parallel with each other tested by an application of Tukey test were given as followed. The detail analysis of each parameter is given in Appendix 3.

4.4.1 Soil pH

The soil pH show significant difference among different transects studied in the whole foreland.(Figure 6, Appendix 4). There is increase in value of soil pH from transect 1 to transect 5 i.e soil nearer to glacier moraine is acidic and on moving away from glacier the basicity of soil increases.

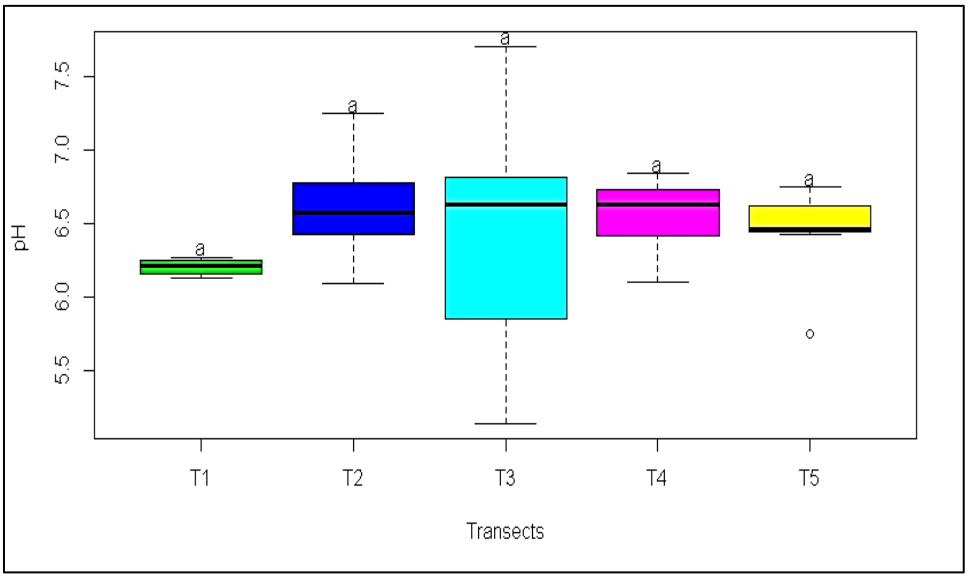


Figure 6: Variation in Soil pH among transects.

4.4.2 Bulk density

The soil bulk density of glacier foreland decreases with increase in distance away from glacier (Figure 7, Appendix 4).

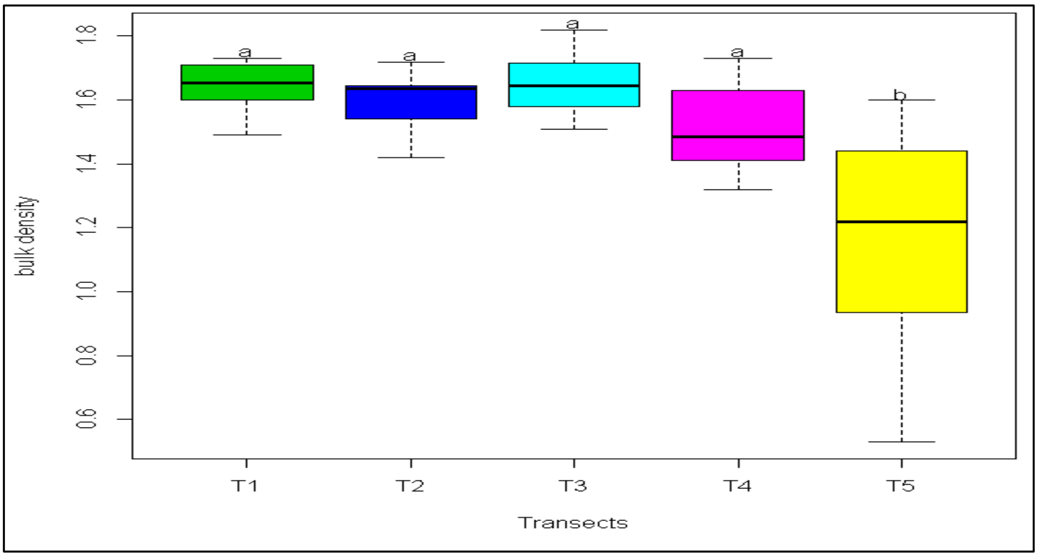


Figure 7: Variation in soil bulk density among transects.

4.4.3 Rock cover

The rock cover percentage was found significantly increasing on moving from transect 1 to transect 5 though the increment was not in linear pattern among transects studied (Figure 8, Appendix 4).

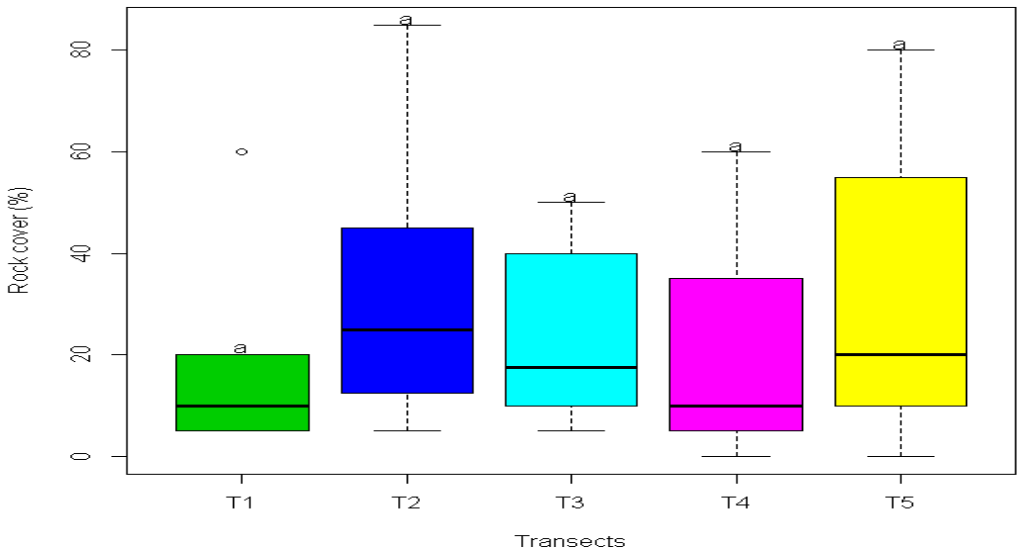


Figure 8: Variation in rock cover among transects.

4.4.4 Vegetation cover

There were significant increase in vegetation cover from transect 1 to transect 5. (Figure 9 appendix 4).

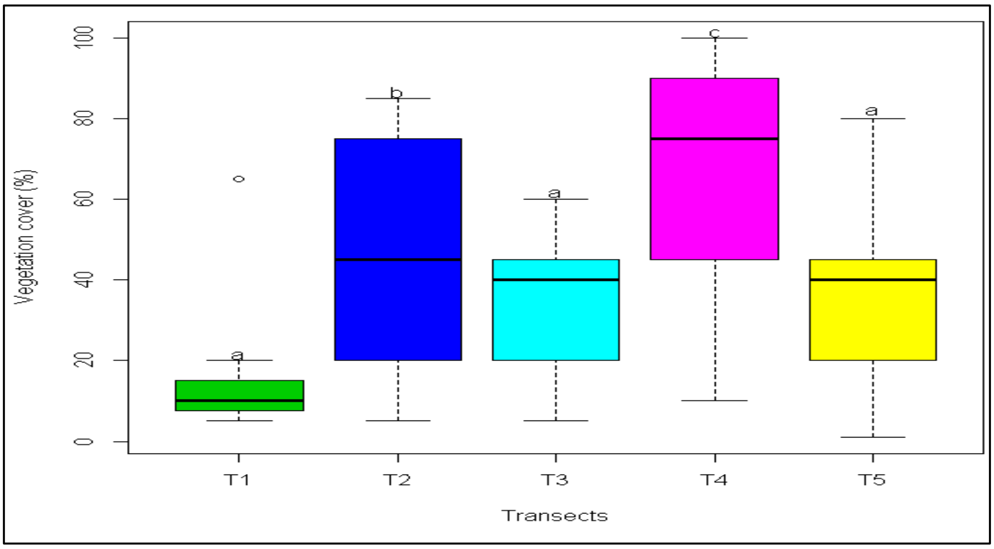


Figure 9: Variation in vegetation cover among transects.

4.4.5 Open space

Open space decreases as distance increased away from glacier moraine i.e. the open space is high in transect 1 in comparison to transect 5 (Figure 10, Appendix 4).

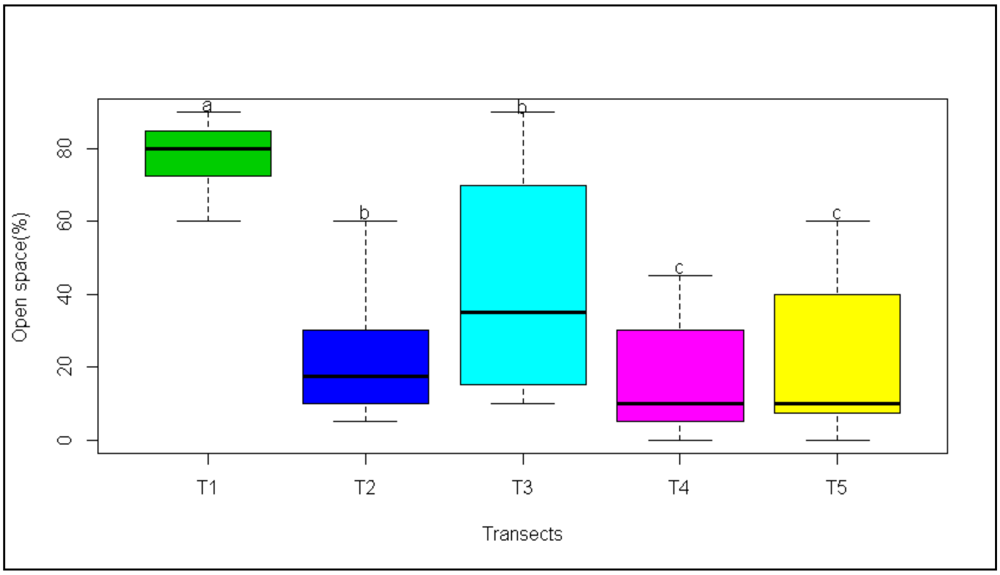


Figure 10: Variation in open space among transects.

4.4.6 Relative Radiation Index (RRI)

There were significant increase in Relative Radiation Index as distance increases away from glacier (Figure 11, Appendix 4).

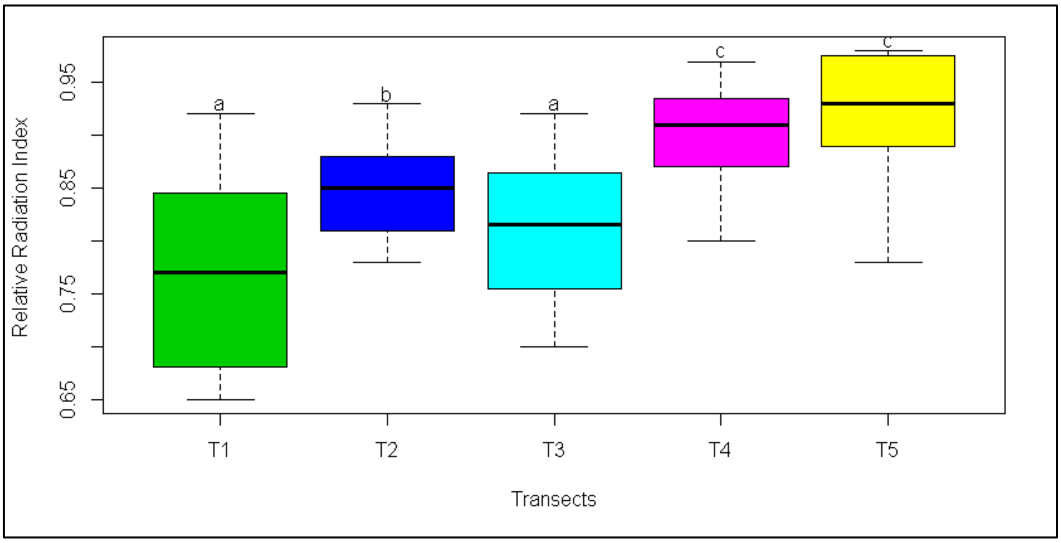


Figure 11: Variation in Relative Radiation Index among transects.

4.4.7 Soil Organic Carbon (SOC)

The soil organic carbon of glacier foreland showed increase with increasing distance from glacier foreland (Figure 11, Appendix 4).

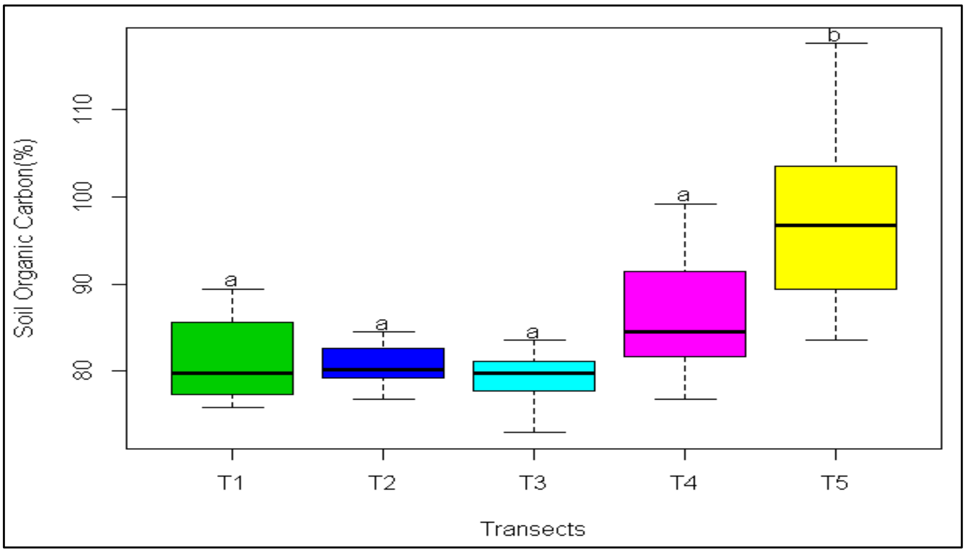


Figure 12: Variation in Soil Organic Carbon among transects.

4.4.8 Available Soil Nitrogen (N)

The soil nitrogen content increases with increased in distance from glacier.(Figure 13, Appendix 4).

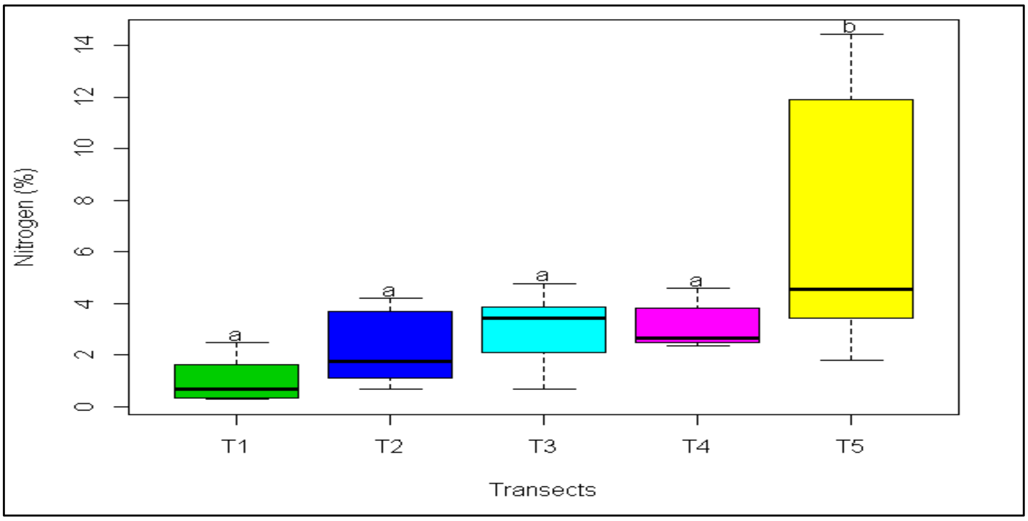


Figure 13: Variation in nitrogen content among transects.

4.4.9 Available soil Phosphorous (P)

The result showed there is increase in value of available soil phosphorus on the transect distance away from glacier, i.e. the available soil phosphorus was comparatively higher in transect 5 than that of transect 1(Figure 14, Appendix 4).

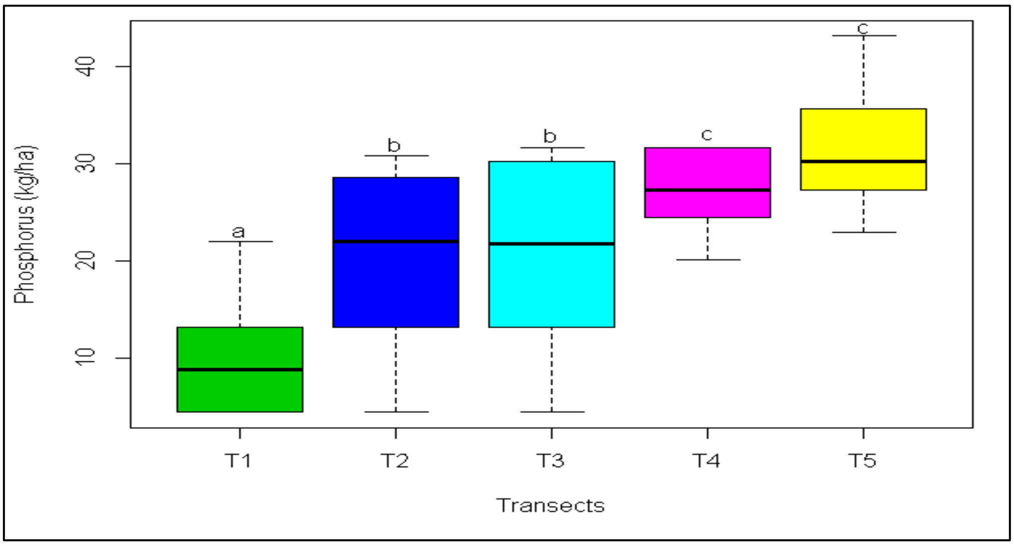


Figure 14: Variation in available Phosphorus among transects.

4.4.10 Soil Potassium

The soil potassium of glacier foreland showed increase in value with increase in distance from glacier (Figure 16, Appendix 4).

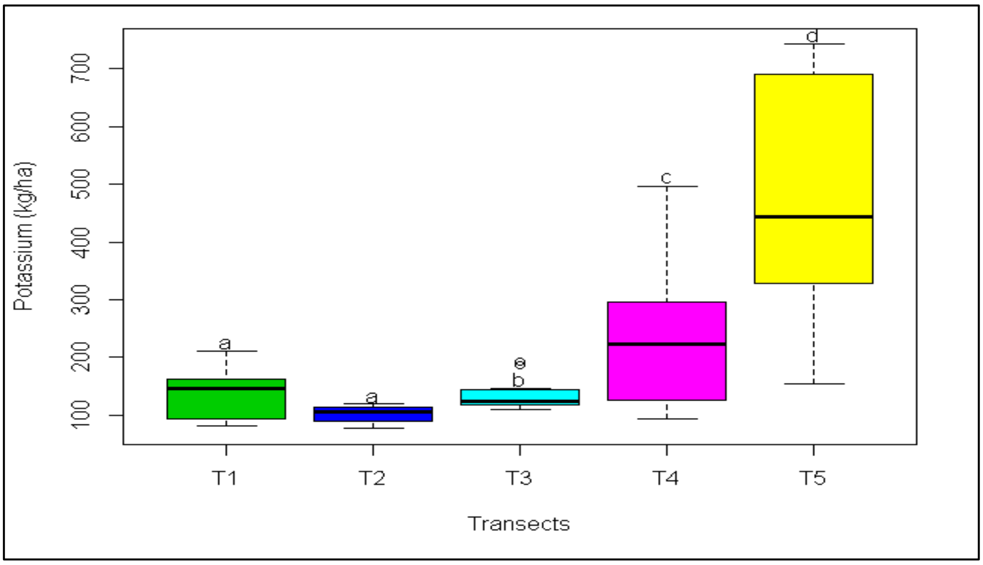


Figure 15: Variation in available Potassium among transects.

4.4.11 Soil depth

The soil depth did not show significant difference with distance away from glacier moraine (Figure 16, Appendix 4).

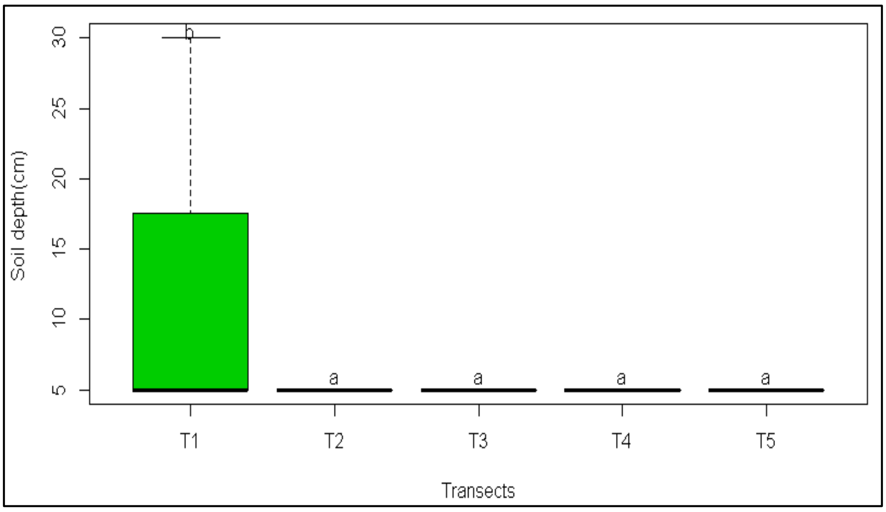


Figure 16: Variation in soil depth among transects.

4.5 Retreating status of Bhimthang glacier from 1984 to 2018

The retreating of glacier was studied through Landsat imagery and sentinel data between the periods of 1988-2018. The area of glacier region in the Bhimthang is continuously decreasing in its volume and area since 1988 to 2018 (Figure 17, 18).

The area of Bhimthang glacier in 1988 was recorded as 1095.47 ha. (Figure 18) In 1999, the glacier area shrinked to 1019.48 ha, so that there was decrease in glaciated terrain by 6.9% (i.e. 75.98 ha.). Between 1999- 2008, the glacier area was found reduced by 64.7 ha. (6.3%) and by 2008 glaciated area in Bhimthang was recorded to be 954.74 ha. By 2018, the total area of glacier region reduced to 848.96, i.e. decrease by 105.77 ha (11.07%) than in 2008. These all data explained that Bhimthang glacier area was found continuously declining with time. There was linear trend in glacier retreating phenomenon since 1988 to 2018 (Figure 18).

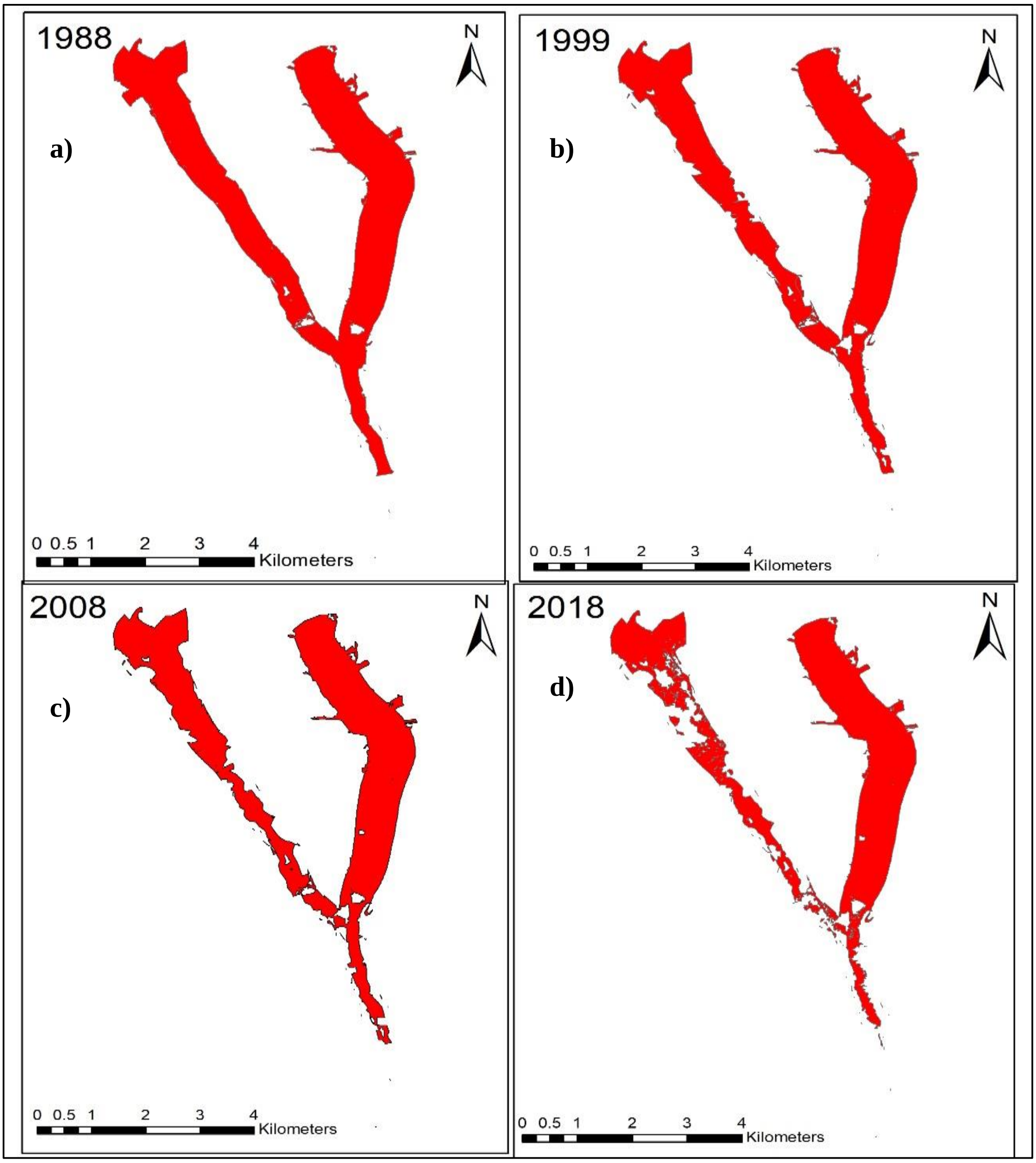


Figure 17: Retreat of Bhimthang glacier; status of glacier a (1988); b (1999); c (2008) and d (2018) (Image source: US Geological Survey Department (USGS) from the period of 1984 – 2018 A.D. (Data downloaded and obtained were Landsat images and Sentinel data. Red solid fill in the picture indicates the glacier area and white patches indicates the deglaciated region on the glacier region.)

Satellite imagery of retreating Bhimthang glacier was studied from 1988 to 2018. The Bhimthang glacier was found shrinking with change in time when observed through

Landsat imagery (Figure 17). This shrinkage was found more drastic in 2018 than 2008 and before (Figure 18).

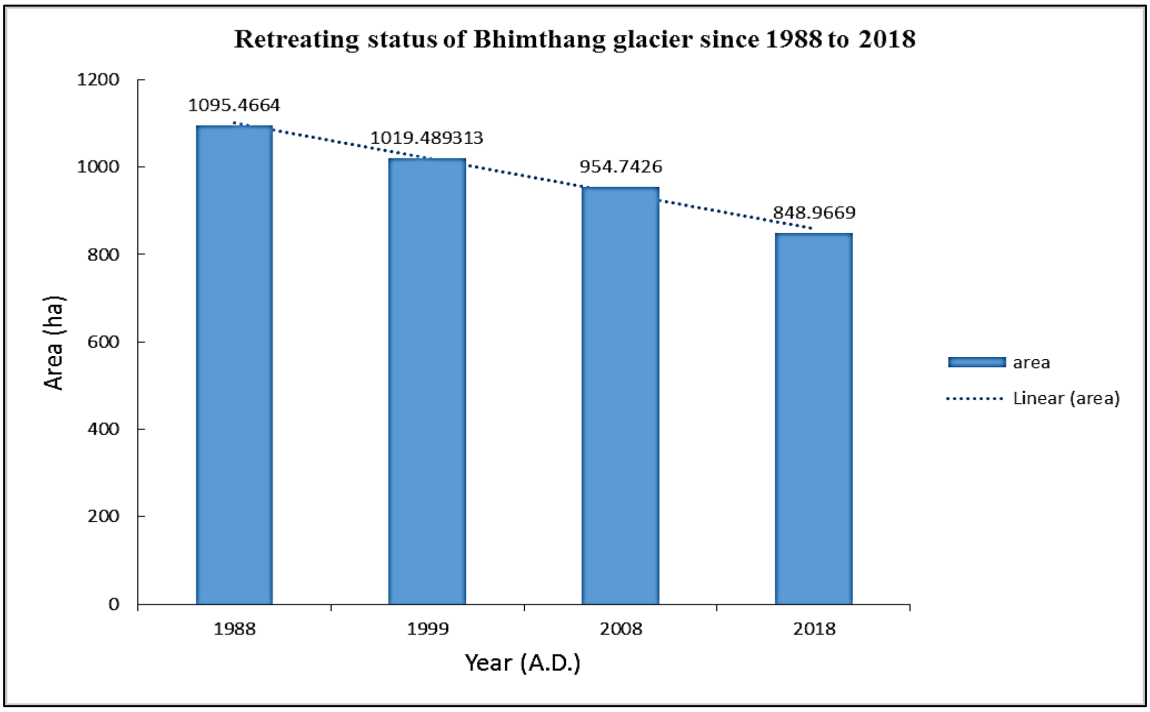


Figure 18: Trend of Bhimthang glacier area from 1988 to 2018.

5. DISCUSSION

5.1 Variation in soil physico-chemical properties by space and time

This present research illustrates that the chronosequence approach to the study of soil development and glacier retreat dynamics of Bhimthang, Manang. There are several researches and scientific studies that had been carried out by different Ecologist regarding the soil development and glacier retreatment dynamics along chronosequence study along with its relation to climate, relief, parent material and vegetation succession in glacier foreland (Matthews, 1992; Egli *et al*., 2001; del Moral and Jones, 2002; He and Tang, 2008; Burga *et al*., 2010; Wietrzyk *et al*., 2013; Vilmundardottir *et al*., 2015). Glacier forelands are characterized by variability and dynamism in their soil physico-chemical properties. The study of soil in recently deglaciated terrain are clearly more complex than has been generally expected in past (Matthews, 1992). There are various expected patterns and hypothesis other than linear relationship of soil properties along spatio- temporal gradient as explained by Matthews (1992). The result of present study give new insights on how soil parameters and their physico- chemical properties showed different patterns along spatio-temporal gradient along glacier foreland which also confirm several expected patterns as explained by different literatures (Matthews, 1992; He and Tang, 2008; Burga *et al*., 2010; Vilmundardottir *et al*., 2015; Wietrzyk *et al*., 2013).

5.1.1 Soil physical properties

The soil physical properties in the glacier moraine soil varied along the spatio-temporal gradient. The soil bulk density showed significant decrease within whole chronosequence from T1 to T5. He and Tang (2008) found that soil BD was not significantly different within whole chronosequence in Hailuogou glacier. Decrease in the soil bulk density with distance away from glacier terminus might be due to accumulation of organic matter. Chapin *et al*. (1994) explained that the bulk density also varied with onset of vegetation establishment. The average soil depth in first transect was comparatively higher than other four transects, away from glacier terminus and didn't explain any significant difference along whole chronosequence. That means the result of this study deviates than that of expected pattern of previous literature. However, the result showed that T1 has comparatively higher value for soil depth and transect away from glacier terminus, i.e. T5 has higher value for BD. This may be explained by compaction of soil due to human disturbances such as trampling, grazing of cattle, etc. and also microhabitat created after falling off stones from T1 to T5 may decrease soil bulk density.

5.1.2 Soil chemical properties

Soil pH in the studied site was slightly acidic to alkaline value ranging from 4.6 to 8.7 with average mean value 6.5±0.1. The value of soil pH tends to increase on moving away from glacier terminus but not linearly significant. Baniya *et al*. (2009) also reported that the average soil pH in abandoned field of Manang was found to be 6.5±0.3 i.e. slightly acidic. They further reported that the significant negative correlation between soil pH and soil moisture. But, this study find significant variation in soil pH among transects though the soil pH varied from slightly acidic to alkaline. Similarly, Gurung (2012) in Ngozumpa glacier foreland of Sagarmatha Eastern Nepal found that the soil pH was between 6.4±0.4 to 6.2±0.6, and pH of the outflow valley area surface soil pH was 4.8. Further, Hodkinson *et al*. (2003) also reported alkaline nature of soil on newly exposed moraine in the north-west Svalbard and Vilmundadottir *et al*. (2015) in front of Breioamerkurjokull Iceland. The variation of soil pH depends on nature of bedrock and degree of plant colonization (King *et al*., 2010). Soil pH is influenced by carbonate concentration of the parent rock which retard acidification resulting the alkaline nature of soil in young moraines (Tcherko, 2003). According to Liu *et al* (2016), the water flowing from melting of snow and glacier is also responsible for alkaline nature of soil in newly deglaciated region. Further, the organic acids secreted from root exudates, rhizo-deposits and decomposition of organic matter are responsible for dissolving carbonate of parent material with time which then result in declining pH with increasing distance (He and Tang, 2008; Liu *et a*l., 2016; Adeleke *et al.*, 2016).

Burga *et al*. (2010) also found similar moderate pH as this study. The result behind this moderate pH might be due to neutralization after glacier retreat, vegetation is rather slow to colonize and weathering.

The increased soil nutrients SOC, N, P and K for the whole glacier foreland increased with increase in distance away from glacier terminus but the increment was not statistically significant when compared among first four transects. This means newly deglaciated soil is poor in nutrient content and carbon accumulation than that of old-aged soil of chronosequence study. This result is also supported by previous findings by He and Tang (2008), Vilmundardottir (2015) and Wietrzyk *et al*. (2013) which stated that the soil nutrients in glacier foreland increase with increase in distance away from glacier terminus during late succession.

The average value of SOC in Bhimthang glacier foreland ranged between 0.729- 1.17 % with mean 0.85±0.01. Similarly, the total nitrogen (TN) content along the chronosequence was found ranged between 0.3- 133.1 kg/ha with average of 5.5±2.2. The result showed there is increase in these nutrient content in those transects away from present glacier terminus. Vilmundardottir *et al.* (2014) also explained that the concentration of SOC and TN increased with increase with soil age. Gurung (2012) found that mean SOC ranged between 7.9 to 38.1 g/kg in 0-10 cm soil depth and 17.4 to 41.6 g/kg in the 10 - 20 cm soil depth in Ngozumpa glacier foreland. He also found that mean TN in these region ranged between 3.4 and 23.9 g/kg in the 0-10 cm depth and 2.8- 13.7 g/kg in the depth of 10 - 20 cm.

The soil organic carbon (SOC) obtained in this region is similar to the concentration found in Skaftafellsjokull island (Vilmundardottir *et al*., 2014) where maximum values of SOC in the oldest moraines reached upto 2.7 %, Damma glacier (Goransson *et al*., 2011) and Ayoloco glacier of Central Mexico (Insam *et al*., 2017) found SOC upto 3.2% in the oldest moraine. TN content found in the study area is similar to the nitrogen found in subalpine forest (3500- 3800 m asl) above the Gangapurna glacier (Ghimire and Lekhak, 2007). Decrease in SOC and TN with age was also found in Werenskoid foreland, Artic foreland (Gorniak *et al*., 2017) where TN decreased by 0.1% in 5 years old moraine to 0.03 % with the soil age.

Soil organic Carbon (SOC) is directly related to the amount of organic matter present in the soil. The micro-organisms respire a fraction of metabolized C in the form of CO_2 and play a vital role in sequestering of SOC in the soil through humification and condensation (Jastrow *et al*., 2007). The availability of TN in soil is greatly influenced by the rate of nitrogen fixation and atmospheric nitrogen deposition which in turn is influenced by water holding capacity of soil (Schmidt *et al*., 2008). The significant and positive correlation between SOC and all other tested soil nutrients for the present study suggested that SOC might have influenced on the availability of other soil nutrients.

Phosphorus in soil exists predominantly in form of inorganic fractions, either adsorbed, incorporated within biomass or associated with soil organic matter (Richardson and Simpson, 2011). The total available phosphorus in Bhimthang glacier foreland was found to be 4.4- 241.5 kg/ha with mean value of 27.6±4.3. There was increase in amount of phosphorus availability in the soil on transect 5 then previous terminus. In long term chronosequence (>500 years), such as the volcanic island of Hawaii and Franz Josef glacier in New Zealand showed decline in availability of phosphorus (Perez *et al.*, 2016) indicating retrogressive phase of ecosystem development but in the present study an increase in P- content in old aged soil than nearer to newly formed glacier terminus. The reason behind this might be that in older soil, the biological phenomenon such as plant development, geochemical cycling of soil nutrients, plant debris decomposition and uptake of nutrients are at faster rate and much developed than in pioneer soil which led to more amount of nutrients available in the soil. Bioavailable phosphorus are usually available in topsoil and bedrocks of glaciated region from weathering of the mineral surfaces. (Schutz *et al.,* 2013) found more phosphorus in younger moraine than old. The reason would be mineralization accelerated due to rapid microbial activities. In present study some plots got high amount of P indicated high microbial activities at microsites created by boulders at old moraines.

The result of available potassium (K) in the present study showed significantly increased at the oldest transect. The last transect (T5) which was away from glacier terminus showed strong positive correlation with K indicating K content was comparatively higher than other younger transects. The value of potassium content in the glacier foreland ranged between 76.8 and 1293.6 kg/ha with mean of 229.8±27.9. Ghimire and Lekhak (2007) reported 6.12 to 24.46 kg/ha of available K- content in soil of subalpine region above Gangapurna glacier foreland, Manang.

This differences were due to two different ecosystems. As the present study lies completely within the glacier foreland where enrichment of minerals directly through weathering of rocks rich in feldspar. Thus high content in potassium in this research than in Ghimire and Lekhak (2007) was justified. Similar findings of high potassium content in the glacier moraine soil from North Dakota (Franzen and Bu, 2018) also supports this present finding. Within the same glacier moraine there were also findings of variable mineral nutrients (Turner and Condron, 2013). The youngest primary soil, poorly weathered, was found limited by N, moderately weathered soil, moderately aged soil was found co-limited by both N and P. whereas the oldest moraine was found limited by Phosphorus.

5.2 Vegetation coverage

In this present study, vegetation cover showed significant positive correlation with rock cover and negative correlation with open space. In transect 1, nearer to glacier terminus open space was much pronounced whereas the soil away from glacier terminus has significant vegetation coverage. The result also showed that relative radiation index value (RRI) increased with increase in distance away from glacier terminus which also support more vegetation than in newly formed terrain. Nearer to the glacier terminus, there was colonization of pioneer communities like lichens (Crustose, foliose), mosses and some cushion types of plants. On moving little distance away from terminus, shrubby vegetation patches of *Rhododendron lepidotum, Cotoneaster microphyllus, Lonicera spinosa, Salix lindleyana, Gaultheria tricophylla, Potentilla spp, Aster spp, Erigeron multiradiatus, Taraxacum eriopodum, Dactylorhiza hatagirea, Primula capitate, Bistorta vivipara, Selinum wallichianum, Anaphalis royleana, Gentiana depressa, Kobresia pygmaea, Saxifraga parnassifolia,* and *Pedicularis spp* and *Potentilla fruticosa* were noticed. The dominant tree species of *Abies spectabilis, Taxus wallichiana, Tsuga dumosa* and *Pinus wallichiana* with scattered trees of *Betula utilis* and *Acer pectinatum* were observed around the study site, far away from glacier terminus.

Most ecological studies of glacier foreland chronosequence are based on observed correlations between vegetation zonation and terrain age. Following deglaciation, the most obvious successional trend on recently deglaciated terrain is the increase in vegetation cover and corresponding decrease in open space with increasing terrain age though rates are extremely varied (Matthews, 1992). Vegetation chronosequence are also characterized by similar limitations to soil chronosequence.

Almost all the studies indicate an increase in the number of species richness with increasing terrain age, at least on the younger ground (Matthews, 1992). The result of present findings also showed increase in vegetation cover with increase in distance away from glacier terminus. The transects 4 and 5 have high vegetation cover which may be due to intermixing of early and late successional plants in process of succession which is also supported by Baniya *et al*., (2009). Mong and Vetaas (2006) reported glacier foreland was pre-colonized by cushion plants and with time as succession proceed, reported *Pinus wallichiana* predominating above Gangapurna glacier foreland and terminal moraines of Marsyangdi river.

The soil close to the glacier terminus is almost deprived of vegetation and comprised of very heterogeneous morphotypes such as moraines, rock fields, flood plains, sand hills, erosion channels and mudslides as other Schulz *et al*., (2013); Whelan, (2013). Jones and del Morel (2005) explained as vegetation develops, species patterns are more likely to be controlled by environmental conditions, resource availability and species interaction by stochastic events such as seed dispersal which could led to turnover in both species richness and vegetation cover as succession proceed.

Dispersal of seeds and propagules did not see limiting factor in this study. Establishments of some late succession species such as seedlings of *Betula utilis* and *Abies spectabilis* in safe sites of young moraine as stochastic method of succession Mong and Vetaas (2006). However, the change in vegetation cover was not linear. This irregularities in vegetation cover would be explained by its associated rock cover. High windy and steepy slope lead fragile habitats that may make difficult to establish pioneer colonizer. Thus there were moraines with highly erodible habitats which lead different colonization sites. Hence erratic development of vegetation cover along Bhimthang glacier foreland was justified.

5.3 Glacier retreat

In the present study, Bhimthang glacier foreland represents a spatio-temporal gradient. The exact age of Bhimthang glacier foreland is unknown as there is lack of well-documented history on glacier advancement and retreating phenomena. Landsat imagery and sentinel data between the periods of 1988-2018 showed continuously decreasing in its volume and area from 1095.47 to 848.96 ha.

Several literature earlier findings that glaciers in the mountainous region are retreating fast (Bajracharya *et al*., 2014; Gurung, 2012; Shrestha and Aryal, 2011). Bajracharya *et al.* (2014) reported that the total glacier area decreased from 191 to 142 km² (26%) in Langtang valley with an average rate of loss from 1.49 km²/year and from 63 to 46 km² (27 %) in Imja valley with an average rate of loss of 0.57 km²/year. They also found that Ngozumpa Glacier has reduced from 82.6 km^2 to 80.7 km^2. Similarly, Armstrong (2010) reported the glaciers in the eastern Nepal are retreating at higher rate than in the western Nepal. Shrestha and Aryal (2011) have reported that the glacier system at the lower elevations, below 4000 m have responded significantly to recent global warming. So,the retreating Bhimthang glacier was also in line with above mentioned glaciers.

IPCC (2014) reported that the amount of snow and ice on the Polar region and mountain are diminishing due to increasing global warming. The loss in glacier mass was high during 2002 to 2011 than since 1992 to 2002. Furthermore, Bajracharya *et al.* (2014) reported that the glacier area of Nepal is decreasing 30 km^2/year since 1970s and glaciers of Nepal will disappear by 2050 A.D. If this trend continues. Department of Hydrology and Meteorology (DHM, 2017) reported that an average maximum temperature has been increasing by 0.056 °C / year while minimum temperature by 0.002 °C / year in Nepal since 1971. Increase in temperature and global warming might be the reason why glacier areas in the mountainous region are rapidly retreating and forming newly exposed terrain.

6. CONCLUSION AND RECOMMENDATION

6.1 Conclusion

This present work is attempted to study the variation in content of soil properties along a spatio- temporal gradient along Bhimthang glacier foreland, Manang, Central Nepal. The study also emphasized on finding the relationship between tested soil properties and retreat of glacier along spatio-temporal gradient in chronosequence order. The results of the study showed that all the tested and analyzed physico-chemical properties of soil increases with increase in distance away from glacier, where the exception is soil depth with no significant difference along chronosequence. Thus, the hypothesis "soil physico-chemical properties steadily developing on the glacier foreland show linear relationship i.e. increases with the increasing distance away from the glacier terminus" is accepted. With increase in soil age, there is also increase in soil nutrients and the other physical as well as chemical properties also varied between newly formed soil and old aged soil along glacier foreland. Bhimthang glacier is continuously retreating in its volume and area in linear tend from 1988 to 2018. With the melting of ice surface along glacier soil, the soil formation and vegetation succession process immediately takes place. The newly formed deglaciated soil is deprived of higher plants and is primarily colonized by pioneer communities followed by seral communities. As increase in distance away from glacier, open space and barren soil is almost occupied by vegetation of climax stage. Thus, the young soils in newly formed glacier forefields are generally scarcely vegetated and low in nutrients such as C, N, P and K whereas increases linearly with increase in age of soil or increase in distance away from glacier.

6.2 Recommendations

These recommendations are made based on this present study.

- Conducting long term monitoring of glacier retreating phenomenon by collecting sufficient baseline of data so as to study the climate change phenomenon (one of the proxy methods), since glaciers are sensitive indicator to climate change.
- To study the variation of soil properties along glacier foreland, it would be better if microbes would be included.
- Conservation and management of glacier areas should be encouraged since glaciers and its associated lands are integrated with mountainous livelihood.

REFERENCES

Adeleke, R., Nwangburaka, C. and Oboirien, B. 2016. Origins, roles and fate of organic acids in soils. A review. *South African Journal of Botany* **108**: 393-406.

Armstrong, R. L. 2010.The Glaciers of the Hindu Kush-Himalayan Region: A Summary of the Science Regarding Glacier Melt/Retreat in the Himalayan, Hindu Kush, Karakoram, Pamir, and Tien Shan Mountain Ranges. ICIMOD, Kathmandu. 2p.

Asahi, R., Morikawa, T., Ohwaki, T., Aoki, K. and Tage, A. 2001. Visible-light photo catalysis in nitrogen-doped titanium oxide. *Science* **293**: 269-271.

Bajracharya, S.R. Mool, P.K., Shrestha, B.R. 2007. *Impact of climate change on Himalayan glaciers and glacial lakes: Case studies on GLOF and associated hazards in Nepal and Bhutan*. Kathmandu, Nepal: ICIMOD.

Bajracharya, S.R., Maharjan, S.B., Shrestha, F., Bajracharya, O.R. and Baidhya, S. 2014. *Glacier status in Nepal and decadal change from 1980 to 2010 based on Landsat data.* Kathmandu: ICIMOD.

Baniya, C. B. 2011. Response of plant species to abandonment of subalpine fields, Manang, Nepal. *Journal of plant science* **8**: 10–15.

Baniya, C. B., Solhøy, T., Gauslaa, Y. and Palmer, M. W. 2012. Richness and Composition of Vascular Plants and Cryptogams along a High Elevational Gradient on Buddha Mountain, Central Tibet. *Foliageo Botanica* **47**: 135–151.

Baniya, C.B., Solhøy, T. and Vetaas, O. R. 2009. Temporal changes in species diversity and composition in abandoned fields in a trans-Himalayan landscape, Nepal. *Plant Ecology* **201**: 383–399

Bardgett, R. D., Richter, A., Bol, R., Garnett, M. H., Baumler, R., Xu, X., Lopez-Capel, E., Manning, D. A.C., Hobbs, P. J., Hartley, I. R. and Wane, W. 2007. Heterotrophic microbial communities use ancient carbon following glacial retreat. *Biology Letter* **3**: 487-490

Bradley. J. A., Singarayer, J. S. and Anesio, A. M. 2014. Microbial community dynamics in the forefield of glaciers. *Proceedings the Royal Society B* **281**: 1-9.

Burga, C.A., Krus, B., Egli, M., Wernli, M., Elsener, S., Ziefie, M., Fischer, T. and Mavris, C. 2010. Plant succession and soil development on the foreland of the Morteratsch glacier (Pontresina, Switzerland): Straight forward or chaotic?. *Flora* **205**: 561-576.

CBS. 2012a. National Population and Housing Census 2011. National report Government of Nepal, Central Bureau of Statistics, Kathmandu, Nepal.

Chapin, F.S., Walker, L.R., Fastie, C.L. and Sharmen, L.C. 1994. Mechanism of primary succession following deglaciation at Glacier Bay, Alaska. *Ecological Monographs* **64**: 149-175.

Chapman, J. L. and Reiss, M. J. 1995. *Ecology principles and applications.* Press Syndicate of the University of Cambridge, Melbourne, Australia. 203p.

Chaudhary, R.P. 1998. *Biodiversity in Nepal: Status and Conservation*. Craftsman Press, Bangkok.

Crocker, R. L. and Major, J. 2013. Soil Development in relation to vegetation and surface age at Glacier Bay, Alaska. *Journal of Ecology* **43**: 427-447.

Darmody, R G, Allen, C. E. and Thorn, C E. 2005. Soil topochronosequences at Storbreen, Jotunheimen, Norway. *SSSA Journal* **69**: 1275p.

del Moral, R. and Jones, C. 2002. Vegetation development on Pumice at Mount St. Helens, USA. *Plant Ecology* **162:** 9-22.

DHM. 2017. Observed climate trend analysis in the districts and physiographic regions of Nepal (1971-2014). Department of Hydrology and Meteorology, Kathmandu.

Egli, M., Fitze, P. and Mirabilla, A. 2001. Weathering and evolution of soils formed on granitic, glacial deposits: Results from chronosequences of Swis alpine environment. *Catena* **45**: 19-47.

Frazen. D.N. and Bu, H. 2018. *North Dakota Clay Mineralogy Impact Crop Potassium Nutrition and Tillage Systems*: *NDSU Extension*. North Dakota State University, Fargo, North Dakota.

GEN; CREH; NU; DHM (2006) Data Report 4 (2001-2004), GEN 2001-2002: Imja Glacier Lake in Khumbu, East Nepal. Kathmandu: DHAS and DHM.

Ghimire, B. and Lekhak, H.D. 2007. Local effects of global changes in the Himalayas: Manang, Nepal. Tribhuvan University, Nepal and University of Bergen, Norway. [Chaudhary, R.P., Aase, T.H., Vetaas, O.R. and Subedi, B.P. (Eds)]. pp 139-149.

Goransson, H., Venternik, H.O. and Baath, E. 2011. Soil bacterial growth and nutrient limitation along a chronosequence from a glacier foreland. *Soil Biology and Biochemistry* **43**: 1333-1343.

Gorniak, D., Marszalek, H., Kwasniak-Kominek, M. and Pzepa, G.2017. Soil formation and initial microbial activity on foreland of Artic glacier, SV (Svalbard). *Applied Soil and Ecology* **114**: 34-44.

Goudie, A. 1983. *Environmental Change*, Second Edition, Clarendon Press, Oxford.

Grime, J. P. 1977. Evidence for the existence of three primary strategies in plants and its relevance to ecological and evolutionary theory. *The American Naturalist* **11**: 1169–1194.

Gupta, P.K. 2002. *Methods in environmental analysis of water, soil and air*. Second Edition. Agrobios, India.

Gurung, J. 2012. *Soil development and plant succession following de-glaciation in the Nepal Himalaya: Response to climate change* [MSc. Thesis]. School of Science, Kathmandu University, Dhulikhel, Nepal.

Gurung, J. and Bajracharya, R. 2012. Climate change and glacial retreat in the Himalaya: implications for soil and plant development, Kathmandu University. *Journal of science, engineering and technology* **8**: 153-163.

Haeberli, W. and Hoelzle, M. 1995. Application of inventory data for estimating characteristics of and regional climate-change effects on mountain glaciers: a pilot study with the European Alps. *Annals of glaciology* **21**: 206p.

Hall, K. J. and Walton, D.W. H. 1992. Rock weathering, soil development and colonization under a changing climate, Philosophical Transactions: Biological Sciences, *Antarctic and Environmental Change* **338**: 269p.

Haugland, J. E. 2006. Short-term periglacial processes, vegetation succession, and soil development within sorted patterned ground: Jotunheimen, Norway. *Arctic, Antarctic, and alpine research* **38**: 82p.

He, I. and Tang, Y. 2008. Soil development along primary succession on moraines of Hailuogou glacier, Gongga Mountain, Sichuan, China. *Catena* **72**: 259-269.

Higuchi, K., Watanabe, O., Fushimi, H., Takenaka, S. and Nagoshi, A. 2010. Glaciers of Asia- GLACIERS OF NEPAL- Glacier distribution in Nepal Himalaya with comparison to the Karakoram Range. Image atlas of glaciers of the world, U.S. *Geological Survey Professional Paper* **1386** [William, R.S. and Ferringo, J. G. (Eds)]: 293-320.

Hodkinson, I.D., Coulson, S.J. and Webb, N.R. 2003. Community assembly along proglacial chronosequences in the high Artic: Vegetation and soil development in North-West Svalbard. *Journal of Ecology* **91**: 651-663.

Huggett, R. J. 1998. Soil chronosequences, soil development, and soil evolution: a critical review. *Catena* **32**: 155-172.

ICIMOD/UNEP. 2001. Inventory of glaciers, glacier lakes and glacier lake outburst floods, monitoring and early warning system in the Hindu Kush-Himalaya region, Nepal. 247 pages. Kathmandu, Nepal.

Insam, H., Delgado- Granados, H., Nagler, M., Waldhuber, S., Podmirseg, S.M. and Quideau, S. 2017. Soil micro-biota along Ayoloco glacier retreat area of Lztaccihuatl volcano, Mexico. *Catena* **153**: 83-88.

IPCC 2014. Climate Change 2014: Synthesis Report, Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (Eds.)]. IPCC, Geneva, Switzerland.

Jastrow, J.D. Amonette, J.I. and Baily, V.I. 2007. Mechanism controlling soil carbon turnover and their potential application for enhancing carbon sequestration. *Climate Change* **80**: 5-23.

Jenny, H. 1941. *Factors of soil formation*. McGraw-Hill Book Company, New York.

Jones, C.C. and del Moral, R. 2005. Patterns of primary succession on the foreland of Coleman glacier, Washington, USA. *Plant ecology* **180**: 105-116.

Kadota, T., Fujita, K., Seko, K., Kayastha, R.B. and Ageta, Y.1997. Monitoring and prediction of shrinkage of a small glacier in the Nepal Himalaya. *Annals of Glaciology* **24**: 90-94.

Khadka, N., Zhang, G. and Thakuri, S. 2018. Glacier lakes in the Nepal Himalaya: Inventory and Decadal dynamics (1977-2017). *Remote Sensing* **10**, 1913.

Liu, J., Kong, W., Zhang, G., Khan, A., Guo, G., Zhu, C., Wei, X., Kang, S. and Morgan-Kiss, R.M. 2016. Diversity and succession of autotrophic microbial community in high-elevation soils along deglaciation chronosequence. *FEMS Microbiology and Ecology* **92**: 1-11.

Matthews J, A. 1992. *The Ecology of Recently-Deglaciated Terrain*. Cambridge University Press.

Miniaci, C., Bunge, M., Duc, L., Edwards, I., Burgmann, H. and Zeyer, J. 2007. Effects of pioneering plants on microbial structures and functions in a glacier forefield. *Biology and Fertility of Soils* **44**: 289-297.

Mong, C.E. and Vetaas, O.R. 2006. Establishment of Pinus wallichiana on a Himalayan glacier foreland: Stochastic distribution or safe site?. *Artic, Antarctic and Alpine Research* **4**:584-592.

Oke, T.R. 1987. *Boundary Layer Climates*. 2nd Edition, Methuen, London.

Owen, L.A., Finkel, R.C. and Cafee, M. W. 2002. A note on the extent of glaciation throughout the Himalaya during the global Last Glacial Maximum. *Quaternary Science Reviews* **21**: 147p.

Perez, C.A., Silval, W.A., Aravena, J.C. and Armesto, J.J. 2017. Limitations and relevance of biological nitrogen fixation during post-glacial succession in Cordillera Darwin, Tierrra del Fuego, Chile. *Artic, Antarctic and Alpine Research* **49**: 29-42.

Richards, B. W. Owen, L. A. and Rhodes, E. J. 2000. Timing of late Quaternary glaciations in the Himalayas of northern Pakistan. *Journal of Quaternary Science* **15**: 283p.

Richardson, A.E. and Simpson, R.J. 2011. Soil micro-organisms mediating phosphorus availability. *Plant Physiology* **156**: 989-996.

Rowell, D.L. 2014. *Soil Science: Methods and Applications.* Routledge. New York, USA.

Schmidt, S. K., Nemergut, D. R., Darcy, J. L. and Lynch, R. 2014. Do bacterial and fungal com-munities assemble differently during primary succession?. *Molecular Ecology* **23:** 254–258

Schmidt, S.K., Reed, S.C., Nemergut, D.R., Grandy, A.S., Cleveland, C.C., Weintraub, M.N., Hill, A.W., Costello, E.K., Meyer, A.F., Neff, J.C. and Martin, A.M. 2008. The earliest stages of ecosystems sucession in high elevation (5000 m above sea level), recently deglaciated soils. *Proceedings of Royal Society B* **275**: 2793-2802.

Schulz, S., Brankatschk, R., Dumig, A., Kogel-Knabner, I., Schloter, M. and Zeyer, J. 2013. The role of micro-organisms at different stages of ecosystem development during soil formation. *Biogeosciences* **10**: 3983-3996.

Schutte, U. M. E., Abdo, Z., Bent, S. J., Williams, C. J., Schneider, G.M., Solheim, B. and Forney, L. J. 2009. Bacterial succession in a glacier foreland of high arctic. *The ISME Journal* **3**: 1258-1268.

Schweizer, S.A., Hoeschen, C., Schlüter, S., Kögel-Knabner, I, Mueller, C.W.2018. Rapid soil formation after glacial retreat shaped by spatial patterns of organic matter accrual in microaggregates. *Global Change Biology* **24**: 1637-1650.

Serreze, M.C., Walsh, J.E., Chapin III, F.S., Osterkamp, T., Dyurgerov, M., Romanovsky, V., Oechel, W.C., Morison, J., Zhang, T. and Barry, R.G. 2000. Observational evidence of recent change in the northern high-latitude environment. *Journal of Climate Change* **46**: 159-207.

Shrestha, A.B. and Aryal, R. 2011. Climate change in Nepal and its impact on Himalayan glaciers. *Regional Environmental Change* **11**: 65-77.

Shrestha, K.K., Sah, J.P. and Ghimire, S.K. 1995. *Ecology, Exploitation Trend and Conservation of Potential High Altitude Medicinal Plants in Gyasumdo Valley, Manang*. Annapurna Conservation Area Project and King Mahendra Trust for Nature Conservation Kathmandu Nepal.

Singh, J. S.,Singh, S.P. and Gupta, S. R. 2008. *Ecology Environmental Science and Conservation*. S. Chand Publishing. Ram Nagar, New Delhi, India. 282-293p.

Stevenson, F. J. 1994. *Humus Chemistry: Chemistry, Composition, Reactions*. 2nd edition, John Wiley & Sons, New York.

Stres, B., Sul, W.J., Murovec, B. and Tiedje, J.M. 2013. Recently de-glaciated high altitude soils of the Himalaya: Diverse environments, heterogeneous bacterial communities and long range dust input from upper troposphere *PLoS ONE* **8**: 1-10.

Thakuri, S., Salerna, F., Smiraglia, C., Bolch, T., Agata, C.D., Viviano, G. and Tartari, G. 2014. Tracing glacier changes since the 1960s on the south slope of Mt. Everest (Central Southern Himalaya) using optical satellite imagery. *The Cryosphere* **8**: 1297- 1315.

Tsherko, D., Rustemeir, J., Richter, A., Wanck, W. and Kandeler, E. 2003. Functional diversity of soil microflora in primary succession across two glacier forelands. European *Journal of Soil Science* **5**: 685-696.

Turner, B.L. and Condron, M.L. 2013. Pedogenesis, nutrient dynamics and ecosystem development: The legacy of T.W. Walker and J.K. Syers. *Plant Soil* **367**: 1-10.

U.S. Environmental Protection Agency. 2016. Climate change indicators in the United States, 2016. Fourth edition, EPA 430-R-16-004. Available: www.epa.gov/climate-indicators.

Vilmundardottir, O.K., Gisladottir, G. and Lal, R. 2014. Early stage development of selected soil properties along the pro-glacial moraines of Skaftafellsjokull glacier, SE Iceland, *Catena* **121**: 142-150.

Vilmundardottir, O.K., Gisladottir, G. and Lal, R. 2015. Soil carbon accretion along an age chronosequence formed by the retreat of Skaftafellsjokull glacier, SE, Iceland. *Geomorphology* **228**: 124-133.

Walker, L.R., Wardle, D.A., Bardgett, R.D. and Clarkson, B.D. 2010. The use of chronosequences in studies of ecological succession and soil development. *Journal of Ecology* **98**: 725-736.

Whelan, P.W. 2013. Incipient soil development in the recently de-glaciated Easton foreland, Mt. Baker, Washington [MSc. Thesis]. Western Washington University.

Wietrzyk, P., Wegrzyn, M. and Maza, L. 2013. Vegetation diversity and selected abiotic factors influencing the primary succession process on the foreland of Gasbreen, Svalbard. *Polish Science Research* **37**: 493-509.

WWF Nepal Program March .2005. An Overview of Glaciers, Glacier Retreat, and Subsequent Impacts in Nepal, India and China. 16p.

Zemp, M., Roer, I., Kääb, A., Hoelzle, M., Paul, F. and Haeberli, W. 2008. *Global Glacier Changes: Facts and Figures*, UNEP, Geneva and World Glacier Monitoring Service (WGMS), Zurich.

Appendix 1
Terrain attribute recorded for each plot laid along the study area

Sample plot	Altitude(m)	Longitude	Latitude	Aspect (°)	Slope (°)
T1P11	3713	84.4715	28.6284	256˚SW	45˚
T1P12	3685	84.4712	28.6278	232˚SW	25˚
T1P13	3675	84.4713	28.6276	250˚SW	40˚
T1P14	3669	84.4713	28.6276	235˚SW	46˚
T1P16	3666	84.4713	28.6275	235˚SW	41˚
T1P18	3660	84.4712	28.6274	249˚SW	54˚
T1P2	3727	84.4714	28.6306	294˚NW	30˚
T1P20	3661	84.4714	28.6274	246˚SW	55˚
T1P4	3743	84.4713	28.63	262˚SW	35˚
T1P6	3754	84.4714	28.6293	236˚SW	38˚
T1P7	3708	84.4714	28.629	260˚W	20˚
T1P9	3705	84.4715	28.6288	260˚W	38˚
T2P1	3654	84.4715	28.6271	244˚SW	34˚
T2P11	3711	84.4714	28.6286	252˚SW	35˚
T2P13	3707	84.4713	28.629	257˚SW	35˚
T2P15	3709	84.4711	28.6294	227˚SW	25˚
T2P18	3711	84.4712	28.63	260˚W	30˚
T2P19	3712	84.4711	28.6302	260˚W	18˚
T2P20	3710	84.4712	28.6306	270˚W	20˚
T2P3	3651	84.4712	28.6274	232˚SW	35˚
T2P5	3669	84.4712	28.6276	240˚SW	38˚
T2P6	3674	84.4712	28.6278	248˚SW	30˚
T2P8	3699	84.4713	28.6282	276˚NW	35˚
T2P9	3703	84.4714	28.6283	264˚SW	44˚
T3P1	3701	84.4711	28.6315	270˚W	18˚
T3P10	3648	84.4712	28.6285	242˚SW	22˚
T3P12	3671	84.4712	28.6281	285˚NW	23˚
T3P14	3688	84.4712	28.6278	253˚SW	42˚
T3P16	3695	84.4713	28.6276	245˚SW	39˚
T3P18	3691	84.4713	28.6274	254˚SW	46˚
T3P19	3687	84.4713	28.6274	250˚SW	44˚
T3P20	3683	84.4714	28.6273	248˚SW	40˚
T3P3	3693	84.4711	28.6308	263˚NW	25˚
T3P5	3689	84.4708	28.6299	225˚SW	33˚
T3P8	3684	84.4711	28.6291	258˚SW	25˚
T3P9	3613	84.4711	28.6288	250˚SW	12˚
T4P1	3669	84.4709	28.6275	223˚SW	17˚
T4P11	3655	84.47	28.63	230˚SW	20˚
T4P13	3670	84.4699	28.6305	200˚S	18˚
T4P14	3674	84.4698	28.6307	240˚W	10˚
T4P16	3673	84.4695	28.6311	210˚S	20˚
T4P17	3677	84.4693	28.6313	220˚SW	5˚
T4P2	3671	84.4708	28.6277	298˚NW	8˚
T4P20	3704	84.4689	28.6315	100˚E	10˚
T4P3	3672	84.4703	28.6282	234˚SW	12˚
T4P5	3668	84.4706	28.6287	75˚NE	18˚
T4P7	3614	84.4704	28.6291	250˚W	5˚
T4P9	3640	84.4703	28.6296	260˚W	18˚
T5P1	3654	84.4689	28.6314	230˚SW	0˚
T5P10	3638	84.4698	28.6288	230˚SW	20˚
T5P12	3640	84.4699	28.6284	230˚SW	15˚
T5P13	3645	84.4701	28.6281	220˚SW	20˚
T5P14	3645	84.4701	28.6278	180˚S	18˚
T5P16	3654	84.4705	28.6274	190˚S	18˚
T5P18	3647	84.4709	28.6268	250˚W	40˚
T5P20	3619	84.4713	28.6258	270˚W	5˚
T5P3	3654	84.4693	28.6309	230˚SW	4˚
T5P5	3663	84.4695	28.6304	200˚S	20˚
T5P7	3637	84.4696	28.6296	240˚W	5˚
T5P9	3635	84.4697	28.6291	210˚S	20˚

Appendix 2

Climatic data of study area (Mean monthly maximum and minimum temperature (°C), monthly precipitation (mm) from 1985 – 2018 A.D.

a) Monthly mean of maximum temperature (°C)

Year	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
1987	10	10.6	18.6	19.4	21.9	23.6	23.6	23.9	22.6	20	14	12.9
1988	12.1	11.3	18.3	20.6	22.1	23.4	22.6	21.6	22.2	19.9	15.3	12
1989	9.9	10.7	15.4	19.2	25.7	25.9	22.3	22.6	21.2	18.8	13.3	11.8
1990	14.3	10	12.8	18.1	21.1	24.3	23.3	23.3	21.4	16.7	16.5	12.9
1991	12.2	12.7	15.1	18.3	21.8	23	24.3	22.9	22.2	18.6	13.2	11.4
1992	11	9.7	16.1	19.9	19.3	22.3	22.9	22.4	21.4	17.5	14.6	12.1
1993	9.9	11.9	12.8	17.9	20.9	23	23.5	22.7	19.4	18.2	14.6	12.5
1994	11.3	10.4	15.5	18.4	21.6	23.9	24.1	22.1	20.7	17.4	12.9	10.5
1995	6.6	9.3	13.7	18.3	21.7	22.7	22.5	22	20.4	18.4	14.1	10.8
1996	9.9	10	15.6	17.9	21	21.7	22.8	21.8	20.9	15.7	14.4	13.3
1997	9.5	9.5	13.8	15.3	19.5	22	23.1	22	20.8	14.4	13	7.3
1998	10	10.3	12.7	18.5	21.1	23.9	22.4	22.4	22	19.1	16.2	13.1
1999	10.3	14.6	17.4	21.2	21.1	21.5	22.2	21.8	21.2	17.8	14.9	10.9
2000	9.8	8.4	12.4	19.2	22	21.6	22.5	22.3	20	19	14	12.9
2001	11.4	12.9	13.7	17.3	20.6	22.3	23.2	22	20.6	18.5	15.4	11.8
2002	9.6	11.9	15.1	18.7	20.4	22.3	22.9	22.7	20.3	17.5	14	11.4
2003	11.4	10.9	14.3	19.3	19.5	22	22.5	22.5	21	19	14.5	10.3
2004	9.5	12.6	18.2	18.7	20.8	22.1	22.4	22.9	21.5	16.5	12.9	13
2005	9.1	11.2	17	18.4	20.3	23.4	22.3	22.9	21.7	17	14.5	13.1
2006	13.6	15.9	14.5	17.4	20.8	21.9	22.9	22.5	21.7	18	14.3	13.7
2007	11.9	9.5	14.7	19.9	21.7	23.4	22.7	22.5	20.9	18.1	14.3	12.8
2008	9.5	11.2	14.9	18.1	20.4	22.8	22.8	22.3	20.7	17.9	16.4	14.1
2009	14	15.1	15.3	19.5	19.6	22.8	23.7	22.9	21.4	17.9	14.6	12.3
2010	13.3	12	17.8	20.9	21	22.6	22.3	22.6	20.9	18.7	15.6	13.7
2011	10.4	12.7	16	17.3	21.5	22.1	22.8	22.5	21.7	18.1	14.8	12.2
2012	7.9	12	15.7	17.3	20.6	23.5	22.5	22.6	21.8	18.2	14.4	14.1
2013	11.3	12.4	15.4	18.6	20.7	22.7	22.5	22.6	21.8	34.4	15.2	12.3
2014	10.4	11.8	15.1	18	20.7	23.8	23	23.6	21.9	17.5	15.4	12.6
2015	8.7	13.1	14	19	21.6	22.2	22.85	22.9	22.3	18.2	16.1	12.1
2016	10.3	14.2	16.4	20	20.4	23.1	23	23.1	22.1	18.9	16.7	16.4
2017	8.8	15.3	16.4	19.5	21.3	23.5	22.9	23.5	23.5	17.9	16.8	15.6
2018	10.2	14.6	15.9	20.2	20.5	22.5	23.1	24	23	18.8	17	16

b) Monthly mean of minimum temperature (°C)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1987	-6.2	-5.1	3.7	4.9	7.7	11.3	13.3	12.9	11.6	6.9	0	-2.8
1988	-3.4	-3	2.9	7.1	8.8	11.7	13	12.2	10.9	6.9	0.7	1.3
1989	1.6	-0.8	-0.9	4.00E-01	-0.4	12.3	13.5	13.3	11.7	3.6	0.4	-1.5
1990	-0.7	-1.4	0.1	2.9	7.5	12.7	14.3	13.5	11.1	5.5	0.7	-2.5
1991	-2.7	-1.5	1.3	2.8	6.4	12.6	14.5	13.9	11.4	5.6	1.2	-2
1992	-3	-2.6	2.3	2.5	4.9	10.6	12.6	13.2	10.3	6.2	0.5	-0.7
1993	-1.1	-1.6	-1	3	6.2	11.7	13.9	13.9	10.3	5	1.6	-2.1
1994	-1.8	-2.8	1.5	2.4	6.1	11.9	14.2	14	11.8	5.5	0.7	-0.9
1995	-3.4	-0.2	2.3	4	9.1	14.2	14.6	14	11.7	6.8	2.5	-0.3
1996	-1.3	-0.3	3.5	4.5	7.9	12.2	14.6	13.7	11.6	6.1	2.5	-0.5
1997	-1.6	-0.5	1.5	3.6	7.5	11.3	14.5	13.4	11.8	2.7	1.9	-2.7
1998	-1.5	1	2	5.8	9.7	0.5	14.4	14.7	12.3	7.9	3.4	0.3
1999	-1.9	2	3.5	6.4	10.2	12	14.2	13.7	12.3	6.6	2.5	-0.4
2000	-0.9	-2.6	0.4	5.9	10.4	13.3	14.5	14.1	11.1	6.4	3.2	-0.5
2001	-0.9	0.2	1.2	4.2	9.7	13.3	14.9	14.4	11.4	7	2.2	-1
2002	-1.4	0	1.9	5.6	9.3	13.1	14.4	13.8	10.8	5.4	2.4	-0.7
2003	-1.2	-1.2	4.8	3.8	7.1	12.6	14.3	14.6	12.8	5.4	2.4	-0.4
2004	-1.9	0.5	3.1	6.2	9.4	12.6	14.6	14.3	12.9	5.1	1	0.1
2005	-0.8	0.2	1.7	4.4	7.1	11.6	14.5	14.4	12	5.8	0.9	-1
2006	-0.3	2.3	2.2	5	10.3	12	14	13.7	11.5	5.3	1.3	-0.4
2007	-1.3	-1.5	1.8	5.8	8.3	12.9	13.7	13.8	12	6.4	1.2	-1.6
2008	-0.5	-1.5	1.1	3.8	6.8	0.8	13.7	13.3	9.8	4	1.7	-0.4
2009	-0.6	-0.3	3.3	5.3	7.2	10.9	13.8	13.4	10.6	4.4	0.7	-1.7
2010	-1.8	-1.5	1.7	5.6	7.6	11.4	13.6	13.8	11.4	5.5	2.5	-3
2011	-3.2	-1.3	1.2	2.9	7.9	11.4	14	13.1	11.7	5.1	1.8	-3.1
2012	-3.9	-1.1	2.2	3.5	6.1	11.3	14.9	13.4	11.2	3.7	0.3	-0.8
2013	-1.4	-0.3	1.5	4.6	8	12	14.7	13.8	11.6	7.7	0.6	-0.9
2014	-2.3	-0.4	2.6	3.7	7.4	12.5	13.5	14.4	11.9	4.6	1.8	-0.6
2015	-1.1	0.3	2.6	4.1	8.1	11.4	14.1	14	11.7	5.6	2.2	-1.3
2016	-2	0.8	3.1	5.2	7.7	12.8	14.4	13.5	11.4	6.2	0.3	0.4
2017	-1.8	-0.4	3.6	4.8	8.4	12.2	14.9	13.8	11.9	5.3	2.8	0.8
2018	-2	1	2.9	5	9	11	14	14.2	11.2	6	1.4	0.2

c) Monthly mean Precipitation (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1987	0	0	2.6	53.4	33.6	5.4	9.8	26.5	6	82	0	0
1988	0	25.9	1	1.1	8.4	2	46	14.7	13.6	7.8	0	0
1989	0	0	23.5	1.1	0	3.7	53.5	31.8	46.9	6.6	5	0
1990	0	12.1	48	58	52	14.4	69.6	10.6	13.2	14.8	2.8	2
1991	28	28.2	21.4	17	20.4	19.8	17.4	33.3	2.8	0	12.4	0
1992	15	27.5	3.1	8	21.7	0	32.4	58	9.1	15.2	10	0
1993	14.4	8.2	45.3	8.1	8.4	13	21	43.3	121.7	0	0	0
1994	18.9	3	24.4	49	44	9	44.4	50	31.9	0	0	0
1995	24.3	7.4	88	11	8	63.6	36.4	62.2	78.2	1	52	0
1996	8	39.6	11.2	38.9	9.2	4.3	25.2	75.9	19.5	146	0	0
1997	1.3	8	40	15.6	6.1	20.4	30.8	49	6.8	27.2	9	11.8
1998	0	4.4	47.1	2.4	4.2	15	52.2	33.1	6.1	30.8	6	0
1999	10.4	1.8	3.1	6.8	8.8	100	54.2	28	22.4	19.9	0	0
2000	1.6	5.4	33.8	8.3	15.2	45.1	38.8	21.6	22	0	0	11.8
2001	0	27.1	43.7	30.7	2.9	24.9	24.1	43.2	40.9	0	2.4	0
2002	20.2	52.1	35.3	18.1	14.7	9.6	24.8	41.2	62.7	9.7	19.8	0
2003	4	24	16.2	37	20.8	48.6	34.2	80.3	46.2	7	0	3.6
2004	19	1.4	0.5	29.5	24.8	15.2	49.4	51.8	18.8	19.4	0	0
2005	13.5	4.2	0	18.7	9	17.9	92.6	33.2	16.2	104	0	0
2006	0	6	80.1	23.5	25	39	55	38.5	27	7	0	0
2007	0.5	45	39	8	5.9	15	81.4	45.6	68.5	0	3	0.1
2008	3	10	14.3	10	17.2	21.6	36.9	41.8	106	0	0	0
2009	0	0	27.3	28.8	53.5	9.6	32.8	55.3	24.2	84.8	6.6	0
2010	0	33	6.1	6	15.4	57.7	85.7	23.2	50.2	6.6	2.3	0
2011	16	28.5	1.8	21	2.9	44.2	37.2	44.8	24.8	0.9	0	0
2012	18.2	15.1	3.7	24.6	25.6	9.2	60.1	39.5	12.5	4.1	0	2
2013	15.9	62.8	3	28.9	20.5	120	68.2	48.8	17.7	18.7	0.7	0
2014	27.8	27.8	9.6	36.9	34.6	10.9	71.3	20.8	9.6	75.3	0	25.3
2015	83.8	15.3	98.1	46.6	6.8	76.4	50	28.9	8.1	8.4	6.2	0
2016	4.3	3.2	23.8	36.4	22.5	15.2	104	21.7	25.1	13.8	0	0.5
2017	14	6.8	14.8	24.8	9.8	52.1	105	50.2	46.4	9.2	0	0
2018	6.8	16.4	41.2	21.4	17	8.4	78	33	28	0	0.3	0

Appendix 3

Raw data recorded for soil properties analysis

Plot	Altitude (m)	Soil depth (cm)	pH at 15° C, (1:1)	SOC (%)	N (%)	P (Kg/ha)	K (kg/ha)	Bulk density (gm/ml)	Veg _Cover (%)	Rock Cover (%)	Open Space (%)	RRI
T1P11	3713	5	7.37	0.83592	3.50	4.40	175.20	1.65	10	5	85	0.7026215
T1P12	3685	5	6.65	0.75816	0.84	17.59	187.20	1.61	10	20	70	0.9201738
T1P13	3675	5	6.30	0.8262	0.28	4.40	146.40	1.73	10	5	85	0.7777289
T1P14	3669	5	6.81	0.76788	0.70	21.98	146.40	1.69	5	20	75	0.807419
T1P16	3666	5	6.72	0.80676	0.56	8.79	81.60	1.73	5	10	85	0.842739
T1P18	3660	5	7.18	0.78732	0.42	8.79	103.20	1.69	10	10	80	0.6548376
T1P2	3727	5	6.88	0.78732	7.00	4.40	93.60	1.63	20	60	20	0.6626879
T1P20	3661	5	6.57	0.7776	0.28	8.79	211.20	1.59	5	5	90	0.663089
T1P4	3743	5	6.56	0.8748	0.28	13.19	148.80	1.49	65	20	15	0.7572451
T1P6	3754	30	6.74	0.76788	2.38	8.79	96.00	1.66	20	5	75	0.8566225
T1P7	3708	30	5.45	0.8748	2.38	4.40	146.40	1.59	10	10	80	0.8532628
T1P9	3705	30	4.60	0.89424	0.84	13.19	81.60	1.73	10	5	85	0.7428937
T2P1	3654	5	6.09	0.7776	1.26	26.38	211.20	1.55	80	5	15	0.8451385
T2P11	3711	5	7.25	0.81648	3.78	30.78	86.40	1.64	15	85	10	0.8039291
T2P13	3707	5	6.39	0.84564	4.20	13.19	86.40	1.65	50	40	10	0.7808243
T2P15	3709	5	6.16	0.76788	2.38	17.59	93.60	1.63	40	20	40	0.9336009
T2P18	3711	5	6.55	0.80676	1.82	30.78	115.20	1.53	30	50	20	0.8017403
T2P19	3712	5	7.77	0.79704	1.68	4.40	115.20	1.64	50	30	20	0.8604829
T2P20	3710	5	6.65	0.79704	3.78	13.19	103.20	1.64	80	15	5	0.8247938
T2P3	3651	5	5.45	0.83592	3.64	8.79	112.80	1.56	5	85	10	0.8882021
T2P5	3669	5	6.85	0.78732	0.98	26.38	76.80	1.47	20	30	50	0.8391645
T2P6	3674	5	6.60	0.79704	1.12	30.78	120.00	1.66	20	20	60	0.8498947
T2P8	3699	5	6.70	0.84564	0.70	26.38	184.80	1.42	85	10	5	0.6902826
T2P9	3703	5	6.48	0.81648	1.12	17.59	105.60	1.72	70	10	20	0.666188
T3P1	3701	5	6.30	0.7776	2.24	4.40	127.20	1.65	50	25	25	0.834761
T3P10	3648	5	6.76	0.79704	4.76	13.19	103.20	1.51	40	50	10	0.8980937
T3P12	3671	5	6.50	0.81648	3.92	28.70	144.00	1.70	60	10	40	0.7595184
T3P14	3688	5	5.85	0.79704	2.66	31.58	120.00	1.64	20	10	70	0.746028
T3P16	3695	5	6.79	0.80676	3.36	31.58	110.40	1.71	35	10	55	0.8095681
T3P18	3691	5	6.83	0.83592	1.96	31.58	187.20	1.73	10	10	80	0.7047359
T3P19	3687	5	5.84	0.729	0.70	28.70	110.40	1.82	20	10	70	0.7452341
T3P20	3683	5	6.79	0.74844	1.00	25.83	192.00	1.72	5	5	90	0.7877653
T3P3	3693	5	5.14	0.81648	3.50	13.19	134.40	1.52	40	30	30	0.8201684
T3P5	3689	5	6.97	0.79704	4.76	17.59	146.40	1.58	50	30	20	0.9206581
T3P8	3684	5	5.80	0.79704	3.64	13.19	120.00	1.58	40	50	10	0.8376029
T3P9	3613	5	7.70	0.7776	3.78	4.40	120.00	1.61	40	50	10	0.8926326
T4P1	3669	5	6.34	0.886464	3.07	20.08	122.40	1.55	90	5	5	0.9418469
T4P11	3655	5	6.48	0.99144	4.61	31.58	93.60	1.32	95	5	5	0.9301382
T4P13	3670	5	6.10	0.8262	2.37	20.08	271.20	1.48	10	50	40	0.9739077
T4P14	3674	5	6.75	0.8262	12.59	31.58	429.60	1.67	50	30	20	0.9059945
T4P16	3673	5	6.71	0.80676	1.53	28.70	273.60	1.40	70	20	10	0.9667186
T4P17	3677	5	7.29	0.94284	2.51	25.83	496.80	1.42	50	5	45	0.9063733

T4P2	3671	5	6.64	0.970056	3.77	31.58	105.60	1.36	40	40	40	0.8379048
T4P20	3704	5	6.83	0.76788	2.79	22.95	319.20	1.73	30	60	10	0.878834
T4P3	3672	5	6.51	0.76788	2.51	25.83	175.20	1.59	80	10	10	0.9171189
T4P5	3668	5	6.63	0.88452	2.51	31.58	273.60	1.48	90	5	5	0.7964626
T4P7	3614	30	6.62	0.84564	2.51	31.58	129.60	1.70	100	0	0	0.8886823
T4P9	3640	5	6.84	0.84564	5.73	25.83	134.40	1.49	80	10	10	0.8604872
T5P1	3654	5	6.70	0.83592	2.79	34.45	667.20	1.37	1	20	39	0.8777205
T5P10	3638	5	6.36	1.0206	11.77	163.85	456.00	0.60	20	10	60	0.9301436
T5P12	3640	5	6.58	1.04976	5.04	43.08	741.60	1.07	20	80	0	0.9275474
T5P13	3645	5	6.75	0.88452	1.82	241.49	153.60	1.57	40	60	0	0.9503447
T5P14	3645	5	6.44	0.90396	133.07	25.83	1293.60	0.53	20	10	40	0.982846
T5P16	3654	5	6.24	1.14696	12.05	28.70	429.60	1.22	40	50	10	0.980598
T5P18	3647	5	5.75	0.99144	14.43	28.70	340.80	1.40	40	5	5	0.7777313
T5P20	3619	5	7.46	1.00116	4.06	22.95	316.80	1.22	60	10	40	0.8744272
T5P3	3654	5	6.27	0.91368	3.49	37.33	693.60	1.48	40	20	40	0.8970717
T5P5	3663	5	6.65	1.17612	7.00	34.45	340.80	0.80	50	40	10	0.9787936
T5P7	3637	10	5.42	0.84564	3.36	31.58	686.40	1.60	80	0	10	0.8952756
T5P9	3635	5	6.69	0.94284	4.00	28.70	201.60	1.20	20	70	10	0.9667253

Appendix 4

Variation of soil physico- chemical properties among transects (T1, T2, T3, T4 and T5)

[Note: Tukey multiple comparisons of mean; 95% family-wise confidence level; factor levels have been ordered.

	Significance value adjusted (p) to show relationship of soil physico-chemical parameters between Transects										
Transects	soil pH	Soil Depth	Bulk density	SOC	N	P	K	Rock cover	Veg. Cover	Open Space	RRI
T1-T2	0.99	0.09	0.94	0.99	0.99	0.92	0.99	0.25	0.01	0.0002	0.49
T1-T3	0.99	0.097	0.99	0.91	0.99	0.92	1	0.82	0.25	0.027	0.53
T1-T4	0.96	0.44	0.39	0.33	0.97	0.66	0.5	0.97	0.00001	0.00002	0.00002
T1-T5	0.99	0.13	0.0004	0.0001	0.17	0.0002	0.0001	0.36	0.184	0.0001	0.0001
T2-T3	0.97	1	0.94	0.97	0.99	1	0.99	0.85	0.75	0.18	0.0009
T3-T4	0.97	0.91	0.4	0.065	0.99	0.98	0.5	0.99	0.012	0.048	0.02
T2-T4	0.99	0.91	0.84	0.23	0.2	0.98	0.34	0.58	0.221	0.97	0.028
T2-T5	0.97	0.99	0.0006	0.0005	0.99	0.026	0.0001	0.99	0.84	1	0.004
T3-T5	1	0.98	0.0004	0.0001	0.25	0.025	0.0001	0.93	0.99	0.17	0.003
T5-T4	0.91	0.96	0.0002	0.00008	0.31	0.09	0.0002	0.72	0.021	0.97	0.961

Appendix 5

Procedure for the preparation of reagents for test of SOC, N, P and K in soil laboratory analysis

A. Soil Organic Carbon (SOC)

1. Standard 1 N Potassium Dichromate: 49.04 gm of AR grade $K_2Cr_2O_7$ was dissolved in distilled water and the volume up to 1 litre.

2. 0.5 N Ferrous Ammonium sulphate: 196 gm of the hydrated crystalline salt dissolved in 1 litre of distilled water containing 20 ml of Conc. H_2SO_4.

3. Diphenylamine indicator: 0.5 gm of diphenylamine indicator dissolved in 20 ml of distilled water and 100 ml of Conc.H_2SO_4.

B. Nitrogen

1. Mixed indicator: 0.3 gm of bromocresol green and 0.165 gm of Methyl red indicator was dissolved in 400 ml 95 % ethanol and the volume was brought up to 500 ml.

2. Boric acid indicator (4% H_3BO_3): 20 gm of reagent grade H_3BO_3 was dissolved in about 900 ml distilled water. 20 ml mixed indicator was added to it and adjusted to redish- purple color with NaOH or HCl. This point was indicated when 1 ml tap water turns 1 ml indicator solution to light green, pH was adjusted to 5.0 and diluted to 1litre with deionized water.

3. Sodium Hydroxide (40%): 400 gm NaOH pellets were dissolved in about in 500 ml distilled water and cooled down and the volume was made 1litre.

4. Hydrochloric acid (0.1 HCl): 8.3 ml of concentrated HCl was pipetted into 5oo ml distilled water and then volume was made 1 litre.

C. Phosphorus

1. Sodium Bicarbonate ($NaHCO_3$) 0.5 M extracting solution: 42 gm of $NaHCO_3$ was dissolved in 1 litre distilled water. The pH was adjusted to 8.5 with 1 M NaOH (4 gm NaOH per 100 ml water) solution.

2. Ammonium molybdate solution: 40 gm of ammonium molybdate was dissolved in 1 litre distilled water.

3. Ascorbic acid solution: 26.4 gm of L-ascorbic acid was dissolved in 500 ml distilled water.

D. Potassium

1. Sodium bicarbonate ($NaHCO_3$) 0.5 M extracting solution: 42 gm of $NaHCO_3$ was dissolved in 1 litre water. The pH was adjusted to 8.5 with 1 M NaOH (4 gm NaOH per 100 ml water) solution.

2. Ammonium molybdate solution: 40 gm of ammonium molybdate was dissolved in 1 litre distilled water.

3. Ascorbic acid solution: 26.4 gm of L-ascorbic acid was dissolved in 500 ml distilled water.

PHOTO TEMPLATES

Photo Template 1: Sampling plot laid in field

Sampling design 2 m ×2 m main plot and nested plot of 1 m × 1 m

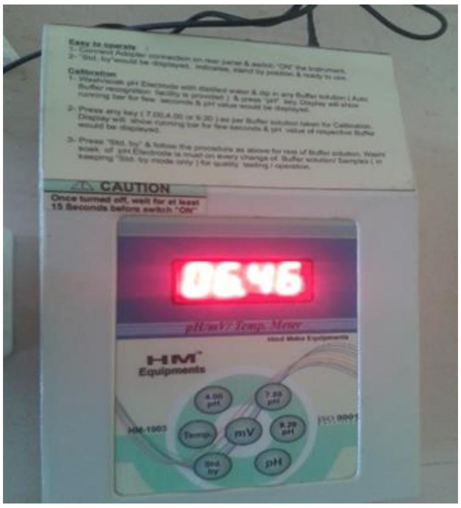
Doing the field activities (me with my Supervisor)

Photo Template 2: Laboratory work during soil test in field

a) Drying of soil samples

b) Weighing of soil

c) Soil Organic Carbon (SOC) Test in lab



d) pH meter used during soil test

e) Soil Nitrogen test


f) Soil Phosphors and Potassium test