Study of Temperature Variation over Nepal and its different topographic regions between 1989 and 2010

By
SHRESTHA SAHAJ 51210647
Supervisor: Professor Dr. SANGA-NGOIE Kazadi

A Thesis Submitted In Partial Fulfillment of the Requirements for the Degree of
MASTER OF SCIENCE

Submitted to the
Graduate School of Asia Pacific Studies
Ritsumeikan Asia Pacific University
Beppu, Oita, Japan
May 2012

ACKNOWLEDGMENTS

I want to extend my heartfelt thanks and gratitude to everyone who helped me to successfully complete this thesis. My foremost gratitude goes to my supervisor Professor Dr. Sanga-Ngoie Kazadi, for advising and teaching me in various ways throughout my two years in the masters' course. Without his guidance, I would not have been able to complete this thesis.

Secondly, I also want to express my thankfulness from the bottom of my heart to my seminar members and ENVOL members for their assistance and encouragement throughout this research work. Special thanks to Mr. Seth Mberego without his assistance and support, I would not have been able to complete this work. Thank you Mr. Seth for all your support and guidance and tolerating me for two years. I would also like to extend my thanks to Professor Dr. Kobayashi Shoko for her earnest contribution during this research and for always guiding me when I was lost.

Thirdly, my heartfelt gratitude goes to my Father, Mother and my dearest sister who supported me not only financially but also morally throughout my studies at Ritsumeikan Asia Pacific University. Also special thanks to my father for finding the source to the temperature data and also to my sister who went through the proof reading.

Last but not the least, my gratitude goes to my friends who always supported me in various ways and also to my part time job manager for understanding the importance of this thesis and allowing me to take leaves when I asked for.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ASL	Above Sea Level
°C	Degree Celsius
GLOF	Glacial Lake Outburst Flood
GDP	Gross Domestic Product
HDR	Human Development Report
H	Himalayan (Region)
ICIMOD	International Center For Integrated Mountain Development
IPCC	Intergovernmental Panel on Climate Change
NEA	Nepal Electricity Authority
MW	Mega Watt
MM	Middle Mountain (Region)
SOI	Southern Oscillation Index
SLP	Sea Level Pressure
SST	Sea Surface Temperature
SW	Siwalik (Region)
TAR	Terai (Region)

ABSTRACT

The mountain environments are regarded as one of the most sensitive indicators of climate change and global warming. There are numerous studies and researches that have discovered that the glaciers in the Himalayas are retreating very fast due to which many new glacial lakes are forming and the existing ones are expanding in size. Due to the fast retreating of glaciers, dangerous flash floods, which are known as Glacial Lake Outburst Flood, have occurred very frequently in Nepal. The increase in the global temperature has directly and negatively affected the glacial environment in the high mountain regions of the world. According to studies, although precipitation is an equally important factor to be considered for climate change, temperature plays the most important role. Moreover, studies have also shown that, fluctuation in the glacial area in the Himalayan region have directly followed the variations with surface air temperature more than with variation in rainfall. Therefore, it has become very important to study the trends in maximum, minimum and mean temperatures in various temporal settings of the country to be able to forecast the future impacts by changing in temperature on the natural environment.

Since Nepal has a very unique topography with altitude ranging from 60 meters in the south to more than 8000 meters in the north, in this research, temperature data from a network of 60 meteorological stations covering all of Nepal was studied to reveal the temperature trends in various temporal and different topographic locations. Using the simple linear regression method, daily, monthly, seasonal and annual maximum, minimum and mean temperature, trends between 1989 and 2010 were studied for the main four topographic regions of Nepal which is divided on the basis of altitude. The results showed that years with lower temperature trends were followed by years with extremely high temperatures which saw events of glacial lake outburst flood. Moreover, the results also indicated that the mean temperature in Nepal had increased by 0.4°C between 1989 and 2010. Most importantly winter season in Nepal is experiencing the highest increasing trend in temperature indicating that winters are becoming warmer with time. Furthermore, the regions with higher altitude in Nepal are undergoing highest increase in temperatures compared to other regions.

CHAPTER ONE: INTRODUCTION

1.1 Background of the Study

Nepal is a land-locked country, which lies between two big countries; India and China. Although the country is deprived of direct access to the world through sea, it is gifted with rich natural resources. It is homeland for some of the highest mountain peaks in the world that provide a rich source of water not only to Nepal but also India, Bangladesh and billions of people in South Asia (Kattlemann, 1987; Alford, 1992; Barnett et al., 2005; Xu, 2008). Although there are over 6000 rivers (CBS, 1995) flowing down from the Himalayas, the majority of Nepal's population still suffers from a clean and stable supply of water for their basic need such as nutrition, sanitation, energy and livelihood (WHO, 2007).

Climate change is an important indicator of global warming (Gray, 2001) that has recently had an enormous impact on Nepal's water source availability and security (Alford, 1992; Stern 2006). Moreover, temperature increase at higher elevation region of Nepal has caused Himalayan glacier to melt permanently, which has led to increase in size of glacial lakes and ultimately resulted in over flow and cause flash floods in villages downstream (Yamada, 1998). The technical term for these flash floods is Glacial Lake Outburst Flood (GLOF) and they occur due to destruction of natural moraine dam which is holding the glacial lake in a very unstable location on the mountains. Recently, these floods have not only occurred more frequently than before but also occurring in different season. For instance, the flash flood from the Himalayas have usually occurred during the summer season in Nepal, however, recently in 2012 an unexpected flash flood occurred during spring season (ICIMOD, 2012).

On the other hand, with rising temperatures, glaciers are melting at a higher rate (MoPE, 2004) causing uncertainty of water from these glaciers for the future if the area of glaciers in the Himalayan region decrease. If most of the glaciers melt in the future, livelihood of billions of people who directly or indirectly depend on the water from the Himalayas will be negatively affected (Singh et al. 1994a).

1.2 Problem Statement

Rising temperature has become an alarming issue for Nepal, especially in the mountainous regions (New et al, 2002). It has direct impacts on the glacial environment of the Himalayan region of Nepal which indirectly influences the natural environment and the livelihood of people living downstream. For instance, glacial lakes are naturally created when the mother glaciers above it melts. When the lakes can no longer hold the increasing amount of water, it releases all the water inside it with a flash and this event washes away everything on its way including houses, properties and also damages agricultural field downstream (Vuichard and Zimmermann, 1987).

In context with above situation, it is necessary to understand the temperature trends not only of Nepal as a whole but also of different topographic locations of the country. Nepal has a very unique topography with low plains on the south extending to high mountain regions in the north and temperature varies with rise in altitude. Moreover, different locations would have different temperature change patterns. Studying the temperature trend of the whole country would not provide enough information for future studies because of variations of temperature in different regions. However, studying the temperature trends of various locations of the country would provide clear information about trends in the temperature change in every region. This would help to locate areas with high temperature increase and further studies can be carried out in those regions. For instance, one of the most important questions that can be answered is; which areas are likely to experience faster retreating of glaciers due to increasing temperature in the near future?

Therefore, this research will examine the temporal heterogeneity and the topographic dynamics of the temperature of Nepal using daily maximum, minimum and mean temperature data of 60 representative stations between 1989 and 2010. This can be further explained within the two categories. Firstly, the temporal variations in the average temperature of Nepal will be studied as the first step to understand the short period changes. By studying the temperature data of Nepal of 22 years between 1989 and 2010, using the results from this study, further analysis can be carried out in the future. It can also help to understand the temperature change patterns that will further help to establish future scenarios for predicting natural calamities such as the glacial lake outburst flood.

Secondly, in addition to looking at temporal variations, it is important to study the topographic temperature variations in Nepal to understand if the temperature variations are different in different regions and by how much because Nepal has a very complex topography. The altitude ranges from about 60 meters in the south to about 8000 meters in the north ((Marahatta et al. 2009). In this part of the study, annual and seasonal maximum and mean temperatures of Nepal over 22 years from 1989 to 2010 will be analyzed in detail by dividing the country into four topographic regions. Finally, this study will also try to study, what kinds of environmental changes (especially in the glacial environment of the Himalayas) has occurred between 1989 and 2010 and what are the consequences or events that have been brought up by the different temperature changes (with special attention to Melting Glaciers and Glacial Lake Outburst Flood in Nepal).

1.3 Objectives of the Study

The objectives of this study are to:

- ✧ Analyze the annual maximum, minimum and mean temperature trend.
- ✧ Study the seasonal maximum, minimum and mean temperature trends for each months.
- ✧ Investigate the monthly maximum, minimum and mean temperature trends.
- ✧ Analyze the annual trends for number of hot and cold days in Nepal.
- ✧ Analyze the annual trends for maximum and mean temperatures for different physiographic regions of Nepal
- ✧ Study the seasonal trends of mean temperature in four major physiographic regions of Nepal.

1.4 Research Questions

Some of the research questions that this studywill try to answer are:

1. How has the maximum, minimum and mean temperatures changed in Nepal over the last 22 years (1989 – 2010)?
2. What are the seasonal and monthly temperature variations in Nepal?
3. Have the number of hot and cold days in Nepal increased or decreased?
4. Which regions of Nepal are experiencing highest temperature variations, and which seasons in those regions are experiencing the highest temperature variations?

1.5 Scope of the Study

A wide range of relevant literature review is carried out to understand the current situation of temperature trend in Nepal and its impact especially on the mountain regions. The main focus of the study will be on the melting glaciers and the increasing number of glacial lakes and its outburst flood. However, in this study, the main aim will be to study the temperature trends of Nepal as a whole and also in various topographic regions of Nepal to have a clear understanding of temperature trends in the country for the future study. Most importantly a very rich data set of maximum, minimum and mean temperatures, obtained from a vast network of 60 meteorological stations covering all of Nepal from 1989 to 2010 will be studied thoroughly. From the results of analysis of this temperature data set, a clearer picture of temperature trends in Nepal will be presented for recommendations and future studies.

1.6 Organization of the Paper

Chapter One was the introductory chapter which covered the background information, the problem statement and the main aims of the study. *Chapter Two* includes the literature study and tries to understand the importance of studying the temperature trends for Nepal. *Chapter Three* explains the research methodology including the data used in this study in order to analyze the temperature trends of Nepal. This chapter also includes the limitation of the study. *Chapter Four* explains the results that were found after analyzing the temperature data of Nepal. *Chapter five* discusses the results and tries to relate to some of the events discussed in the literature review. Finally, *Chapter Six* summarizes the thesis and also includes the conclusion, recommendations from the study and proposition for future works.

CHAPTER TWO – LITERATURE REVIEW

2.1 About Nepal – Country Situation

Landlocked between India and China, Nepal is located at 26°22` to 30°27` N latitude and 80°4` to 88°12` E longitudes with altitudes ranging from 60 meters in the south to 8,848 meters in the north with highest mountain peak in the world; Mt. Everest. Agriculture provides with the main source of income to most of the people in Nepal with eighty percent population engaged in agriculture sector contributing 38 % of the GDP (HDR, 2007/2008). Poverty has existed in Nepal for many years. Currently, 30.9% of the population still lives below poverty line. Nepal is the poorest country in South Asia and twelfth poorest country in the world (HDR, 2007/2008).

Nepal covers an area of 147,181 Km^2 and can be divided into five main regions which are; Terai, Siwalik, Middle Mountains, Himalayas and Trans Himalayas from lowlands to high mountains (Marahatta et al. 2009). In terms of natural resources Nepal has a network of more than 6000 rivers flowing all over the country from the Himalayas in the North. These rivers provide Nepal with hydropower potential of about 83,000 MW, as well as supply water to billions of people in India and China (WECS, 2010). However, Nepal has only been able to exploit about 1 % of its potential in hydropower (NPC/UNDP, 2005). Access to electricity varies widely between the urban and the rural area. In urban areas, the access to electricity is about 87% whereas in the rural areas it is only 27% of population that have access to electricity (NPC/UNDP, 2005).

Majority of people in Nepal depend on primary sources of energy such as forests for firewood, timber and medicine plants and depend directly on the environment and nature. There are large population living near the high hill areas and they are very vulnerable to any change in the environment around them.

2.2 Temperature Trends in Nepal

Rising temperature is causing glaciers to melt worldwide, including the mountainous glaciers of the Himalayas in Nepal. This issue not only puts billions of people who are depended on the water from these mountains at risk from droughts and lack of drinking water in the future, if all the glacial snow melts down permanently but also from floods which have recently become more frequent downstream. Glaciers have been retreating on earth since the end of the little ice age around the 1850s, but during the recent years, glaciers are retreating at an alarming rate than ever (Dyurgerov and Meier, 2000). The rate at which the glaciers melt will worsen with projected climate change over the next few decades. It is expected that the average global temperatures will increase by 1.4 - 5.8 ºC by the end of this century (IPPC, 2001). Based on simulated modeling by Oerlemanns et al. (2000), with 4 ºC increase in temperature; nearly all the glaciers in the world could meltdown.

2.3 Impacts of Temperature Increase in Nepal

The impacts of climate change and rising temperatures in Nepal had been felt in many sectors of Nepal. There are many evidences from the past and it is likely to be more severe in the near future. This part of paper will discuss the impacts in some of the most important areas.

2.3.1 Impacts on Agricultural Sector

Weather is a very important atmospheric condition at the timescale of the surface and has a significant impact on the agriculture (ICIMOD/UNEP, 2007). Agriculture in Nepal is equally more sensitive to short term changes in weather because it affects the production of the crops (Malla, 2008). For example increase in the temperature causes drought, whereas flow of too much water from the Himalayas in short period of time causes floods. Agriculture is a very important sector for Nepal's economic growth. A total of 3,091,000 ha of area are used for cultivation purposes in the agricultural sector, out of which 38.15 % accounts for the GDP (Malla, 2008).

Increase in the temperature has also negatively affected the agricultural sector in Nepal. Some studies show that they have caused high fluctuations in cereal crops such has rice and wheat. For instance, vulnerability measurement test for of rice demonstrated that 4°C rise in temperature would result in marginal increase of yield from 0.09 to 7.5 % and after that it would only continue to decrease (Malla, 2003). Some studies have shown in the case of wheat that, increase in temperatures showed an increase in output in some parts of Nepal but decline in most parts. Maize yield has also shown a decline in production with increase in the temperature (Malla, 2003).

Changes in temperature trends have also negatively affected the herding of livestock in Nepal. Yaks (UNFCCC, 2004); which are the most important local asset in high region of Nepal are very sensitive to climate change because they can only survive in cold conditions between 0 – 10°C. Generally these Yaks are nurtured in areas with altitude between 3000 and 5000 meters ASL. During the winter season when the temperature hits lower peak, these Yaks are brought down to 3000 meters and taken back up when temperature rises. Moreover, these movements are carried out on a fixed time of the season due to equal benefits for every herd for their food. There have been many problems of Yak herds refusing to return back to shelter because they cannot withstand the temperature in the same period of time when they could return before. The increase in temperature trends has affected the local communities and their livestock in a very negative manner and has made it difficult for them to adapt with the changes in climate (Nepal's initial national communication to UNFCCC, 2004).

The important lesson to be learnt is that, the agricultural sector is still one of the most important sectors in Nepal and changes in temperatures in different areas of Nepal could adversely affect the natural ecosystem.

2.3.2 Impacts on Water Resources

Rivers flowing from the mountains are the main sources of water resource in Nepal with river basin spread over diverse geographical locations. It was estimated that the available surface water of 202 cubic kilometers would only fulfill the demand of water in

Nepal however, only 26 cubic kilometers of water is available in dry season showing that water scarcity in Nepal is a major issue if the resource is not manage and used properly (Romilly and Singh, ADB 2009) . Furthermore, rising temperatures have caused glaciers to melt at shocking rates making water availability uncertain for the future.

2.3.3 Impacts on Hydro Electricity

99% of Nepal's electricity comes from the source of Hydropower (EIA, 2006) and these hydropower plants are feed by Runoff Rivers which flow from the Himalayas. According to Nepal Electricity Authority (2008), electricity in Nepal is supplied through 10 medium sized and 49 small hydropower plants which are owned by NEA and some are owned by Individual Power Producers (IPP) which are the private companies (NEA, 2008). Unfortunately, the electricity supply by the NEA since annual year 2005/2006 has been in deficit. See Table 2.1.

Table 2.1 Electricity Demand and Peaking Capacity of Nepal

Existing Hydro	Installed Capacity (MW	Peaking Capacity (MW)	04/05	05/06	06/07	07/08	08/09	09/10
Total (hydro)	574.213	448.24	448.24	448.24	448.24	448.24	448.24	448.24
Total Thermal	56.71	43.00	43.00	43.00	43.00	43.00	43.00	43.00
Peaking Capacity (MW)			530.24	532.74	536.34	621.64	648.64	668.04
Peak Demand(MW)			556.30	593.60	634.20	697.70	757.40	821.70
Surplus (MW)			-26.06	-60.86	-97.86	-76.06	-108.7	821.70
Import (MW)			50	50	50	50	50	50

Net Surplus			23.94	-10.86	-47.86	-26.06	-58.76	-103.6

Table showing Demand and peaking capacity of Electricity from 04-10
Source: NEA (2010)

The installed capacity of hydro electricity in the NEA's national grid accounted for 574.213 MW including 147.083 under private ownerships, 56.71 MW thermal and 50 MW imported from India during the time of deficit as Indo – Nepal power Exchange agreement. Even after utilizing thermal power and imported energy from India during the deficit, it only resulted in a substantial number of hours of load shedding nationwide. It is estimated that Nepal has the capacity of producing 83,000 MW of electricity with its available water resources out of which 46,000 MW are potentially feasible (WEC, 2010). This is one of the highest hydropower potential in the world. There are already many installed hydropower plants and many are under construction, however, the current issue of melting glaciers puts a threat to the hydro electricity sector of Nepal. Many hydropower plants have already been destroyed in the past (discussed later in the paper; table 2.2) by flash floods and on the other hand, availability of water for the future from the glaciers above is still a big debate.

2.3.4 Impacts on the Himalayan Glaciers

Increasing temperature has the most significant impact on the glacial environment in Nepal and this is the most important sector that needs serious research and study. There is a large number of scientific evidence proving that the glaciers in the mountain region in most part of the world is decreasing drastically due to the warming trends. For instance, according to a research carried out by the United States Geological Survey using Satellite data, there has been a significant reduction of mountain glacier in the Andes, the Himalayas, the Alps and the Pyrenees over the past decade (Wessels et al. 2001). Also in a study by

Dyurgerov and Meier in 1997, published in their research that there was a mass balance reduction of about 6000 to 8000 km2 in glacier area globally over a period of 30 years between 1961 and 1990.

Furthermore, the World Glacier Monitoring Service also announced that the mountain glaciers have decreased at a global scale based on their research measurements taken over the last century. They also revealed that the glaciers that shrunk in the first half of the 20^{th} century had started to grow after 1950s, but the retreat of the glaciers at global scale rapidly accelerated from 1980s (Haeberli and Hoelzle, 2001). And according to IPCC, half of the global mountain glaciers could be lost by 2050 (IPCC, 1996b). Altitudinal Temperature Lapse rate Analysis carried out by MoPE (2004) in aspect to climate change recommended that twenty percent snow mountain area above 5000 meters altitude have high likelihood of completely melting down with an increase of air temperature by 1°C and with 3°C increase, it could result in more than half of the snow in the region to melt down completely. (MoPE, 2004).

The Himalayas, which provided water, supply to billions of people by feeding into seven great rivers in the Asia; Ganga, Indus, Brahmaputra, Salween, Mekong, Yangtze and Huwang He, is also shirking in the glacier area. In 2009, Shrestha and Mool investigated the Dudh Koshi basin in the eastern part of Nepal, which is the country's largest basin with most populated area in terms of glaciers and glacial lakes. Using the Thematic Mapper ((TM)) band 4 and 5 for glacier delineation, 278 glaciers with total area of 482 km2 and an ice volume of 51 km3 were studied. The average minimum retreat rate was calculated at 10 m a -1, observed on Langdak, West Lhotse, Lhotse and Setta glaciers. The Imja glacier retreated at 34 m a -1 from 1962 to 2000 which increased to 74 m a -1 from 2000 to 2007. Imja glacier is the faster retreated glacier now in the Himalayan region (Bajracharya and Mool, 2009). See figure 2.1

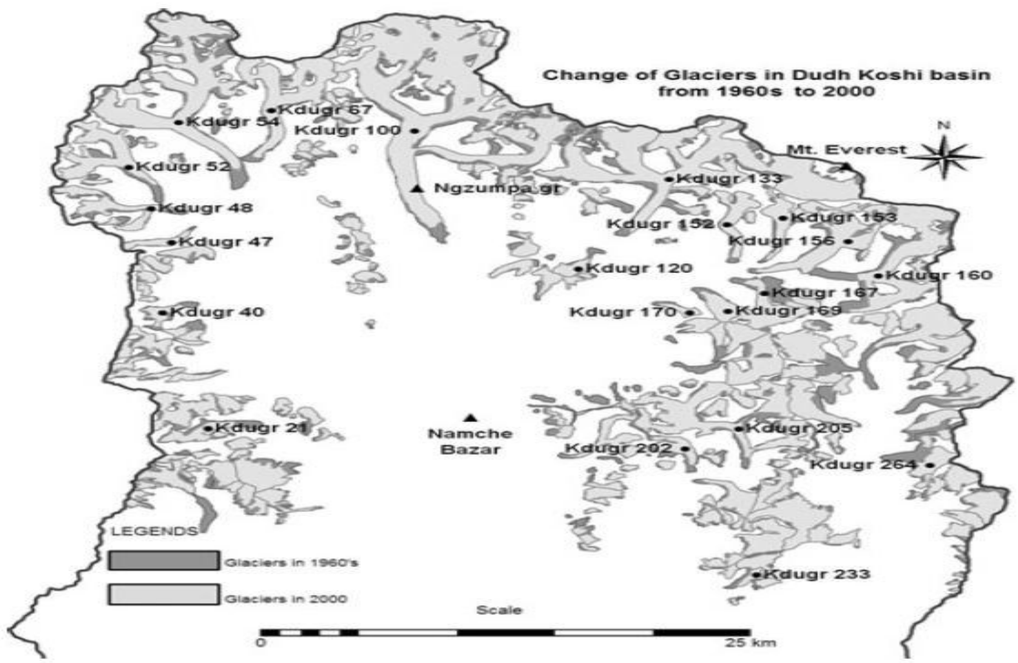


Figure 2.1 Changes noticed in glaciers at the Dudh Koshi Basin in Nepal between 1960 and 2000. (Source: Bajracharya and Mool, 2009)

2.4 Increasing Glacial Lakes in Nepal

With the rapid retreating of glaciers, many new glacial lakes are forming below the mother glaciers and the existing lakes are increasing in size. Using the satellite data LANDSAT image from 2001, Bajracharya and Mool (2005) found that 37 % of glacial lakes in the Dudh Koshi Basin of Nepal has disappeared but they are mostly supra glacial or erosion lakes or too small to be mapped. Some of it has transformed into moraine dammed lakes. Moraine dammed lakes are formed when the melting snow from the mother glacier is contained by a naturally formed terminal moraine, which acts like a dam. However, 21 % of lakes that were associated with the mother glacier had increased in size, 34 major glacial lakes had grown and 24 new major lakes have appeared (Bajracharya and Mool, 2005).

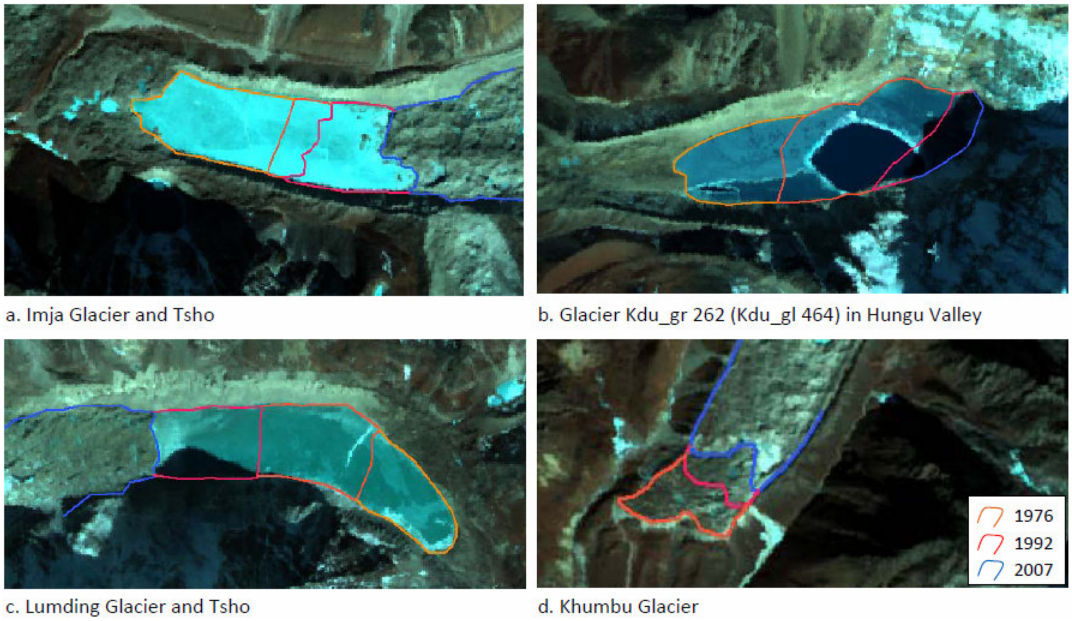


Figure 2.2 Some examples of retreating glaciers and expanding Glacial Lakes in the Dudh Koshi Basin of Nepal. (Source: Bajracharya, 2008)

Tsho Rolpa is the largest glacial lake in Nepal which occupies an area of 1.76 km^2. In the late 1950s, it was just a group of small water bodies, but in 2002 they merged and increased to its present size as shown in figure 2.3 (Shrestha, 2008).

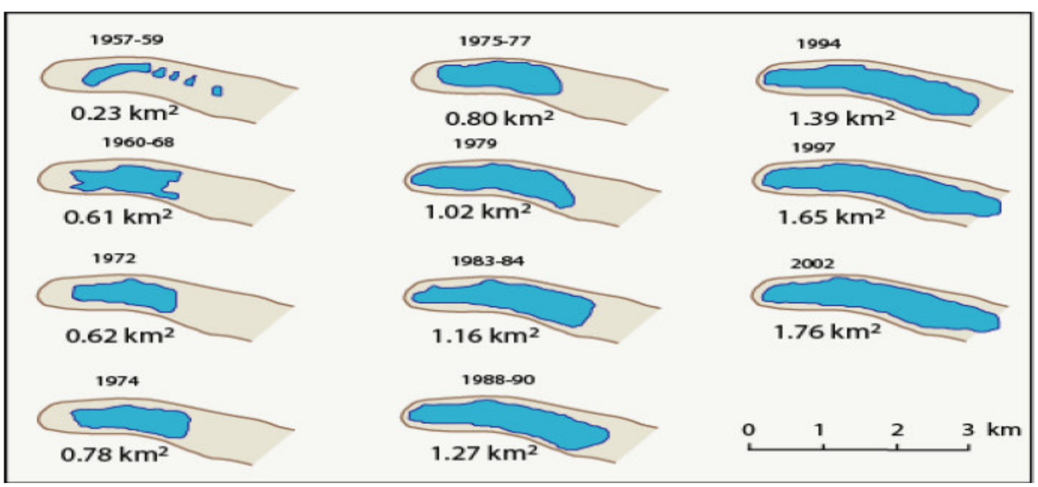


Figure 2.3 Expansion of Tsho Rolpa Glacial Lake in Nepal from 1960 to 2002.
(Source: Shrestha, 2008)

2.5 Potentially Dangerous Glacial Lakes in Nepal

Between 1991 and 2001, an inventory of glaciers and glacial lakes in Nepal was carried out by International Center of Integrated Mountain Development (ICIMOD) using topographic maps publish by the Survey of India and by the Survey Department, Government of Nepal together with LANDSAT TM, Indian Remote Sensing data and some SPOT satellite images (Ives et al. 2010). This inventory identified 3,252 glaciers with a total area of 5,324 km^2, and 2,323 glacial lakes with a total area of about 76 km^2. According to ICIMOD, most of the lakes were small in size and most likely originated in the recent past. A total of 20 glacial lakes were recorded as potentially dangerous glacial lakes in Nepal based on criteria that were defined by the study carried out by ICIMOD. See Figure 2.4.

Figure 2.4 Locations of Potentially Dangerous Glacial Lakes in Nepal.
(Source: UNEP/ICIMOD, 2010)

The criteria defined by ICIMOD included, large lake size and rapid growth, increase in Lake water level, dam conditions, physical condition of the surrounding, condition of the glacier, position of the lakes in relation to moraines and associated glacier and so on. Similar studies were also carried out in Bhutan, Tibet, India and Pakistan. In Bhutan a total of 677 individual glaciers with a total area of approximately 1,317 km^2 and 2,674 glacial lakes out of which 24 were identified as potentially dangerous lakes. In the Tibet Autonomous Region of China, 824 lakes covering an area of 85.19 km^2 were identified out of which 77 were categorized as potentially dangerous lakes.

2.6 Glacial Lakes Outburst Floods Events in Nepal

Although the exact location and other precise information is still not clearly recorded, the first known flash flood that originated from the Hindu Kush Himalayan region of Nepal dates back about 450 years ago that occurred along the *Seti River* District of Nepal. The event is said to have occurred due to a catastrophic outbreak of a lake situated behind the *Macchapuchare* Mountain in Nepal. It was most likely triggered by a seismic activity (Carson, 1985). After that many other flash flood events took place in Nepal in the higher regions, most of which went unnoticed because of their small or negligible impact.

However, in 1981, the *Zhanzhangbo* Glacial Lake located between the boundaries of Nepal and China near Tibet ruptured resulting in flash flood downstream. This flash flood destroyed the *Sun Koshi* Hydropower Station in Nepal, including the Nepal-China friendship bridge, two other bridges and the *Arniko Highway*. *Arniko highway* is one of the most important highways in Nepal as it not only connects Nepal with China but also serves as the main route for transportation of goods between Nepal and China. The total losses were calculated at more than USD 3 million (XuDaoming, 1985).

In an early beautiful afternoon in August 1985, the outbreak of *Dig Tsho* Glacial Lake located below the Langmoche Glacier in the Khumbu Himal region of Nepal destroyed the almost completed Namche Hydro Power Plant at 12 kilo meters downstream with an unexpected flood. It also washed away 30 houses, 14 bridges, trails and cultivations lands were also destroyed. This event killed 4 to 5 people including live stocks. The cost of the destruction made by this event was estimated at US$ 1.5 Million (Ives, 1986; Vuichard and Zimmerman, 1987). Figure 2.5 shows the picture taken during the flash flood. The picture on the left is every scene of the flowing river and on the right is the picture taken during the flood event. The picture on the right shows how the entire area is flooded by the mix of water, ice, debris and other materials brought by the outburst of the glacial lake.

Figure 2.5 Namche Hydropower Site before (left) during (right) the Glacial Flood event in 1985. (Source Vuichard and Zimmerman, 1987)

Similarly on September 3rd 1998, Tam Pokhari Glacial Lake whichh is formed at the tongue of the Sabai Glacier broke open releasing 17 million m3 by a breach 42 m deep downstream. This disaster killed two persons and destroyed 4 bridges and two wooden brides including farmlands (Dwivedi et al 1999). Recently on May 5th 2012 morning, flash flood in the Kaski District of northwestern Nepal killed 29 people and left dozens missing (ICIMOD, 2012). Moreover, this Glacial Lake Outburst Flood that originated from the east of Mount Machhapuchre and flowing down the Seti River caused great loss of property including homes, business, crops and livestock (ICIMOD, 2012).

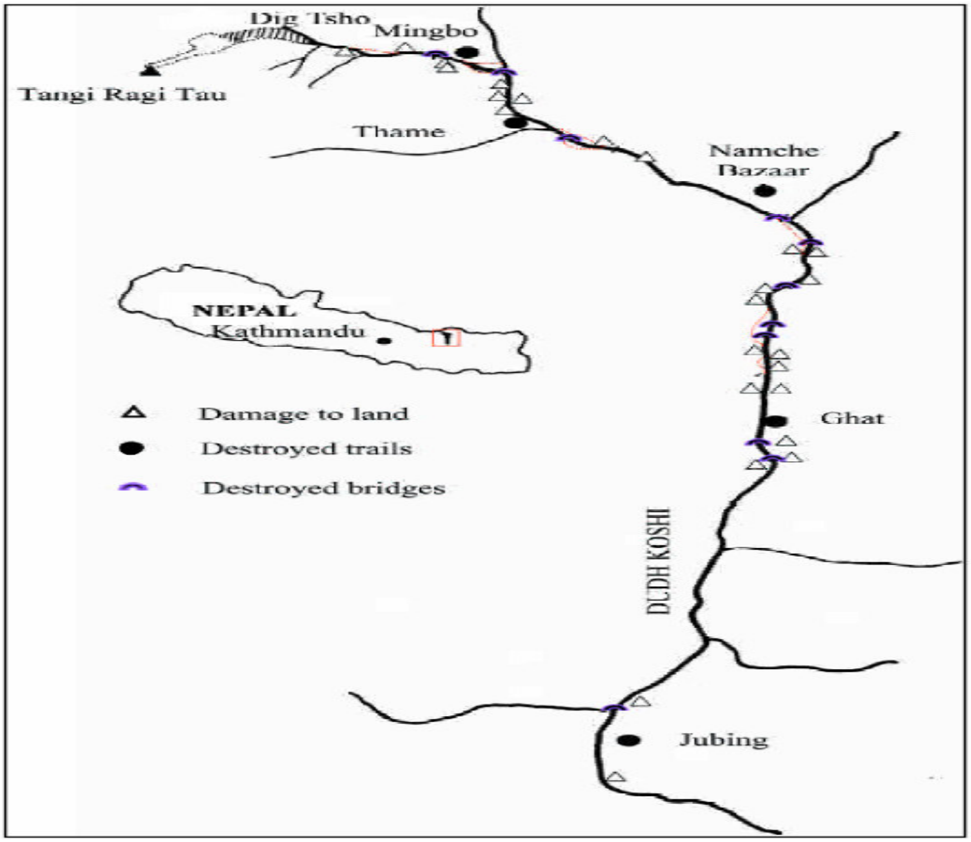


Figure 2.6 Map Showing location and type of destruction by the GLOF on August 1985
(Source: Vuichard and Zimmerman 1986)

These kinds of natural events have mostly occurred during summers in Nepal (see Table 2.2), when temperature and rainfall is highest during the year. However, the GLOF in 2012 occurred in May, during the spring season and shocked the local people around the region. This could be a warning of increasing temperature and its impacts on the glacier environment in the Himalayas.

Table 2.2 shows list of all the recorded Glacial Lake outburst flood events in Nepal and its information. Similarly, Figure 2.7 shows the site where the flood originated. From the table, it can be seen that most of the events have taken place in the Koshi Basin of Nepal. Nepal can be divided in four major river basin systems which are Mahakali, Karanali, Ganghaki and Koshi. Most of the outburst flood events have taken place in the Koshi basin (on the map right part of Nepal). Although most of the details are not available due to the remote location of the site, between the years 1998 and 2003, most outbursts were originated due to the collapse of the moraine.

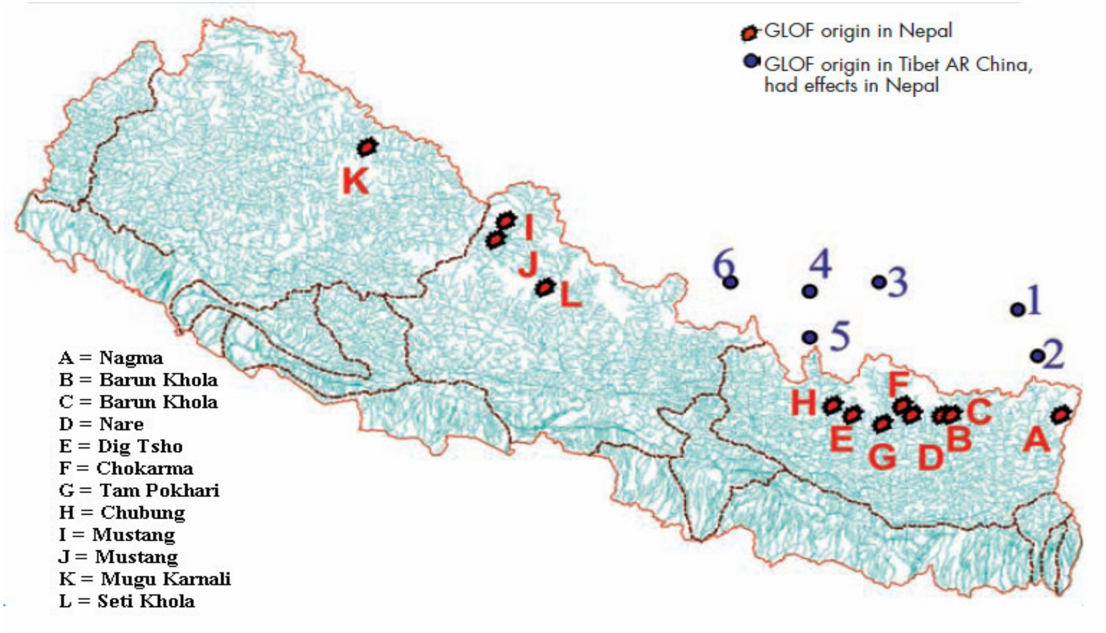


Figure 2.7 Location of Glacial Lake Outburst Floods that occurred in Nepal and Tibet. Source: Modified from Mool et al. (2001a)

Table 2.2 List of Known Glacial Lake Outburst Floods that occurred in Nepal

	Date	River	Lake	Cause	Losses
1	450 Years Ago	Seti Khola	Macchapuchhare	Moraine Collapse	Pokhara Valley Covered by 50-60m Debris
2	Aug 1935	Sun Koshi	Tara-Cho	Piping	66,700 m2 of wheat field, livestock, others
3	Sept 1964	Arun	Gelhalpco	Glacier Surge	Highway and 12 trucks
4	1964	Sun Koshi	Zhangzangbo	Piping	No remarkable Damage
5	Aug 1964	Trisuli	Longda	Not known	Not Known
6	1968	Arun	Ayaco	Not Known	Road, Bridges, others
7	1969	Arun	Ayaco	Not Known	Not Known
8	1970	Arun	Ayaco	Not Known	Not Known
9	Sept 1977	Dudh Koshi	Nare	Moraine Collapse	Mini Hydropower Plant
10	June 1980	Tamor	Nagma Pokhari	Moraine collapse	Villages Destroyed 71 Km from source
11	July 1981	Sun Koshi	Zhangzhangbo	Glacier Surge	Hydropower Station and others
12	Aug 1982	Arun	Jinco	Glacier Surge	Livestock, Farmland

13	Aug 1985	Dudh Koshi	Dig Tsho	Ice Avalanche	Hydropower Station, 14 Bridges and others
14	July 1991	Tamakoshi	Chubung	Morain Collapse	Houses, Farmland and others
15	June 1995	Trisuli	Zanaco	Not Known	Not Known
16	Sept 1998	Dudh Koshi	Tam Pokhari	Ice Avalanche	Human Lives and more than Nrs. 156 Million
17	Unknown	Arun	Barun Khola	Moraine Collapse	Not Known
18	Unknown	Arun	Barun Khola	Moraine Collapse	Not Known
19	Unknown	Dudh Koshi	Chakarma Cho	Moraine Collapse	Not Known
20	Unknown	Kali Gandaki	Unnamed (Mustang)	Moraine Collapse	Not Known
21	Unknown	Kali Gandaki	Unnamed (Mustang)	Moraine Collapse	Not known
22	Unknown	Mugu Karnali	Unnamed (Mugu Karnali)	Moraine Collapse	Not known
23	Aug 2003	Madi River	Kabache Lake	Moraine Collapse	Not Known
24	Aug 2004	Madi River	Kabache Lake	Moraine Collapse	Not known
Source : Ives J D et al. 2010					

2.7 What is Glacial Lake Outburst Flood

A Glacial Lake Outburst Flood (GLOF) is a catastrophic discharge of large volume of water which is mostly the results from melting of the glaciers (WWF, 2005). GLOF is characterized by a type of large river flow that is caused by an outburst of a glacial lake. It is generally caused by increase in volume of melted water in the glacial lake which may lead to over topping, eventually resulting in failure of damming moraine due to instability. These floods contain not only water but also heavy debris and other materials which are collected on its way downstream. Therefore, they flow with great devastating power compared to a normal water flood. The rushing water not only erodes the banks of the river but also causes landslides from the steep slopes along the river channel (Yamada 1998). The total amount of debris flowed in the Zhangzangbo GLOF that occurred in 1981 was estimated to be about four million m3. In the 1985 Dig Tsho GLOF, the volume of the debris was estimated at three million m3 (Vuichard and Zimmerman, 1987). These kinds of flash flood with strong characteristic destroy everything on its way.

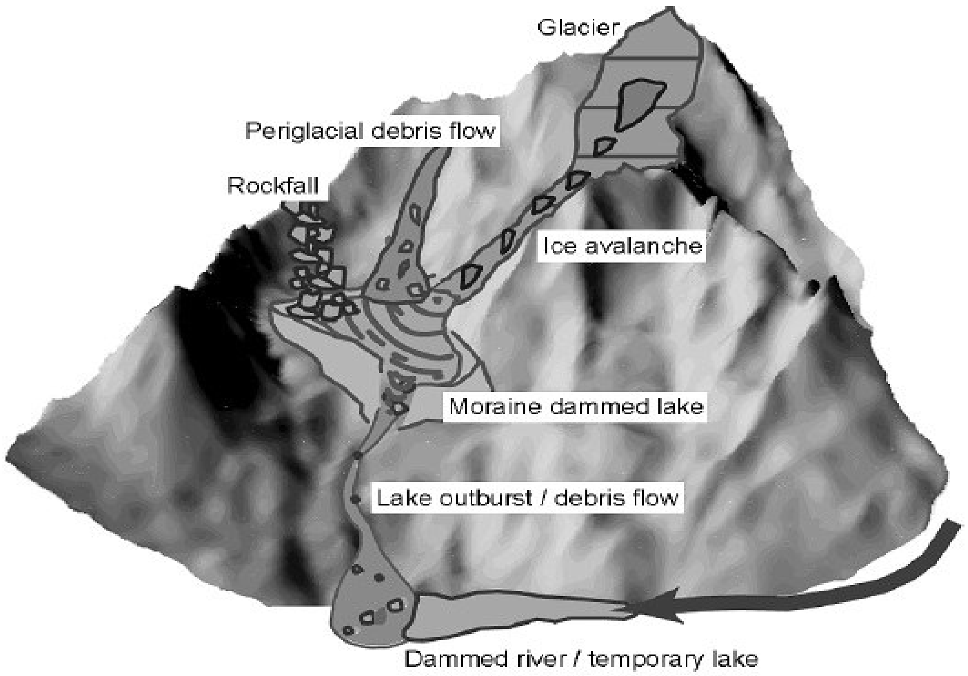


Figure 2.8 Glacial Lake Outburst Flood (Source: Huggel et al. 2004)

2.7.1 What are the Causes of GLOF

The moraine dam materials are almost completely made up by the debris which consists of large boulders, gravel, sand, silt and clay which are not yet merged together. And some moraine contains dead ice which is the softest rock found on the earth and is usually very close to the melting point in the Himalayan region. Therefore, the glacial lakes in the Himalayas regions are dammed by a moraine at a very instable condition which could flood out all the water inside with any critical triggering effect. The glacial lakes could burst due to two main factors (Yamada, 1998).

✧ **External Triggers**

Overtopping of the lake water over the moraine carries sufficient energy to break the moraine dam easily. This overtopping of the water in the lake is generally caused by a big wave created by triggers such as huge mass of snow or glacier avalanche falling down into the lake. Another trigger of the lake burst can be caused by advancing melting snow from the mother glacier beside the lake. Earthquakes should also be considered as external trigger for the lake burst (Yamada, 1998).

- **Self Destruction of a Moraine-Dam**

The moraine dam may self destruct by natural failure; directly related with the water level of the lake, which is the amount of hydrostatic pressure exerted on the dam wall. The size and shape of the glacial lakes may change from season to season every year. During the winters it would be frozen and disappear as a lake, again during the summer it would newly reopen and exist as a lake. This continuous activity weakens the dam which may lead to collapse without any particular triggering effect (Yamada, 1998).

2.8 Previous Studies on Temperature Trends in Nepal

The temperature observation study in Nepal can be dated back from 1960s. McSweeney et al. 2010, studied the mean annual temperatures between 1960 and 2003. Their results showed that mean annual temperature did not increase during the observed period. Moreover, according to their analysis temperatures decreased slightly particularly during the spring and winter season. Frequency of hot days also did not change significantly since 1960s but they noticed significant decrease in frequency of cold days and nights mostly in the winter and increased number of hot nights with rapid rates mostly in autumn season.

Another research on temperature trends in Nepal carried out by Shrestha et al. 2008 using 8 temperature stations between 1971 and 2006 revealed that there was a decrease in cool nights and increase in warm nights. Moreover most of the stations showed warming trends in the maximum temperature and high altitude regions showed more significant trends than low altitude areas.

Furthermore, temperature study between 1977 and 1994 showed that the maximum mean temperatures in Nepal have increased significantly (Shrestha et al. 1999). Shrestha et al. (1999) studied temperature data from 49 meteorological stations all over Nepal using linear regression and found out that the average annual temperature of Nepal had increased at the rate of 0.06 °C. Moreover, the increase in temperature was found more significant in the higher altitude region of Nepal than the lower altitude regions, and higher increased rates in the winter season compared to other seasons in the year (Shrestha et al. 1999).

2.9 Chapter Summary

Almost more than half of world's population depends on the supply of freshwater that is stored naturally in the mountains in form or snow or ice and provide source of water in form of rivers, streams with a melting runoff (Mountain Agenda, 1998). The rapid increase in melting of the glaciers in the Himalayas which provides source of water for drinking, irrigation, industrial use for several communities in South Asia, will cause water levels in the rivers to rise in the near future, which will ultimately result in series of floods and landslides (IPCC, 2001a). However, in far future, if all the ice melts in the moutains, there will be a huge reduction in glacial runoff that feeds the rivers downstream (IPPC 1996b, Wanchang et al. 2000). For instance, the loss of melting water in the Ganga River of India would reduce in the summer by two thirds which will cause shortages for 500 million people and 37 percent of India's irrigated land (Singh et al. 1994a).

One of the most important criteria defined by ICIMOD in 2001 is; temperature and the climatic condition. Large inter-annual variation was especially mentioned in their study as one of the most important factors. Glacier usually changes in size and shape according to the influence of climatic conditions. The climatic change would result in shifting of the glacier to another equilibrium size and shape (Yamada, 1998). Moreover, in a research by Seko and Takahashi (1991), they have proposed that over the last decade, fluctuation in the glaciers in the one of the Himalayan region of Nepal has followed the variations more with temperature than rainfall.

After studying numerous literatures it is known that the fast and nonstop retreating of glaciers and expansion of glacial lakes as well as creation of new glacial lakes in the mountain region of Nepal highlights the importance of not only monitoring the glaciers and glacial lakes but also requires a detailed study of temperature variations and trends on temporal and spatial settings. Therefore, by studying the temperature trends on seasonal as well as annual variation, future prediction and decision making, incase of natural calamities such as Glacial Lake outburst flood or adapting to changes in the natural ecosystem becomes easier for professionals and researchers in various fields.

It was also understood after reviewing the literature that previous studies on temperature trends in Nepal have failed to include large number of temperature station data in their studies. Although most of them have analyzed the annual temperature trends and seasonal trends they did not consider monthly temperature trends. Moreover, previous studies have either studied the mean temperatures or maximum and minimum temperatures with the latest year being 2006. Therefore, the significance of this research is that it aims to study the temperature trends of the country using daily maximum, minimum and mean temperature data from 1989 to 2010. And the analysis includes average of daily, monthly, seasonally and annual temperatures which are further analyzed in detail by dividing into four main topographic regions.

CHAPTER THREE: METHODOLOGY AND DATA

This chapter describes the general approach and methods adopted to address the objectives of the study. The chapter also explains the data and the limitations of the study. Moreover, this chapter includes the location of the meteorological station from where the temperature data was collected.

3.1 Methodology

To study the annual, seasonal and monthly temperature trends of Nepal on temporal and spatial basis, daily maximum, minimum and mean temperature from 60 meteorological stations in Nepal from 1989 to 2010 were used. The source of the temperature data is explained later in this chapter. The network of station was selected in a way that it encompasses all the climatic zones of Nepal as much as possible. However, due to the complex topography of the country and the limited number of stations, especially in high altitude areas, it was not possible to include temperature data from those regions.

Annual, seasonal and monthly temperature means were calculated for each year for all the 60 stations for representing whole of Nepal. The seasons were divided as spring (March – April – May), summer (June – July – August), autumn (September – October – November) and winter (December – January – February).

Table 3.1 Seasons and Months

Seasons	**Months**
Spring	March – April – May
Summer	June – July – August
Autumn	September – October – December
Winter	December – January – February

Since rainfall data was not used in this research monsoon season was not considered.

The mean of maximum, minimum and mean temperatures were calculated on annual, seasonal and monthly basis for all the stations from 1989 to 2010 and their trends were computed using linear regression.

Trends for the number of hot and cold days for each season were also calculated. To calculate the number of hot days, the average of daily maximum temperature for spring was first calculated. After calculating the seasonal maximum temperature for the season, the standard of deviation of the average for daily temperature average was calculated. The upper limit of the maximum temperature was calculated by adding the standard of deviation with the seasonal average temperature. All the days in the seasons that exceeded the upper limit of the seasonal maximum mean temperatures were counted as hot days. This calculation was done for each season and each year from 1989 to 2010. Similarly, for calculating the number of cold days, minimum temperature mean for the season was used. The lower limit of the average was calculated by subtracting the standard of deviation from the seasonal average and the days that were below the lower limit were counted as cold days.

To study the temperature trends on spatial scale, the stations were divided into four different categories based on the location of the stations and their altitude. The four different categories were, Himalaya Region, Middle Mountain, Siwalik and Terai. Although Nepal is divided into five topographic regions the highest region; Trans Himalayas was not studied due to unavailability of temperature data. After categorizing the temperature data for the four topographic regions of Nepal, the means for maximum and mean temperatures for those regions were then calculated and the trends were computed using linear regression.

Microsoft Excel was used extensively to rearrange and analyze all the data and also to compute the trends using linear regression. IDRISI Taiga by Clark Lab was utilized for geo referencing and analyzing the spatial distribution of temperature data and for studying the temperature by its location on the map.

3.2 Data Source

Nepal can be divided into five major physiographic regions; *Terai plain*, which is on the northern part of Nepal near India, Siwalik hills, which rises from the *Terai region* in the north and ends with the beginning of the middle hills. *Middle hills* which is also known as the *Mahabharata Range* and ranges from 1000 to 2,500 meters asl. and above it, is the *High Hills* which raises from 2,200 to 4000 meters asl. and then the *High Mountains* which consists of the main Himalayas and inner Himalaya valleys with the elevation from 4000 to 8,848 meters asl. (Marahatta et al. 2009). Figure 3.1.

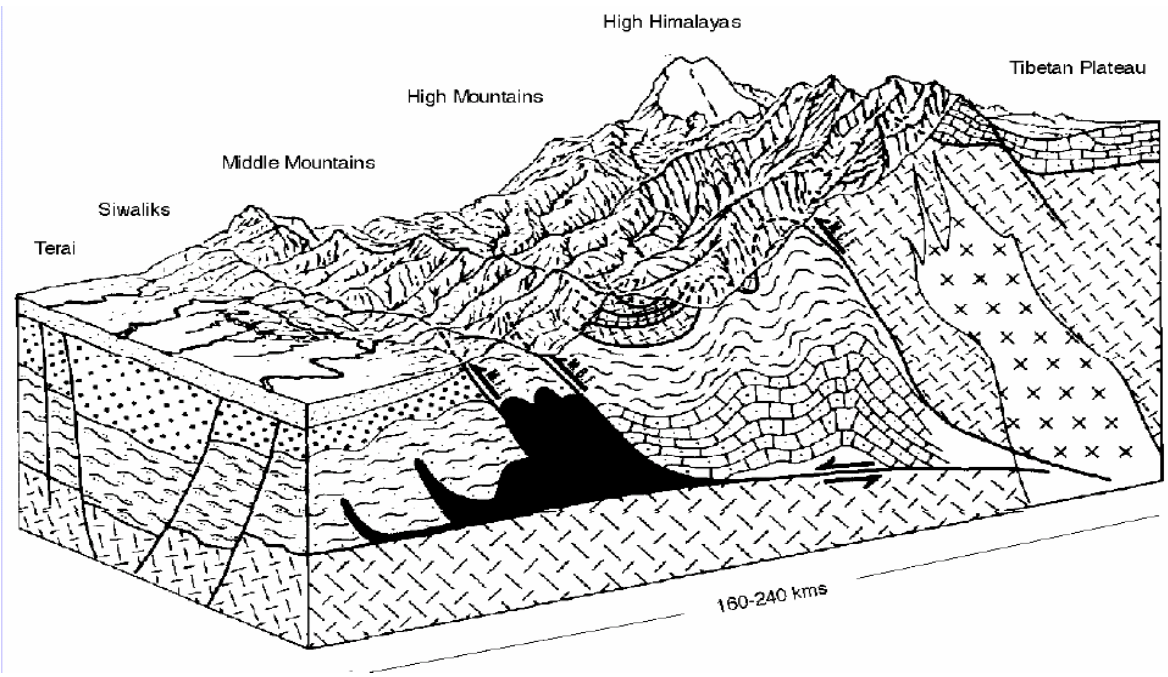


Figure 3.1 Topographic Division of Nepal (Source: WWF, 2005)

In order to study the temporal and topographical temperature trends of Nepal, temperature data was bought from the Government of Nepal, Ministry of Environment, Department of Hydrology and Meteorology. The data comprised of daily maximum and minimum temperature data from 68 meteorological stations from January 1, 1989 to December 31, 2010. With the purpose of representing whole of Nepal 60 stations with complete temperature data were used and the mean temperature was calculated from the maximum and minimum temperatures. The location of the weather stations is illustrated in the figure 3.2 and the list of the meteorological stations is illustrated in table 3.1.

Table 3.2 Details of the 68 Stations used in this study

SN	Index No.	Station Name	Long E	Lat N	Alt M	Phy Reg
1	0103	Patan West	80.32	29.28	1266	MM
2	0104	Dadeldhura	80.35	29.18	1848	MM
3	0105	Mahendra Nagar	80.13	29.02	176	TAR
4	0107	Darchula	80.34	29.51	1097	MM
5	0202	Chainpur West	81.22	29.55	1305	MM
6	0203	Silgadhi Doti	80.98	29.27	1360	MM
7	0209	Dhangadhi (Atariya)	80.60	28.68	1360	TAR
8	0218	Dipayal (Doti)	80.5646	29.1506	652	SW
9	0303	Jumla	82.17	29.28	2300	MM
10	0307	Rara (not used)	82.07	30.48	3048	
11	0311	Simikot (not used)	81.50	29.58	2800	
12	0312	Dunai (not used)	82.55	28.56	2058	
13	0402	Dailekh	81.72	28.85	1402	MM
14	0405	Chisapani (Karnali)	81.27	28.65	225	SW
15	0406	Surkhet (Birendra Nagar)	81.62	28.60	702	SW
16	0409	Khajura (Nepalganj)	81.57	28.10	190	TAR
17	0508	Talsipur	82.30	28.13	725	SW
18	0511	Salyan Bazar	82.10	28.23	1457	MM
19	0513	Chaur Jhari Tar	82.12	28.38	910	SW
20	0601	Jomsom	83.43	28.47	2744	H
21	0605	Baglung	83.36	28.16	984	SW
22	0609	Beni Bazar	83.34	28.21	835	SW
23	0614	Kushma	83.42	28.13	891	SW
24	0702	Tansen	83.32	27.52	1067	MM
25	0705	Bhairhawa Airport	83.43	27.52	110	TAR
26	0706	Dumkhauli (not used)	84.13	27.41	154	
27	0715	Khanchikot	83.09	27.56	1760	MM
28	0716	Taulihawa	83.04	27.33	94	TAR
29	0725	Tamghas	83.15	28.04	1530	MM
30	0802	Khudi Bazar	84.37	28.28	823	SW
31	0804	Pokhara Airport	84.00	28.22	827	SW
32	0805	Syangja	83.53	28.06	868	SW

33	0809	Gorkha (not used)	84.62	28.00	1097	MM
34	0815	Khairini Tar	84.10	28.03	190	TAR
35	0816	Chame	84.14	28.33	2680	H
36	0902	Rampur	84.42	27.62	256	SW
37	0906	Hetaunda N.F.I	85.05	27.42	466	SW
38	0909	Simara Airport	84.98	27.17	130	TAR
39	0922	Gaur	85.18	26.46	90	TAR
40	1004	Nuwakot	85.10	27.55	1003	MM
41	1022	Godavari	85.40	27.58	1400	MM
42	1024	Dhulikhel	85.33	27.37	1552	MM
43	1030	Kathmandu Airport	85.37	27.70	1336	MM
44	1036	Panchkhal	85.38	27.41	865	SW
45	1038	Dhunbesi	85.11	27.43	1085	MM
46	1043	Nagarkot	85.52	27.72	2150	MM
47	1055	Dhunche	85.18	28.06	1982	MM
48	1103	Jiri	86.23	27.63	2003	MM
49	1107	Sindhuli Gadhi	85.58	27.17	1463	MM
50	1111	Janakpur Airport	85.97	26.72	90	TAR
51	1121	Karmaiya	85.28	27.07	131	TAR
52	1122	Jaleshwor	85.47	26.39	172	TAR
53	1206	Okhaldhunga	86.50	27.32	1720	MM
54	1212	Phatepur	86.56	26.44	100	TAR
55	1213	Udayapur Gadhi	86.31	26.56	1175	MM
56	1215	Lahan	86.26	26.44	138	TAR
57	1220	Chailsa (not used)	86.62	27.52	2770	H
58	1303	Chainpur (East)	87.33	27.28	1329	MM
59	1307	Dhankuta	87.35	26.98	1160	MM
60	1314	Terahathum	87.33	27.08	1633	MM
61	1319	Biratnagar Airport	87.27	26.48	72	TAR
62	1320	Tarahara	87.27	26.70	200	SW
63	1323	Dharan British Camp (not used)	87.28	26.78	400	SW
64	1324	Bhojpur (not used)				
65	1405	Taplejung	87.67	27.35	1732	MM
66	1407	Ilam Tea Estate	87.90	26.92	1300	MM
67	1419	Phidim (Pancthar)	87.45	27.09	1205	MM
68	1421	Gaida (Kankai)	87.54	26.35	143	TAR
*The Station Numbers are given according to the Department of Hydrology and Meteorology station number						

index. The numbers increase from Western Nepal to Eastern Nepal and Northern to Southern part of Nepal. *Almost all the Stations Temperature Data used in the research is from 1989 – 2010. *TAR stands for Terai Region, SW Stands for Siwalik Region, MM for Middle Mountain, H for Himalayas Regions of Nepal.

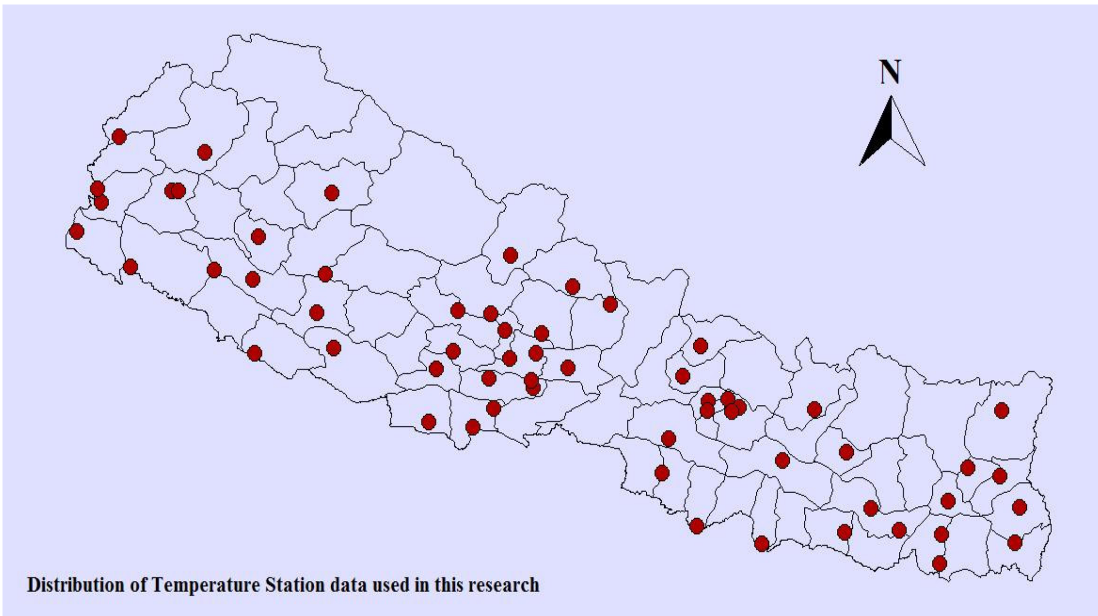


Figure 3.2 Map Showing distribution and location of the 60 Meteorological Stations' data used in the study

The SOI (Southern Oscillation Index) was obtained from the Australian Government, Bureau of Meteorology. The SOI data were used to study the effects and the impacts caused by the El Niño Southern Oscillation phenomenon in the temperature variation of Nepal. The SOI indicated the development and intensity of El Niño or La Niña events occurring in the Pacific Ocean by calculating the difference between the sea level pressure (SLP) at Tahiti and Darwin. These two cities are generally used to represent the barometric pressure. When the SLP is high at Darwin, it is low at Tahiti and the wind will strongly blow from high pressure areas to low pressure areas. These pressures have close correlation with the sea surface temperatures (SST) in the Pacific Ocean. Negative values of the SOI which is greater than -8 is an indication of El Niño episodes and these values are usually escorted by warming of the Pacific Ocean, while SOI greater than +8 are called La Niña episodes and they are accompanied by cooling of the Pacific Ocean.

3.3 Limitations of the Study

Although access to temperature data from large number of meteorological stations in Nepal was made, only fewer station data from the high mountain region was possible to include in this study, compared to the middle and the lower region. Because meteorological stations in very high altitude and remote areas were difficult to get access to. Therefore, to study higher mountain regions of Nepal, temperature data from only those available stations were used.

The data used in the study is maximum, minimum and mean temperature data from 1989 – 2010. The seasons were divided into spring, summer, autumn and winter based on March-April-May, June-July-August, September-October-November, December-January-February respectively. However, since rainfall data was not considered in the study, monsoon season in Nepal was not counted for. Moreover, winter in Nepal starts from December, therefore, winter season for last annual year in the study (2010) was not calculated.

Field work was not carried out due to very less financial budget and all analysis and studies were based on the temperature data, other published papers, internet articles and news.

CHAPTER FOUR: RESULTS

This chapter analyzes temperature data of Nepal from 1989 to 2010. The results in this chapter are divided into two parts. The Fist part contains results for annual, seasonal and monthly mean temperatures analysis for whole of Nepal. The second section of this chapter contains results from topographic wise analysis of maximum and mean temperatures of Nepal.

4.1 Results

4.2 Annual Mean Temperature Analysis Results

The annual mean temperature analysis results section is divided into, 365 days Running Average for maximum, minimum and mean temperatures for 1989 to 2010 and standardized anomaly for annual maximum, minimum and mean temperatures.

4.2.1 365 Days Running Average

To calculate the average of maximum, minimum and mean temperature of Nepal, 60 meteorological stations temperature data were used to represent the whole of Nepal. The maximum, minimum and mean temperatures were combined for all 60 stations to calculate the average for each day temperature.

The 365 days running average of maximum, minimum and mean temperatures for all of Nepal is shown in figure 4.1, figure 4.2 and figure 4.3 respectively. The curves in each graph represent the average of daily running temperature of Nepal from the year 1989 to 2010 and the straight line is the trend line that represents the linear regression trend for 22 years. Average temperature in the y-axis is represented in Celsius (°C). It can be seen that the 365 days running average of daily maximum temperature in Nepal has significantly increased in the 22 years. Moreover, the year 1997 shows lowest maximum and minimum temperature trends, followed by 1998 and 1999 showing the highest temperatures.

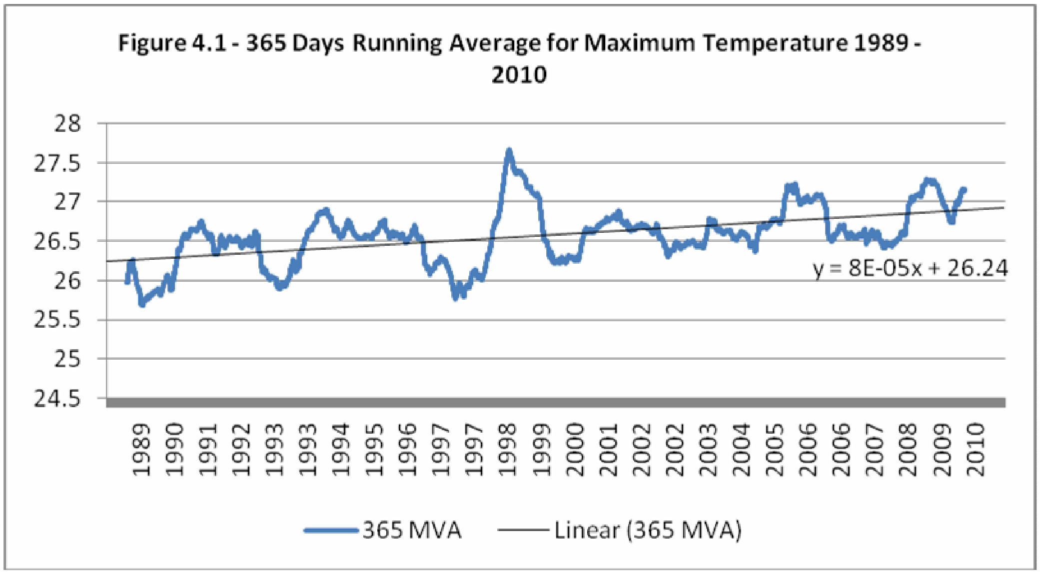


Figure 4.1 - 365 Days Running Average for Maximum Temperature 1989 - 2010
28
27.5
27
26.5
26
25.5
25
24.5
y = 8E-05x + 26.24
1989
1990
1991
1992
1993
1993
1994
1995
1996
1997
1997
1998
1999
2000
2001
2002
2002
2003
2004
2005
2006
2006
2007
2008
2009
2010
365 MVA
Linear (365 MVA)

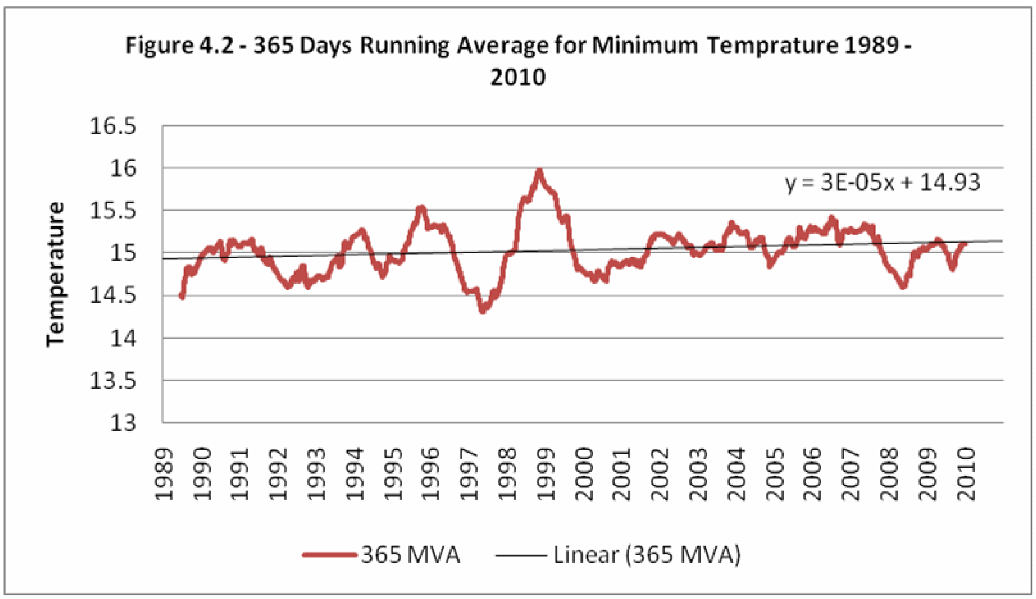
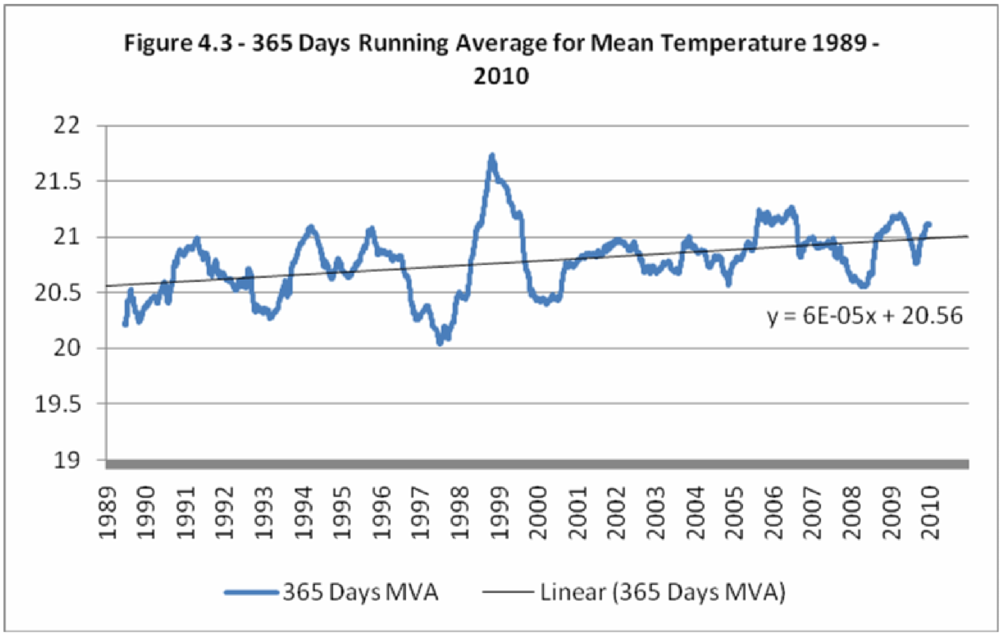


Figure 4.2 - 365 Days Running Average for Minimum Temprature 1989 - 2010
Temperature
16.5
16
15.5
15
14.5
14
13.5
13
y = 3E-05x + 14.93
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
365 MVA
Linear (365 MVA)



4.2.2 Standardized Anomaly for Maximum, Minimum and Mean Temperatures

Similarly, annual standardized anomaly for annual maximum, minimum and mean temperature average was calculated for the whole of Nepal. The annual average for each temperature was calculated using the daily temperature data.

Figure 4.4, 4.5 and 4.6 shows the annual maximum, minimum and mean average temperature anomaly which can be used to identify the warm phases between 1989 and 2010. The positive inclined line in the figures clearly demonstrate an increasing trend in maximum, minimum and mean temperatures over the last twenty two years between 1989 and 2010. The anomaly for maximum annual temperature and mean annual temperatures shows an increasing trend. Moreover, annual year 1998 and 1999 witnessed highest temperatures, marking it as the tipping point of the 10 years of temperature cycle. 1997 has the lowest temperature during the study period. It seems that there are more years with low temperature anomalies before the 1998 – 1999 but after that, there have been more annual years with high temperature anomalies. The bars in Figure 4.6 show annual mean mean temperature anomaly with lines representing standardized Southern Oscillation Index mean for annual average of 1989 – 2010.

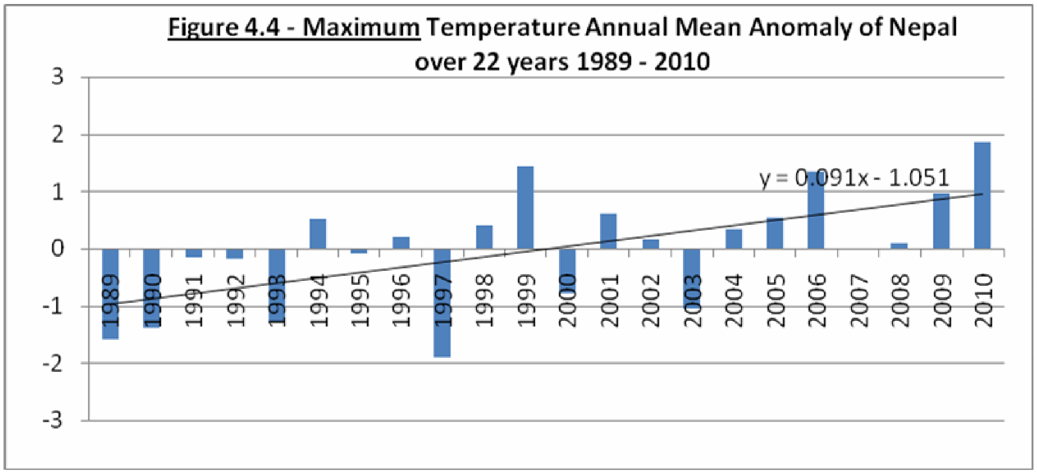


Figure 4.4 - Maximum Temperature Annual Mean Anomaly of Nepal over 22 years 1989 - 2010
y = 0.091x - 1.051
3
2
1
0
-1
-2
-3
1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010

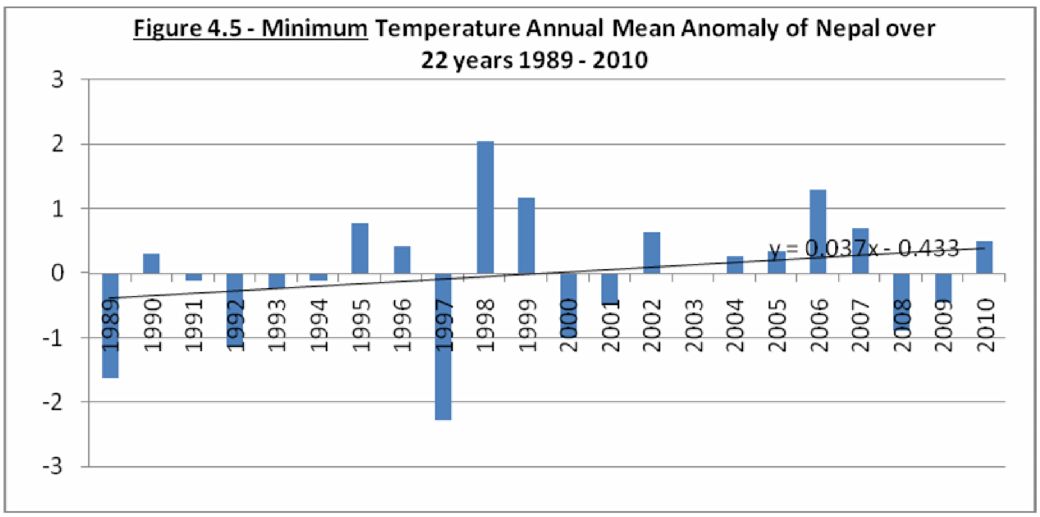


Figure 4.5 - Minimum Temperature Annual Mean Anomaly of Nepal over 22 years 1989 - 2010
y = 0.037x - 0.433
3
2
1
0
-1
-2
-3
1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010

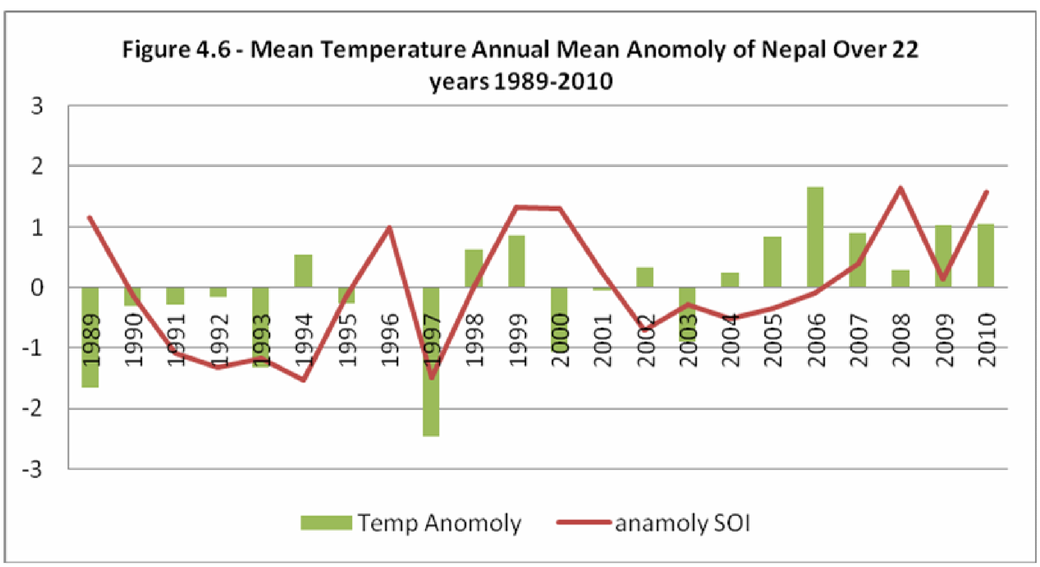


Figure 4.6 - Mean Temperature Annual Mean Anomoly of Nepal Over 22 years 1989-2010
3
2
1
0
-1
-2
-3
1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010
Temp Anomoly
anamoly SOI

4.3 Seasonal Mean Temperature Analysis Results

Seasonal maximum mean, minimum mean and mean mean temperatures were calculated for spring, summer, autumn and winter. Out of the four seasons, winter showed the highest coefficient variation for all maximum, minimum and mean temperatures, informing that winter season temperatures have most variation in temperature amongst all the four seasons in Nepal. Minimum seasonal average temperature for winters shows significantly high variations. (Figure 4.9) It was evident that the cold temperatures in winters and springs had most variations in temperatures between 1989 and 2010, whereas, summer and autumn experience comparatively less variations.

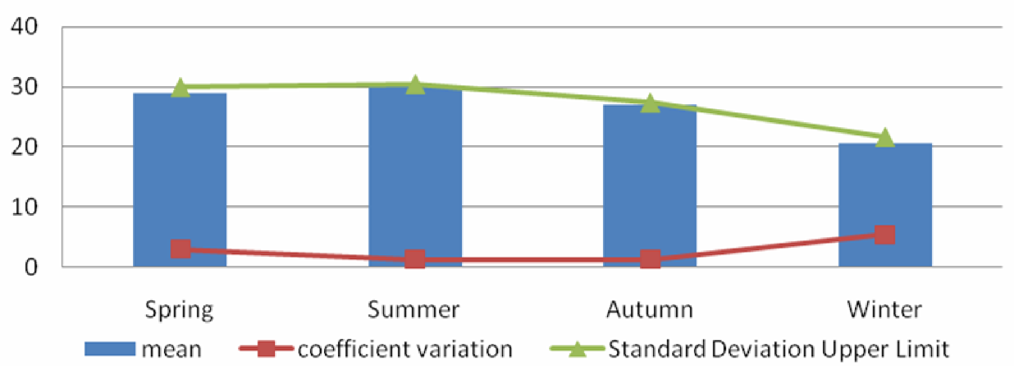


Figure 4.7 - Seasonal Average of Max Temperature with Coefficient Variation of Seasonal Temerature Trends 1989 - 2010

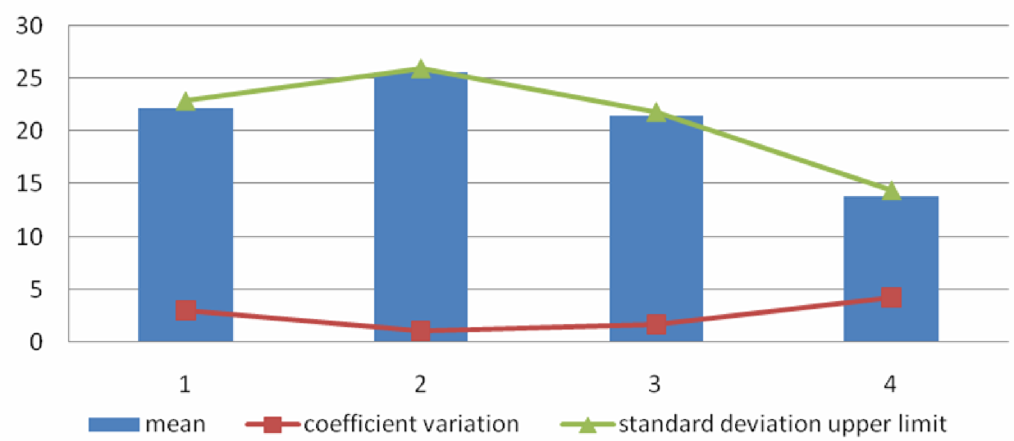
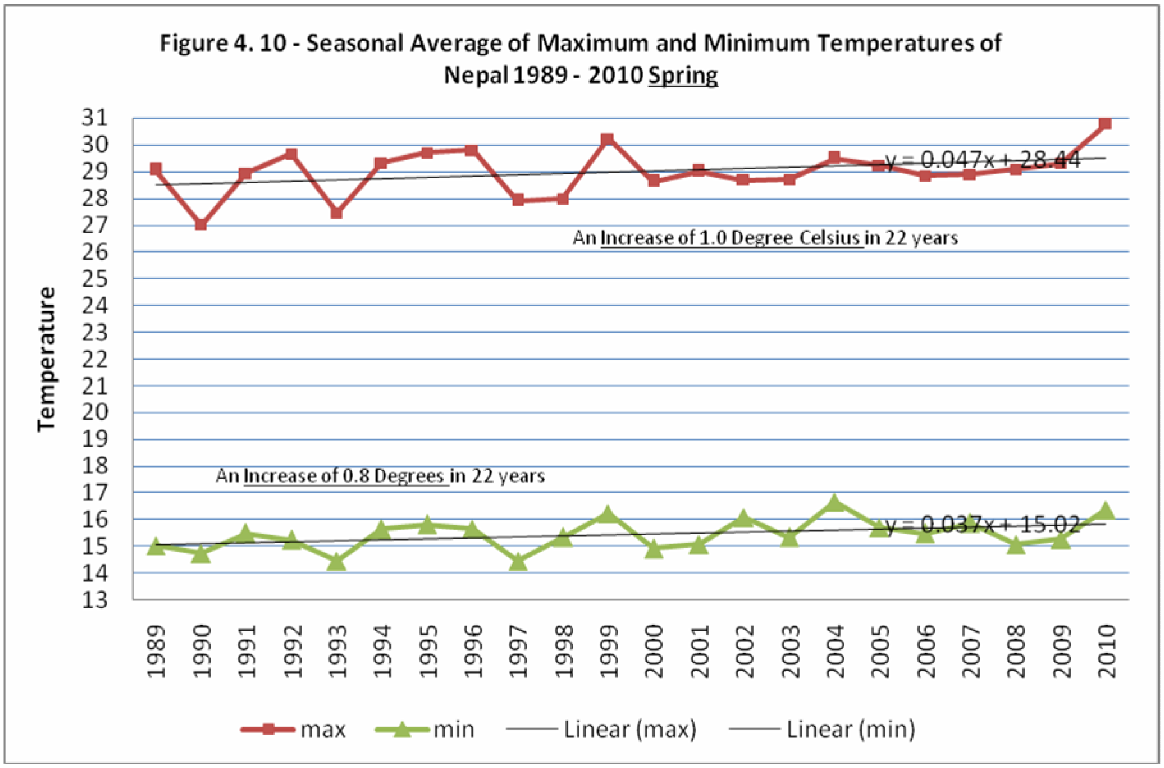


Figure 4.8 - Seasonal Average of Mean Temperature with Coefficient Variation of Seaonal Temerature Trends 1989 - 2010

4.3.1 Spring

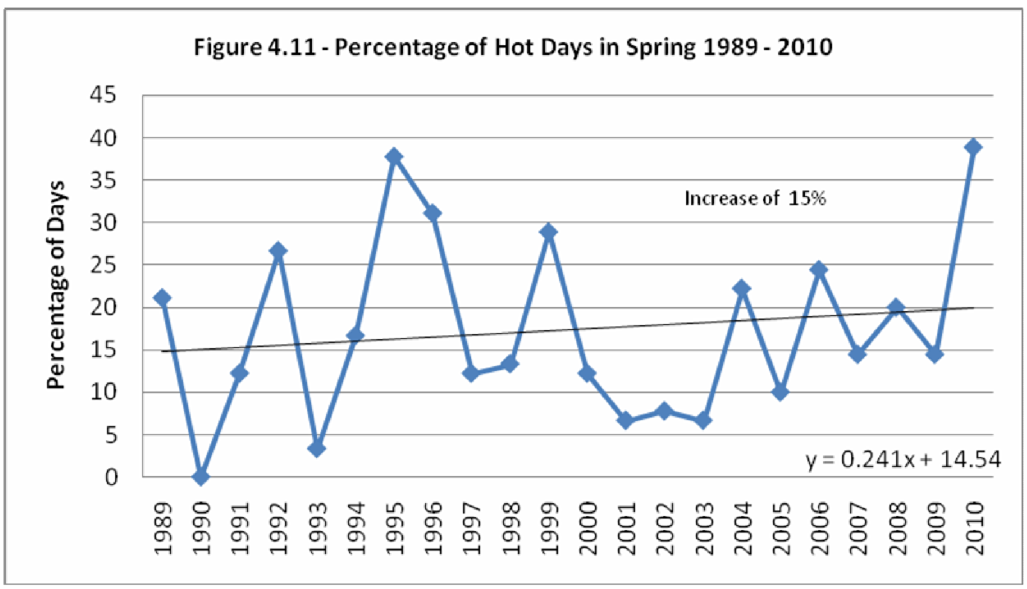
The maximum, minimum and mean seasonal mean temperatures were plotted on the graph which can be seen in figure 4.10. The seasonal mean temperatures were calculated by first categorizing the season by March-April-May as spring, June-July-August as summer, September-October-November as autumn and December-January-February as winter. After categorizing the seasons, daily maximum, minimum and mean temperature means were calculated for each season and then those averages were used to calculate the annual average for each seasons.

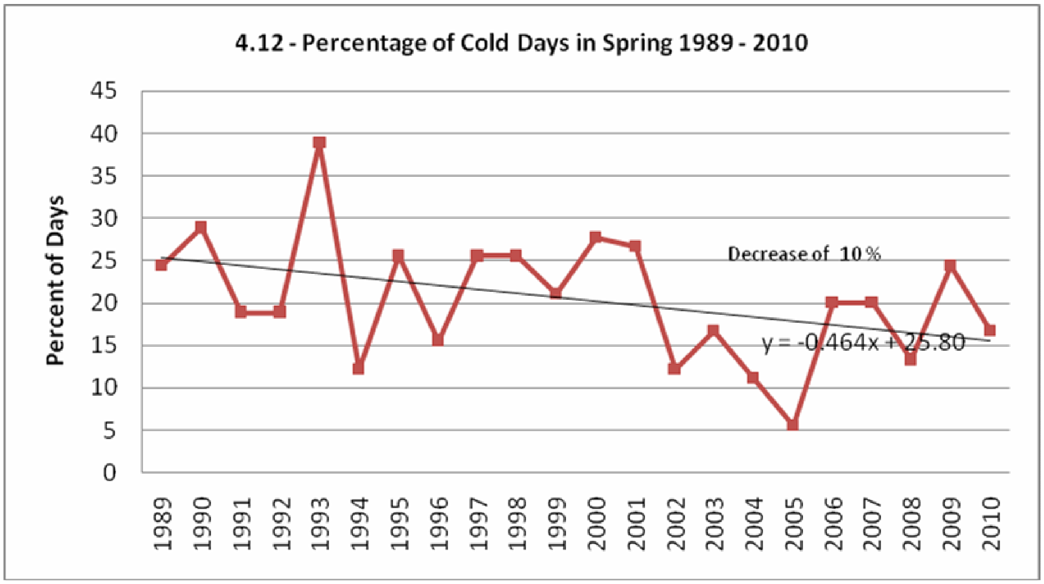
It was evident that both maximum and minimum temperatures in spring increased by 1 °C and 0.8 °C between 1989 and 2010 respectively. Spring season showed the second highest increase among the four seasons in Nepal. The minimum temperature in the spring shows the highest increase compared to minimum temperatures of other seasons, which indicates that the minimum temperature in spring is becoming warmer the most.



Trends of Hot and Cold Days in spring season

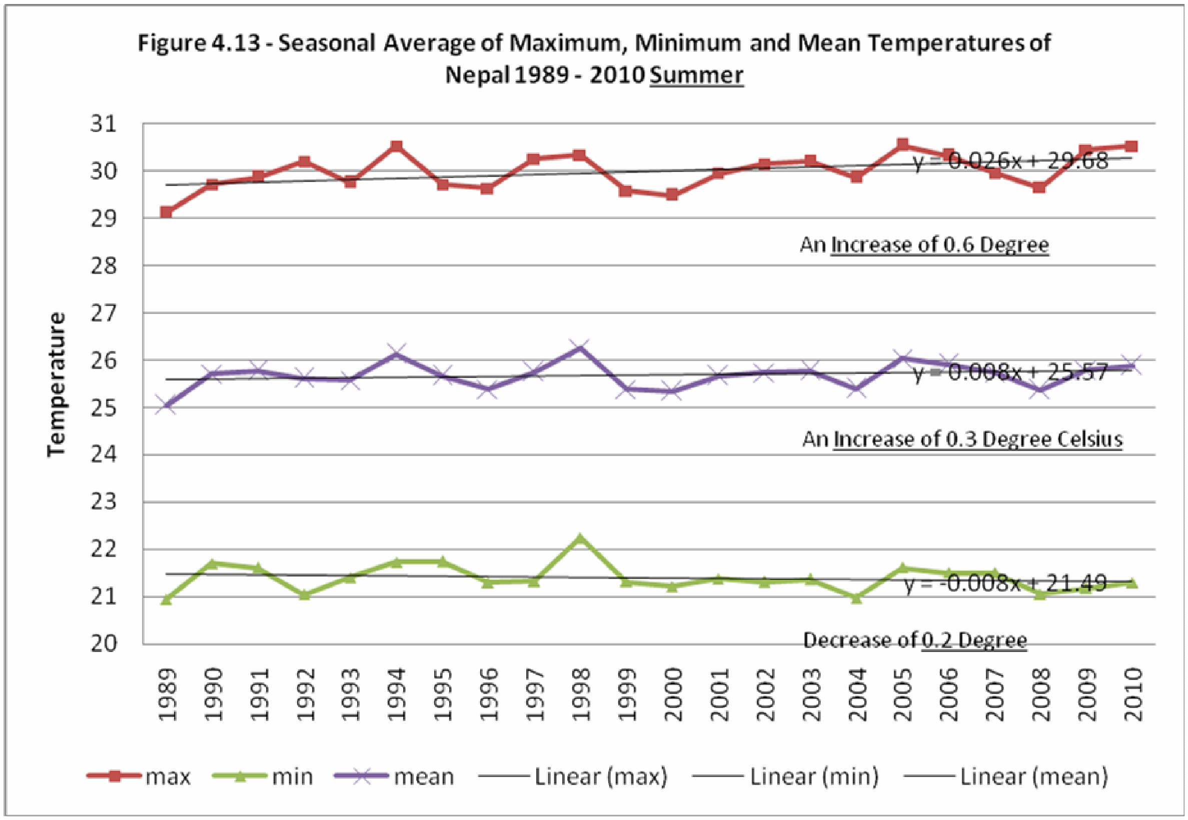
Figure 4.11 shows the percentage number of hot days and figure 4.12 shows percentage of cold days for spring season in Nepal between 1989 and 2010. It is evident that the number of hot days increased by 5%. It is also evident that the number of cold days decreased at a high rate, which is 10 % in last 22 years. Spring season showed the highest decrease in cold days amongst all four season. Fewer cold days means that spring is becoming warmer which indicates the probability of shorter winters and longer summers. As a result, effects of the hot days such as increased melting rates of glaciers or flash floods that occur in summer season can be anticipated in spring season in the near future.





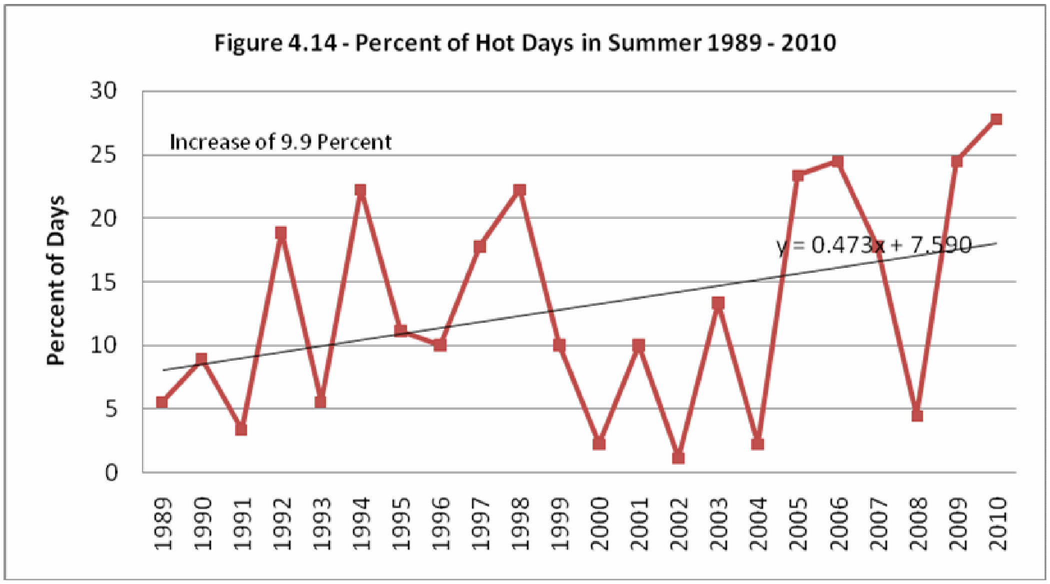
4.3.2 Summer

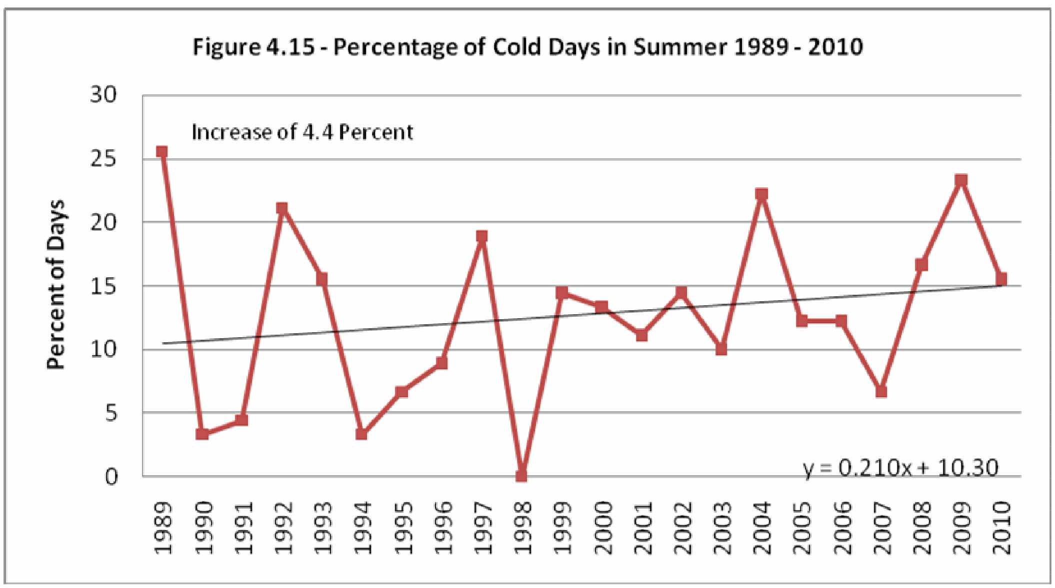
To calculate the summer season average temperature, maximum, minimum and mean average temperature for the months of June, July and August were taken for each year from 1989 to 2010. Figure 4.13, indicates that the maximum seasonal mean temperature in last 22 years showed an increase by 0.6 °C whereas the minimum seasonal mean temperature showed a decrease in seasonal average temperature by 0.2 °C.



Trends of Hot and Cold Days in summer season

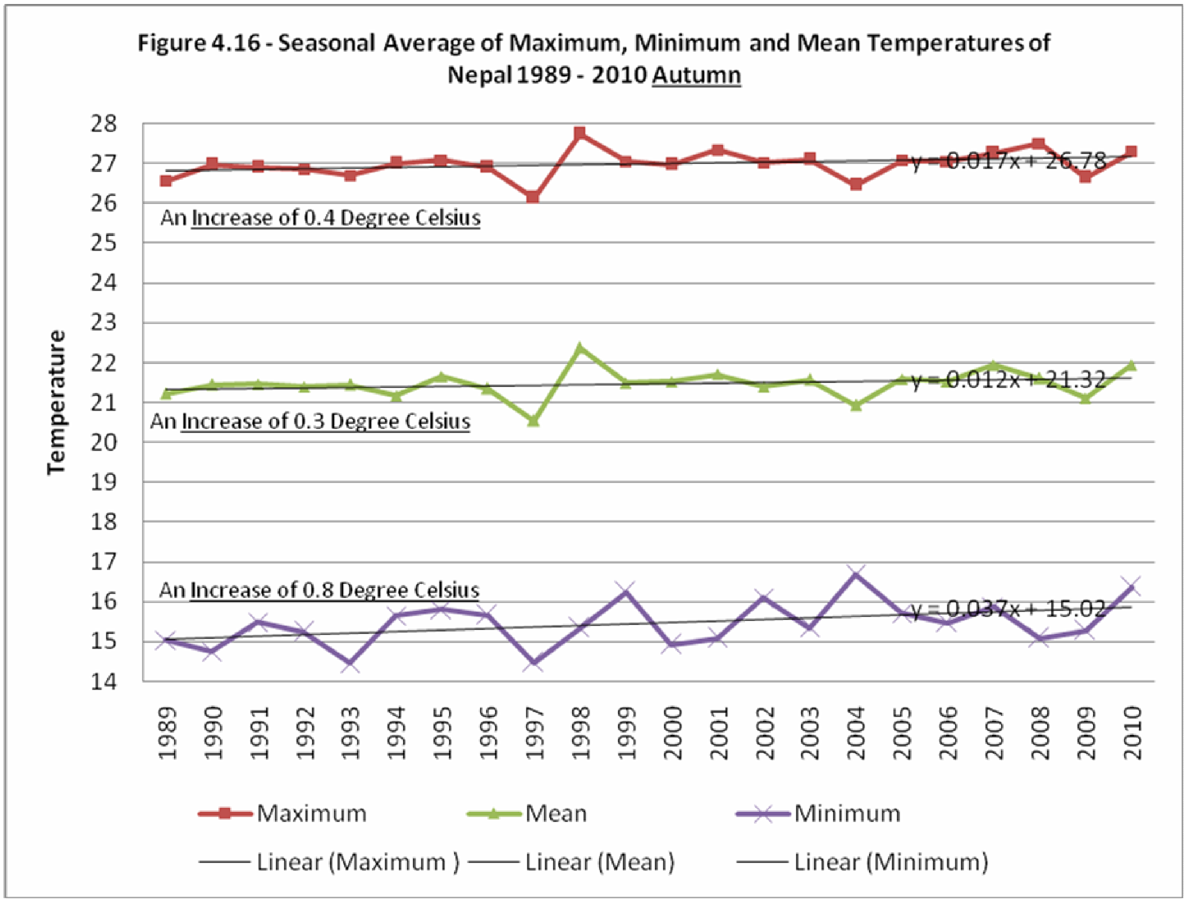
Figure 4.14 shows trend of percentage of hot days and figure 4.15 shows cold days in summer season in Nepal. The number of hot days increased by 9.9 percent by 2010, but the percent of cold days in summer also surprisingly showed an increase by 4.4 percent. This means that summers in Nepal are not only becoming warmer but also cold days are becoming colder - showing extreme temperature variations. The least number of cold days between the time periods of 1989 to 2010 can be seen in the year 1998.





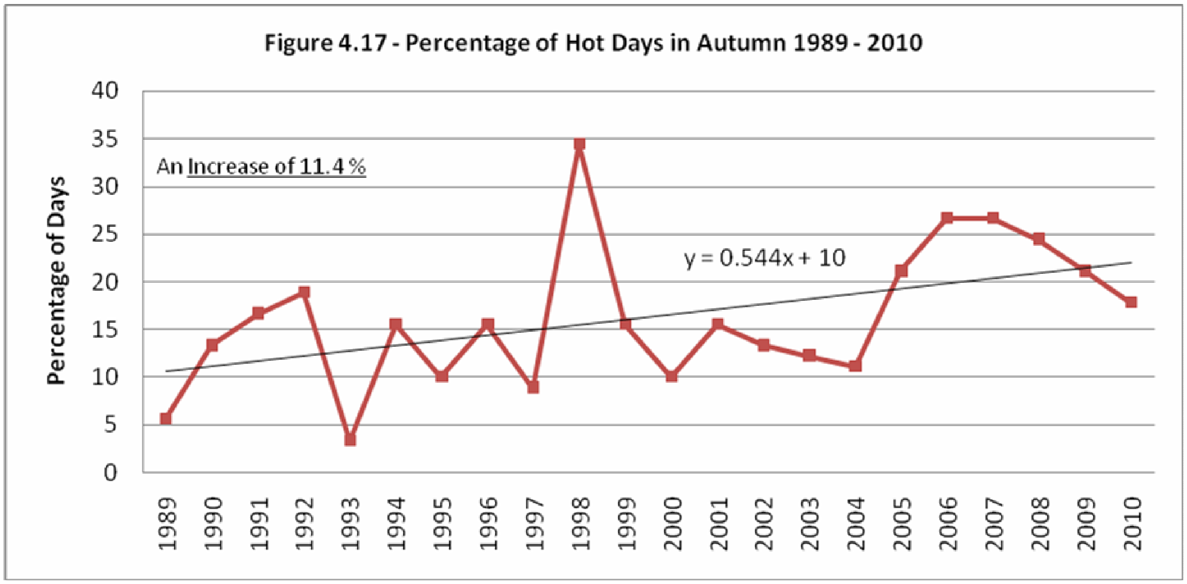
4.3.3 Autumn

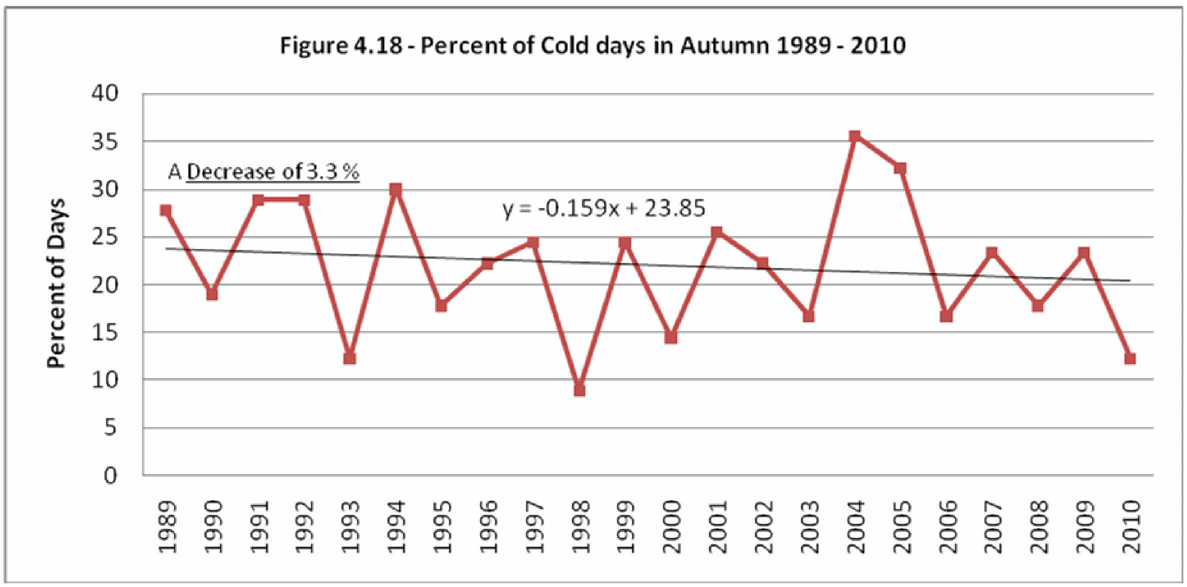
As seen in Figure 4.16, the minimum mean temperatures in autumn showed highest increase of 0.8 °C in 22 years. The minimum mean temperature in autumn season is increasing more than maximum temperature. The year 1998 shows the highest maximum mean temperature between 1989 and 2010.



Trends of Hot and Cold Days in autumn season

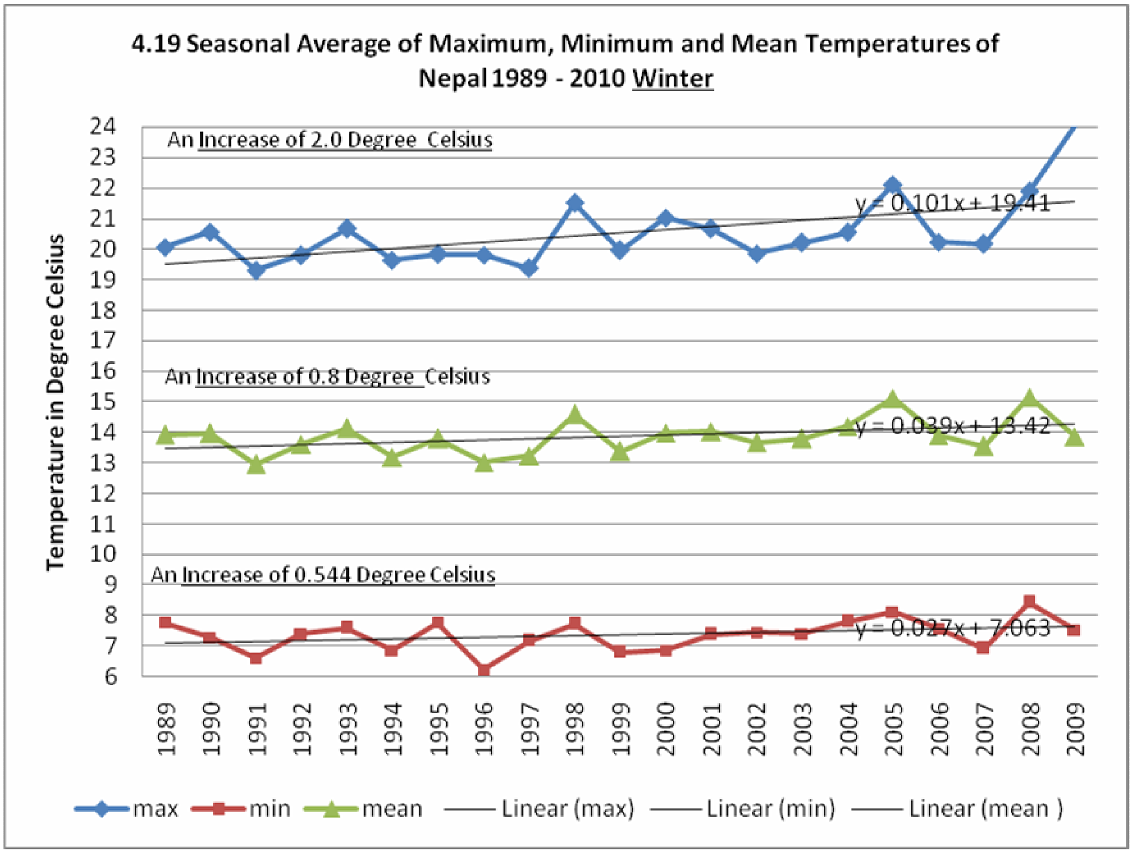
Similarly, Figure 4.17 and Figure 4.18, illustrates the trends in percent of hot days and cold days respectively. Cold days in autumn are certainly decreasing. Results show that there has been a decrease of number of cold days in autumn by 3.3 Percent in 22 years time period from 1989 – 2010. However, the hot days are increasing at an alarming rate of 11.4 percent which is slightly higher than rate of increase in hot days in summer. The year 1998 has shown the maximum number of hot days and also the least number of cold days in autumn season.





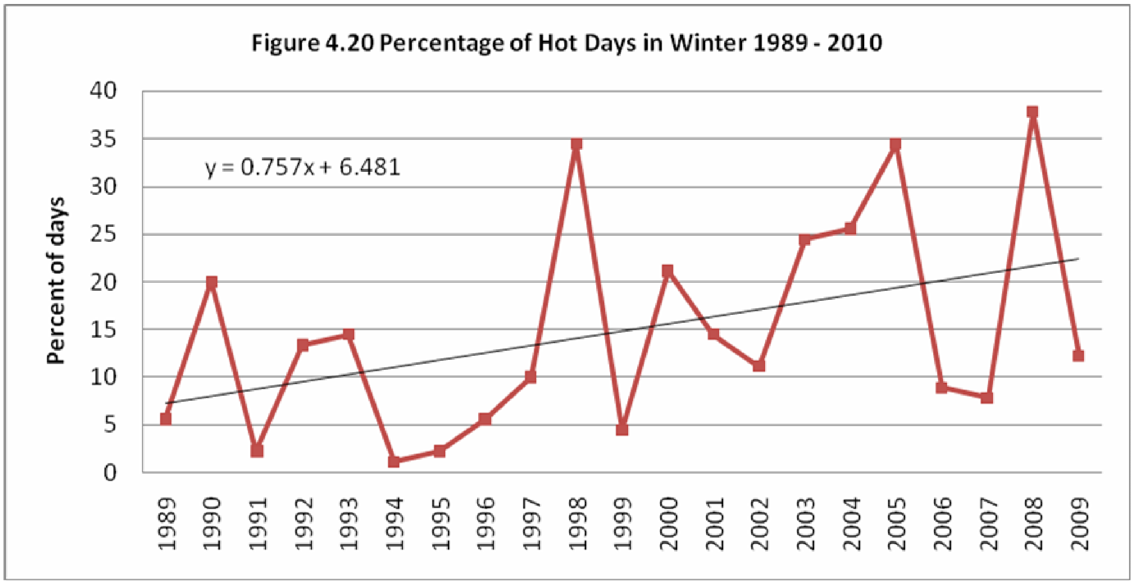
4.3.4 Winter

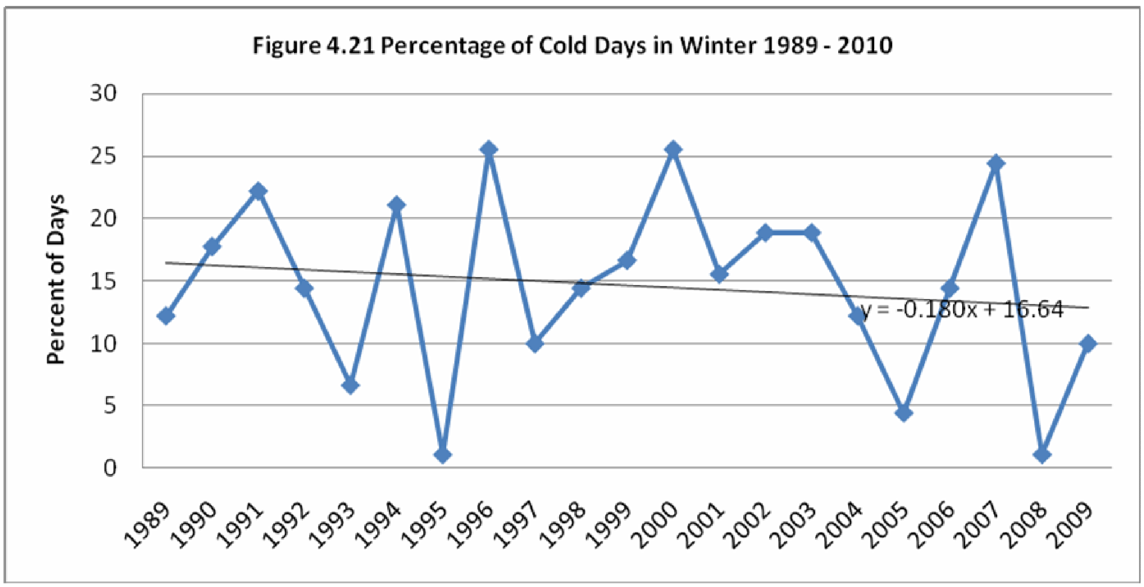
Results in figure 4.19, shows that maximum mean seasonal temperature for winters have increased by 2 °C between 1989 and 2010. The maximum temperature in winter season is increase the most during the year. Winters in Nepal have become warm by 2 °C in the past 22 years.



Trends of Hot and Cold Days in winter season

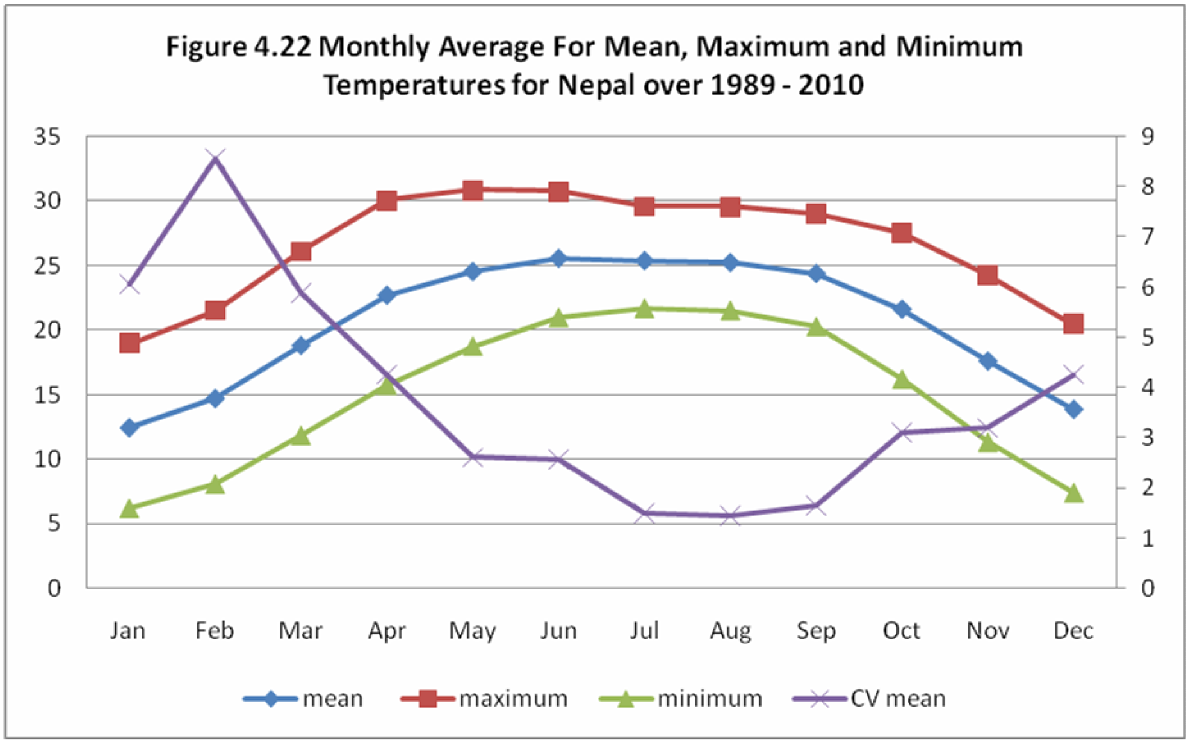
Similarly, the percentage in trends of hot days and cold days in winters were also calculated. The number of days that exceeded the upper limit of the maximum mean temperatures in winter has increased by 15.2 percent in the last 22 years. Winters show the most rapid increase in number of hot days during the year. Winters in Nepal are becoming warm at a very increase rate. However, the cold days in winters have decreased at the rate of 3.6 percent in the last 22 years, showing that winters are certainly becoming warmer at an alarming rate in Nepal.



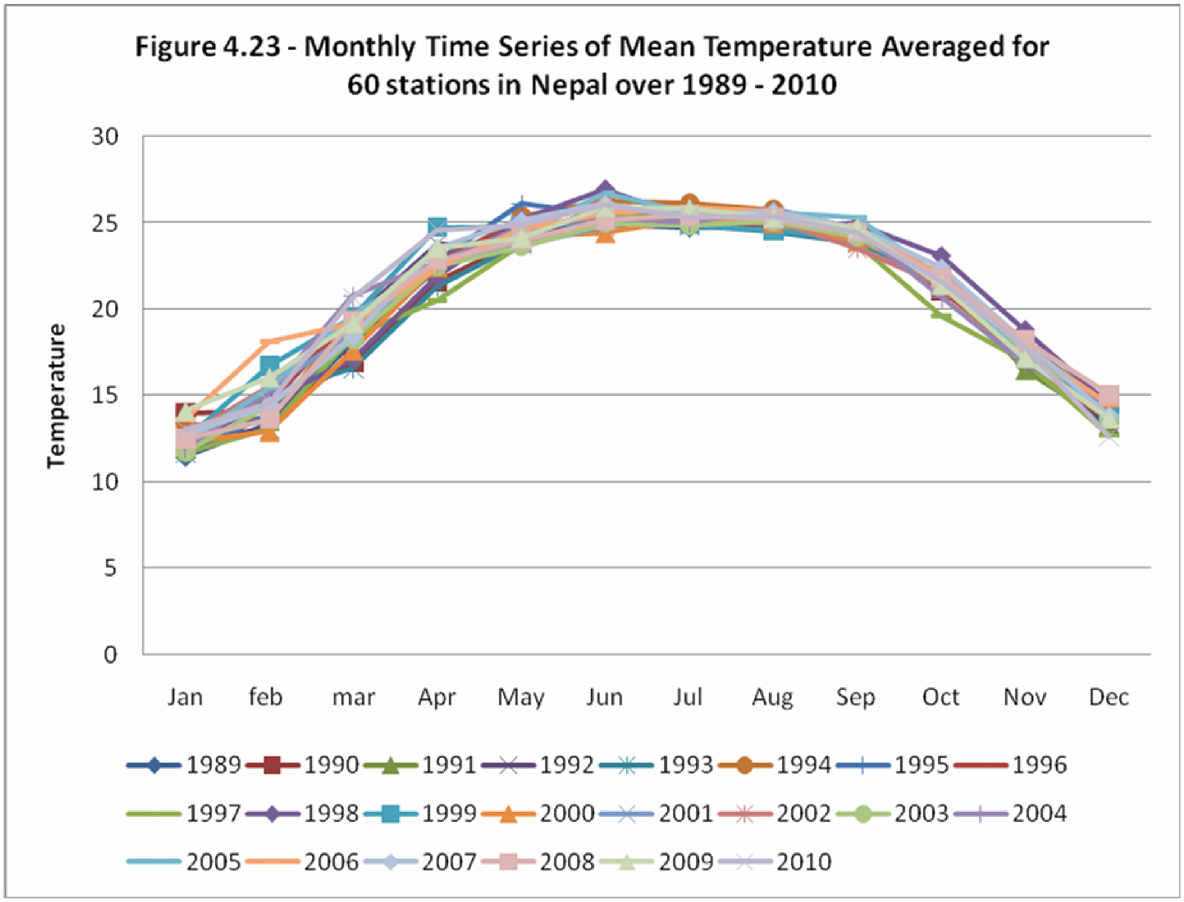


4.4 Monthly Mean Temperature Analysis Results

Knowing from the Results that winter seasons have the most temperature variations and the trend is an increasing one, monthly temperature average for maximum, minimum and mean temperatures of Nepal for each month from 1989 to 2010 was calculated. The monthly averages were calculated by considering the daily temperatures for each month. The average temperature for each month was calculated for all the month from 1989 to 2010. When the monthly average temperature for mean, maximum and the minimum is combined as shown in figure 4.22, the coefficient variation is significantly highest for the month of February.



The monthly temperature means of mean temperature of all the 60 stations representing Nepal over the years 1989 – 2010 is shown in the figure 4.23. These patterns are based on the mean monthly values of mean values of monthly mean temperature for 60 stations that represents Nepal in this study. In this graph, each monthly mean mean Temperature curve for 22 year period is represented by its time series. The 22 years annual curves follow similar temporal variations but they differ significantly in amplitude. It can be clearly seen from the graph that the months of June – August are the warmest months of the year and the months of December and January are the coolest. Moreover, it is also clear from the graph that the month of February has the highest variation in the temperature in the 22 years time period. Similar variations in monthly mean maximum and minimum temperature are shown in the month of February and the mean mean temperature for the month of June and July do not show much variations.



4.5 Analysis of Temperature Trends based on Different Topographic Regions

Annual and seasonal mean mean temperature trends were calculated and analyzed based on the topographic division of Nepal. Nepal can be divided into five regions which are, Trans Himalayas, Himalaya, Middle Mountains, Siwalik and Terai. However, due to unavailable data from meteorological station for the Trans Himalayan region, temperature trends for this physiographic region were not studied in this research. In this research, the stations were divided into Himalaya (H), Middle Mountain (MM), Siwalik (SW) and Terai (TAR) region based on its location and altitude. Table 4.1

Table 4.1 Division of Stations Based on Topography

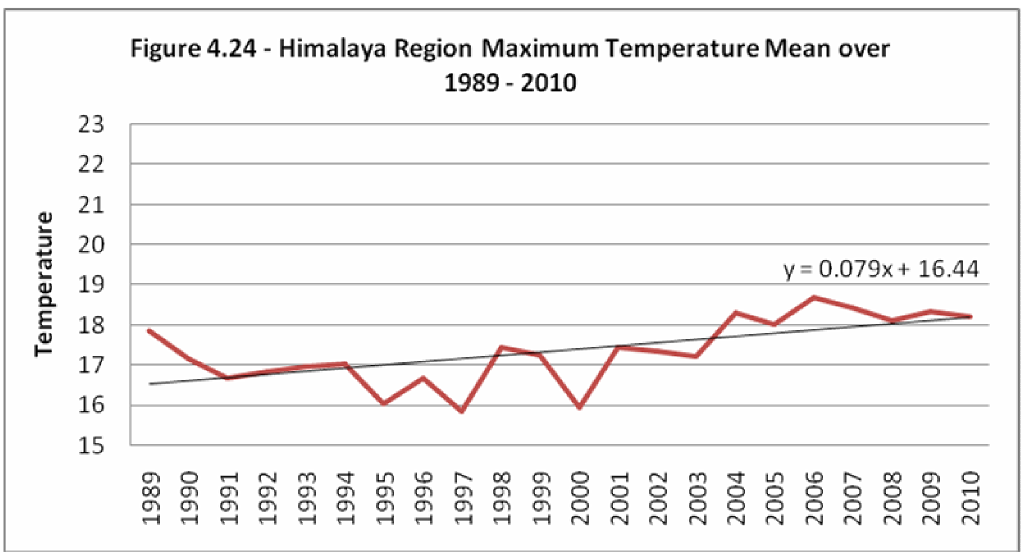
Himalaya Region						
SN	**Index No.**	**Station Name**	**Long E**	**Lat N**	**Alt M**	**Regions**
20	0601	Jomsom	83.43	28.47	2744	H

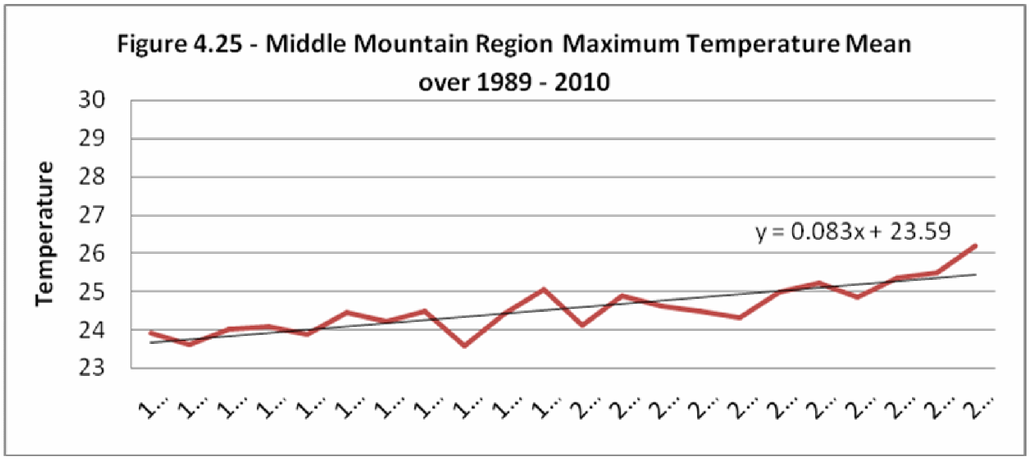
35	0816	Chame	84.14	28.33	2680	H
Middle Mountain Region						
SN	**Index No.**	**Station Name**	**Long E**	**Lat N**	**Alt M**	**Phy Reg**
1	0103	Patan West	80.32	29.28	1266	MM
2	0104	Dadeldhura	80.35	29.18	1848	MM
4	0107	Darchula	80.34	29.51	1097	MM
5	0202	Chainpur West	81.22	29.55	1305	MM
6	0203	Silgadhi Doti	80.98	29.27	1360	MM
9	0303	Jumla	82.17	29.28	2300	MM
13	0402	Dailekh	81.72	28.85	1402	MM
18	0511	Salyan Bazar	82.10	28.23	1457	MM
27	0715	Khanchikot	83.09	27.56	1760	MM
29	0725	Tamghas	83.15	28.04	1530	MM
40	1004	Nuwakot	85.10	27.55	1003	MM
41	1022	Godavari	85.40	27.58	1400	MM
42	1024	Dhulikhel	85.33	27.37	1552	MM
43	1030	Kathmandu Airport	85.37	27.70	1336	MM
45	1038	Dhunbesi	85.11	27.43	1085	MM
46	1043	Nagarkot	85.52	27.72	2150	MM
47	1055	Dhunche	85.18	28.06	1982	MM
48	1103	Jiri	86.23	27.63	2003	MM
49	1107	Sindhuli Gadhi	85.58	27.17	1463	MM
53	1206	Okhaldhunga	86.50	27.32	1720	MM
55	1213	Udayapur Gadhi	86.31	26.56	1175	MM
58	1303	Chainpur (East)	87.33	27.28	1329	MM
59	1307	Dhankuta	87.35	26.98	1160	MM
60	1314	Terahathum	87.33	27.08	1633	MM
65	1405	Taplejung	87.67	27.35	1732	MM
66	1407	Ilam Tea Estate	87.90	26.92	1300	MM
67	1419	Phidim (Pancthar)	87.45	27.09	1205	MM
Siwalik Region						
SN	**Index No.**	**Station Name**	**Long E**	**Lat N**	**Alt M**	**Phy Reg**
8	0218	Dipayal (Doti)	80.5646	29.1506	652	SW

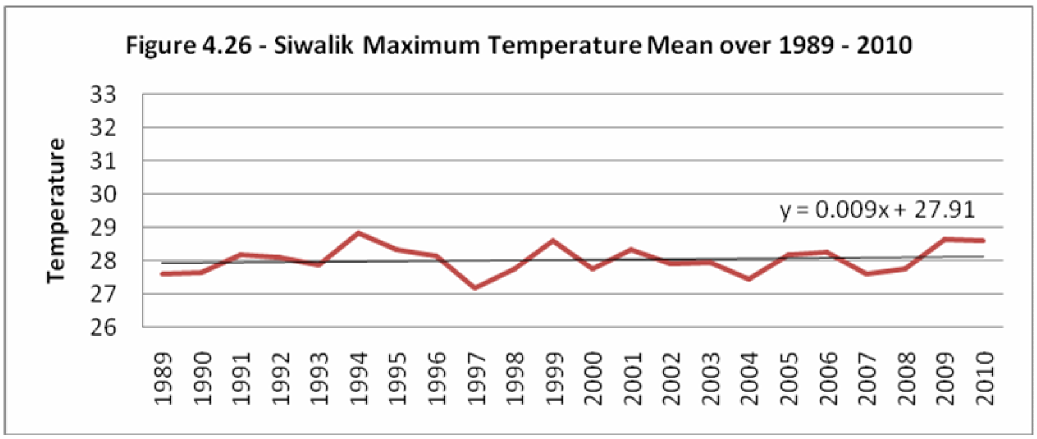
14	0405	Chisapani (Karnali)	81.27	28.65	225	SW
15	0406	Surkhet (Birendra Nagar)	81.62	28.60	702	SW
17	0508	Talsipur	82.30	28.13	725	SW
19	0513	Chaur Jhari Tar	82.12	28.38	910	SW
21	0605	Baglung	83.36	28.16	984	SW
22	0609	Beni Bazar	83.34	28.21	835	SW
23	0614	Kushma	83.42	28.13	891	SW
30	0802	Khudi Bazar	84.37	28.28	823	SW
31	0804	Pokhara Airport	84.00	28.22	827	SW
32	0805	Syangja	83.53	28.06	868	SW
36	0902	Rampur	84.42	27.62	256	SW
37	0906	Hetaunda N.F.I	85.05	27.42	466	SW
44	1036	Panchkhal	85.38	27.41	865	SW
62	1320	Tarahara	87.27	26.70	200	SW
Terai Region						
SN	**Index No.**	**Station Name**	**Long E**	**Lat N**	**Alt M**	**Phy Reg**
3	0105	Mahendra Nagar	80.13	29.02	176	TAR
7	0209	Dhangadhi (Atariya)	80.60	28.68	1360	TAR
16	0409	Khajura (Nepalganj)	81.57	28.10	190	TAR
25	0705	Bhairhawa Airport	83.43	27.52	110	TAR
28	0716	Taulihawa	83.04	27.33	94	TAR
34	0815	Khairini Tar	84.10	28.03	190	TAR
38	0909	Simara Airport	84.98	27.17	130	TAR
39	0922	Gaur	85.18	26.46	90	TAR
50	1111	Janakpur Airport	85.97	26.72	90	TAR
51	1121	Karmaiya	85.28	27.07	131	TAR
52	1122	Jaleshwor	85.47	26.39	172	TAR
54	1212	Phatepur	86.56	26.44	100	TAR
56	1215	Lahan	86.26	26.44	138	TAR
61	1319	Biratnagar Airport	87.27	26.48	72	TAR
68	1421	Gaida (Kankai)	87.54	26.35	143	TAR

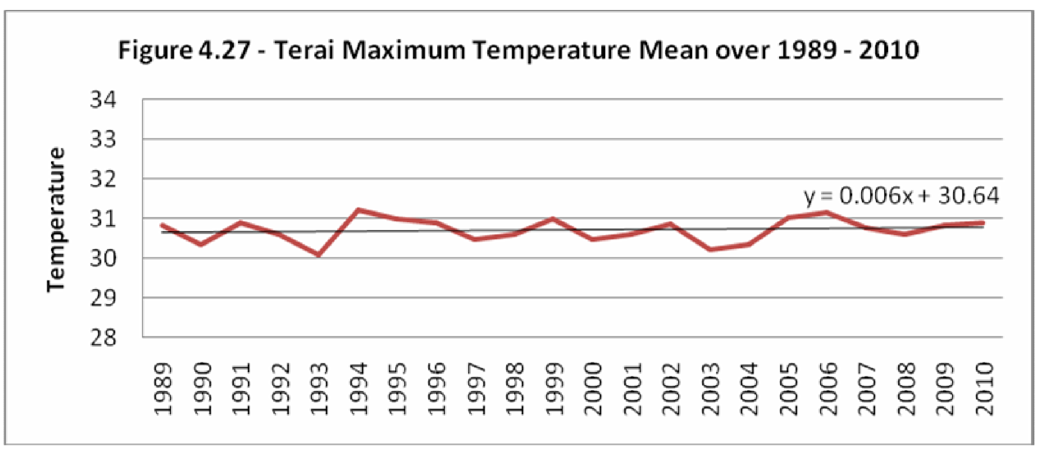
4.6 Annual Maximum Mean Temperatures Results

The Himalaya region of Nepal showed the second most significant increase in the annual maximum mean temperatures with an increase of 1.6 °C over the 22 years from 1989 to 2010. The year 2006 turned out to be the warmest year and 1997 as the coolest year. Similarly, the middle mountain region of Nepal showed the highest increase in the annual maximum mean temperatures with an increase of 1.7 °C over the 22 years. Maximum temperatures for the annual 2010 were the warmest year in the period and 1997 was the coolest year in this region too. Siwalik Region of Nepal also showed an increase of 0.2 °C and the Terai region of Nepal which is closest to India showed an increase of 0.13°C which was the lowest rate of increase in the annual maximum mean temperature compared to other parts of Nepal. See Figures.





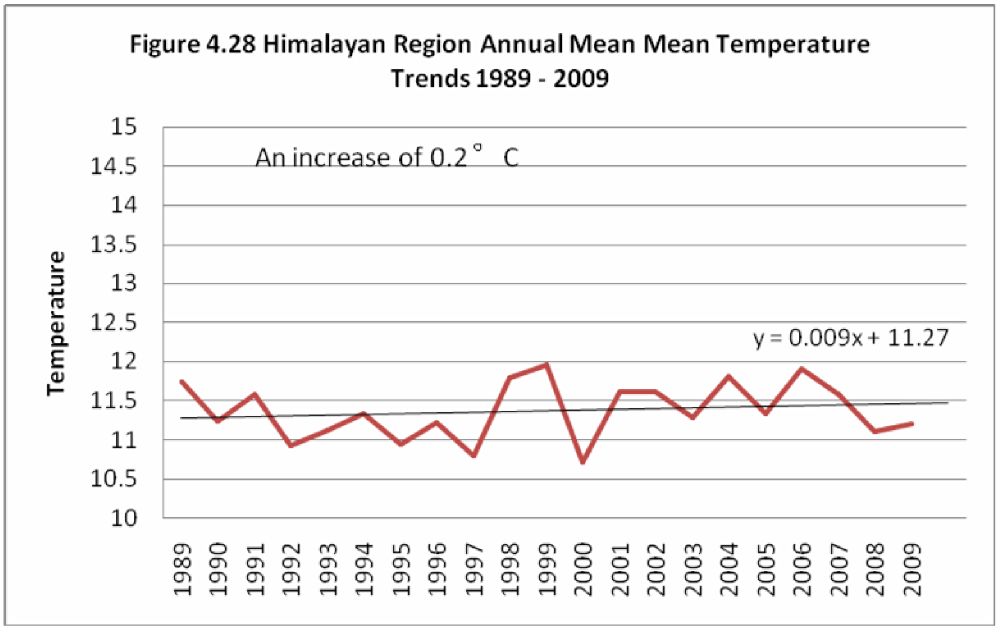




4.7 Annual Mean Mean Temperature Results

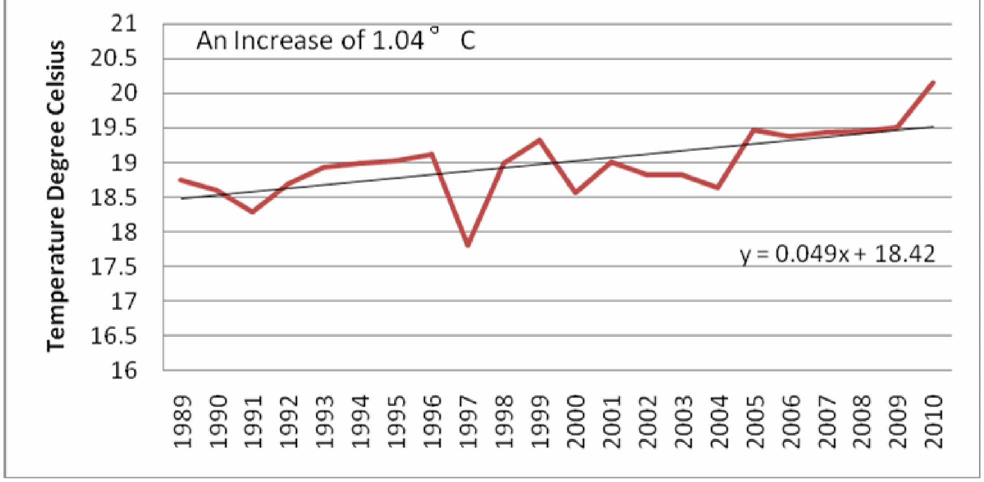
Annual mean mean temperature trends for the four topographic regions were also studied. The annual mean temperature for Himalaya region showed an increase of 0.2 ° C.

The mean temperature for the year 1999 was highest with an average temperature of 11.9 ° C. 2006 also showed a significant warming mean temperature in the last 22 years followed by 1998 and 2004. The coolest years were 2000 and 1997 in this region. Figure 4.28.



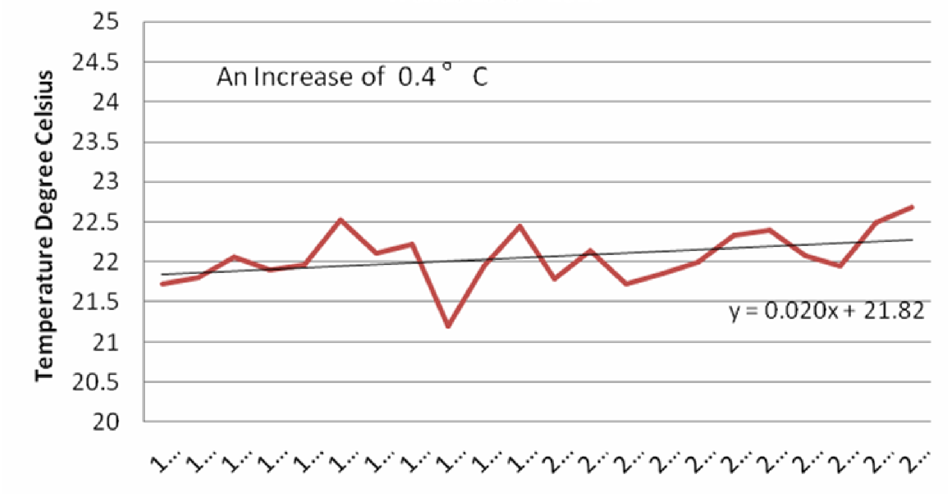
Annual mean mean temperature for the middle mountain region of Nepal showed an increase in the mean temperature by 1.04 °C which is the highest rate of increase in the annual mean mean temperatures all over Nepal. In this region also the coolest year was 1997 followed by a drastic increase in the temperature 1998 and 1999. The year 2010 was the warmest year in the period of 1989 – 2010 in the middle mountain region. See Figure 4.29.

Figure 4.29 Middle Mountain Region Annual Mean Mean Temperature Trends 1989 - 2010

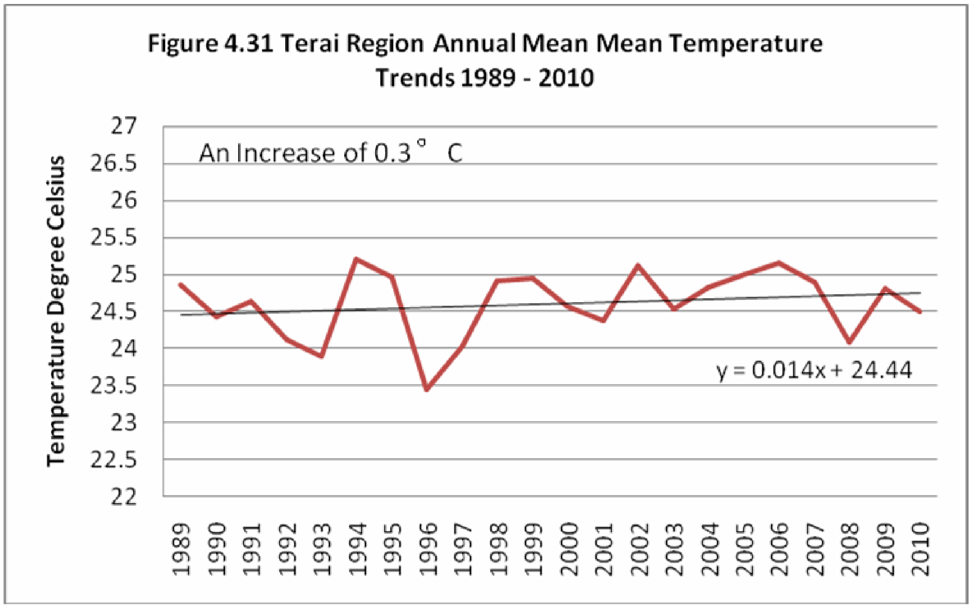


Similarly, Siwalik region showed an increase of 0.4 °C in the annual mean mean temperature with 1997 being the coolest year of the period and 2010 being the warmest year of the period.

Figure 4.30 Siwalik Region Annual Mean Mean Temperature Trends 1989 - 2010



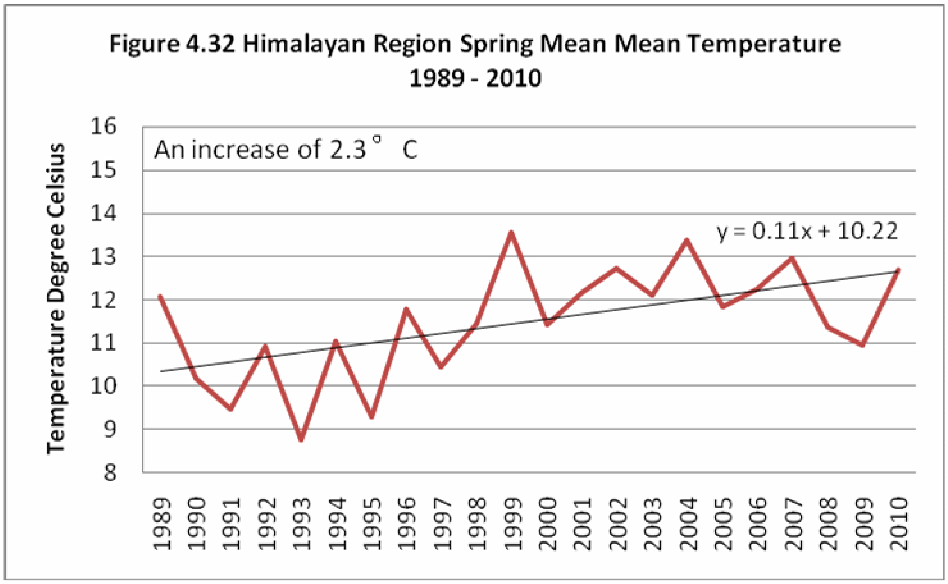
The Terai region is the low lands of Nepal which is closest and sharing the same border with India. This region showed an increase in the annual mean mean temperature at the rate of .03 ° C between 1989 and 2010. The year 1996 was the coolest year in this region, one year before the coolest years in other region. The warmest years were 1994 and 2006.



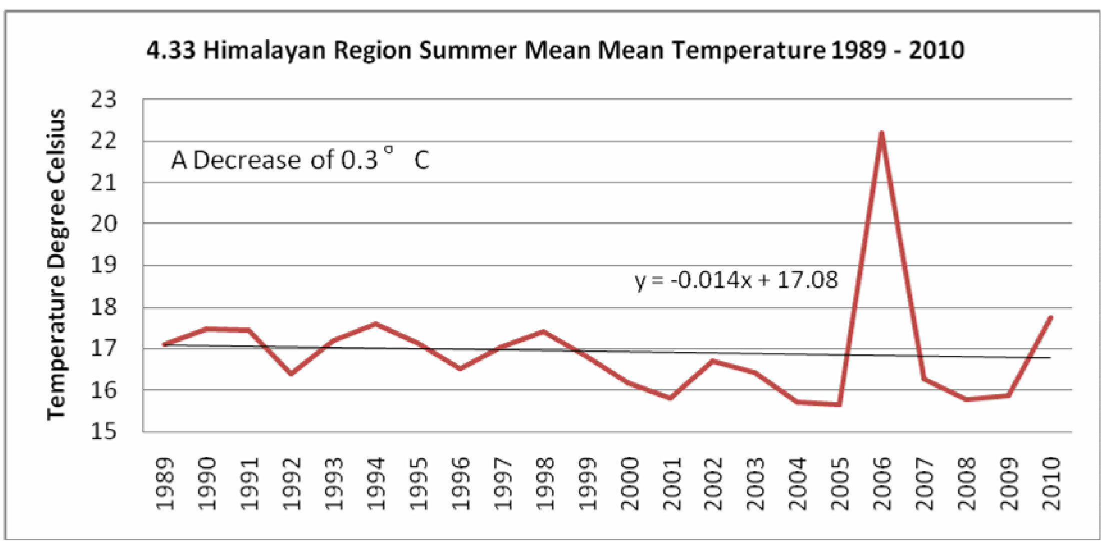
4.8 Seasonal Mean Mean Temperature Results

After studying the annual maximum and mean mean temperatures, for the four topographic regions of Nepal, annual mean mean temperature trends were analyzed based on the four seasons of Nepal; Spring (March – May), Summer (June – August), Autumn (September – November) and Winter (December – February).

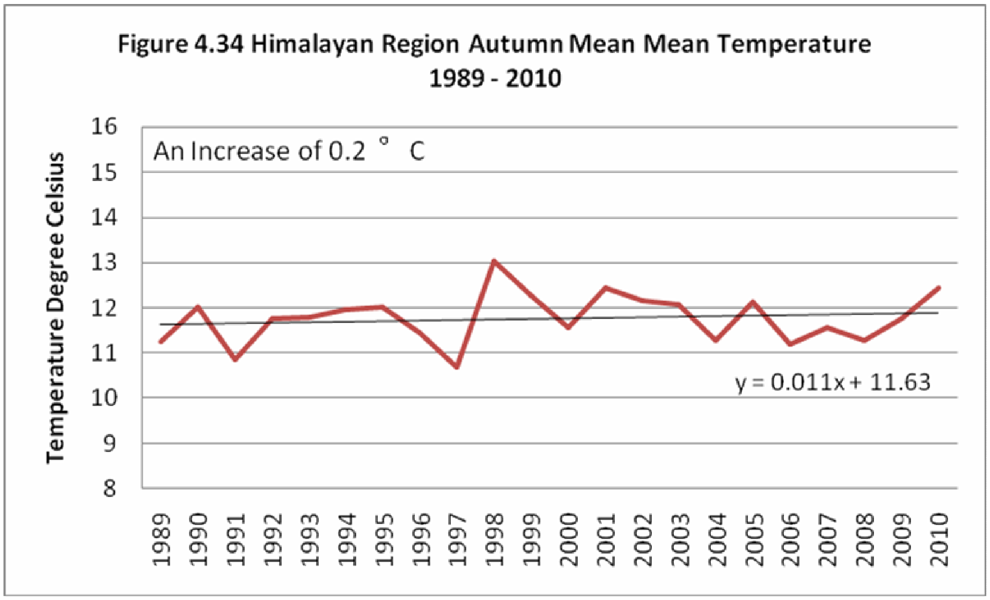
Spring season in the Himalaya region showed an increase in the mean temperature with a surprising increase of 2.3 ° C between 1989 and 2010. The warmest and the coolest spring were in the year 1999 and 1993 respectively. See Figure 4.32.



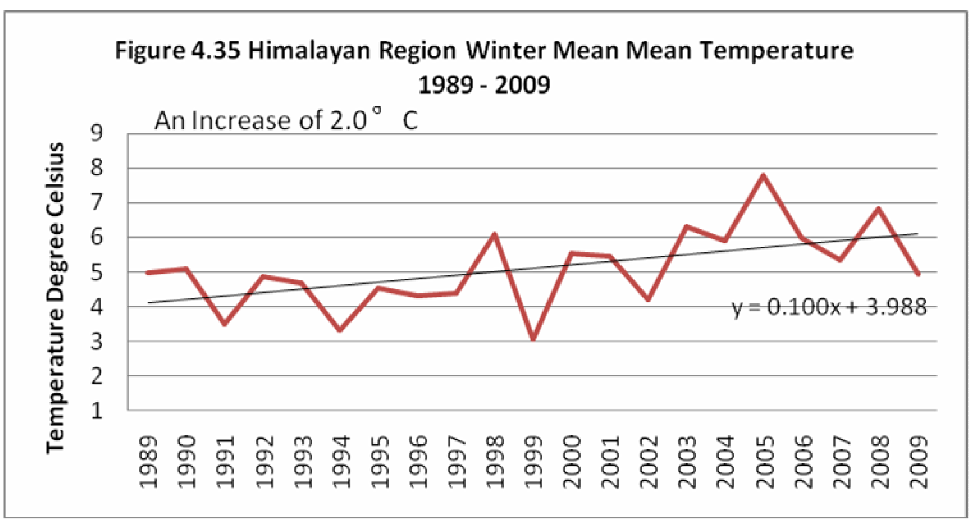
However, even with a significantly high summer mean mean temperature during the year 2006, interestingly the summer in this region showed a decrease of 0.3° C. The temperature trend from 1989 till 2005 showed a decreasing trend with 2005 the coolest summer in this region followed by a very high temperature during the year 2006 and again by 2010 the temperatures showed a sign of increasing trend. Figure 4.33.



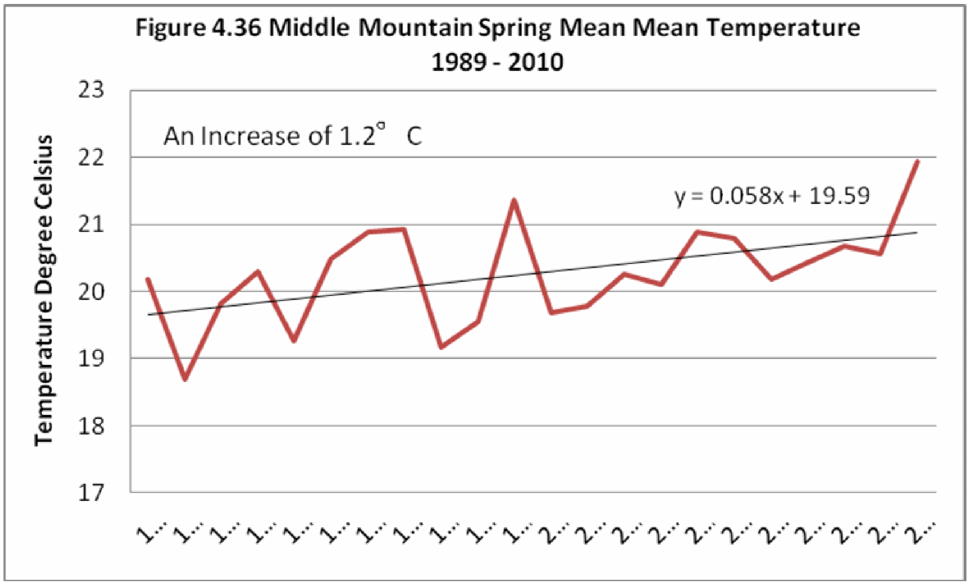
With 1998 the warmest autumn in the period of 22 years from 1989 to 2010, the autumn mean mean temperature increase by 0.2 ° C. The coolest year was 1997 and 1991 for this region in autumn season.



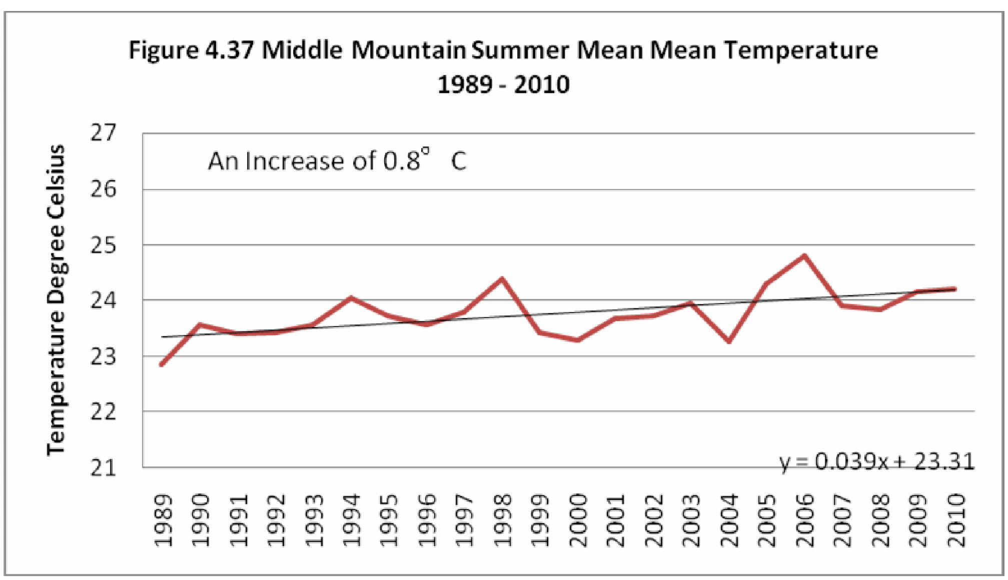
However, this region of Nepal had the coolest mean temperature in winter season in the year 1999 and 2005 as the warmest winter. The overall mean winter temperature increased with a significant rate of 2.0° C by 2010. Although before 1998 the winter mean temperature was comparatively lower, after 1999 the coolest winter year, the winter mean temperature showed a significant increase till 2010.



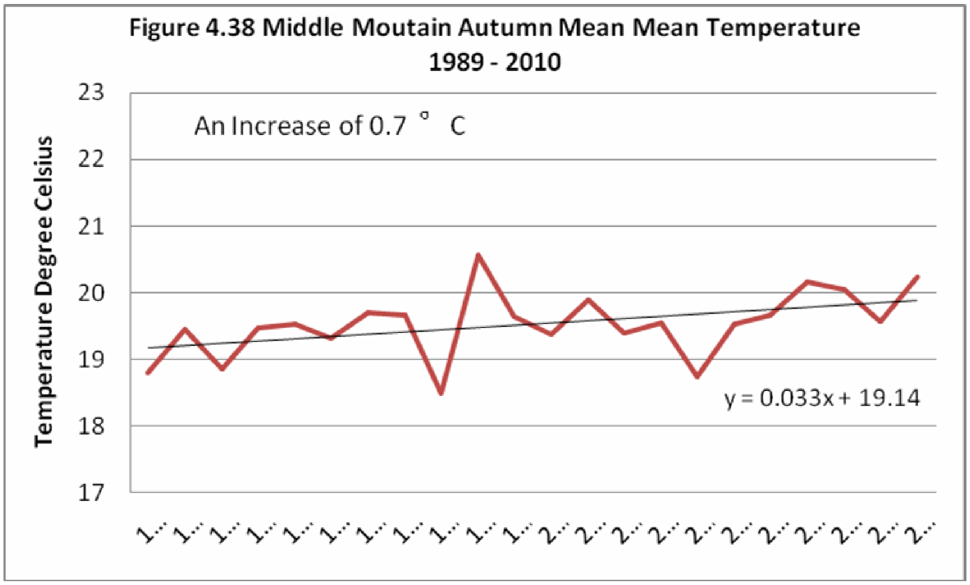
The middle mountain region which is just below the Himalaya region of Nepal in terms of altitude, confirmed an increase in the spring mean mean emperature by an alarming rate of 1.2 ° C. Spring season in this region was also warmest in the year 2010 followed by 1999 and the coolest year was 1997. See Figure below 4.36.



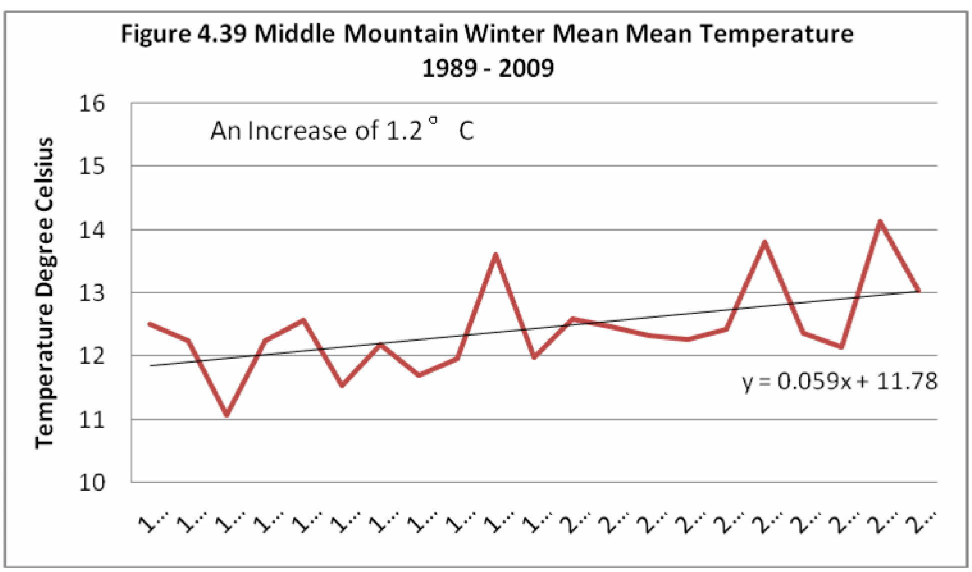
Summer mean mean temperature increased at the rate of 0.8 ° C which is comparatively low rate compared to other seasons but similar to summer season temperature trend compared to other regions. Figure 3.37



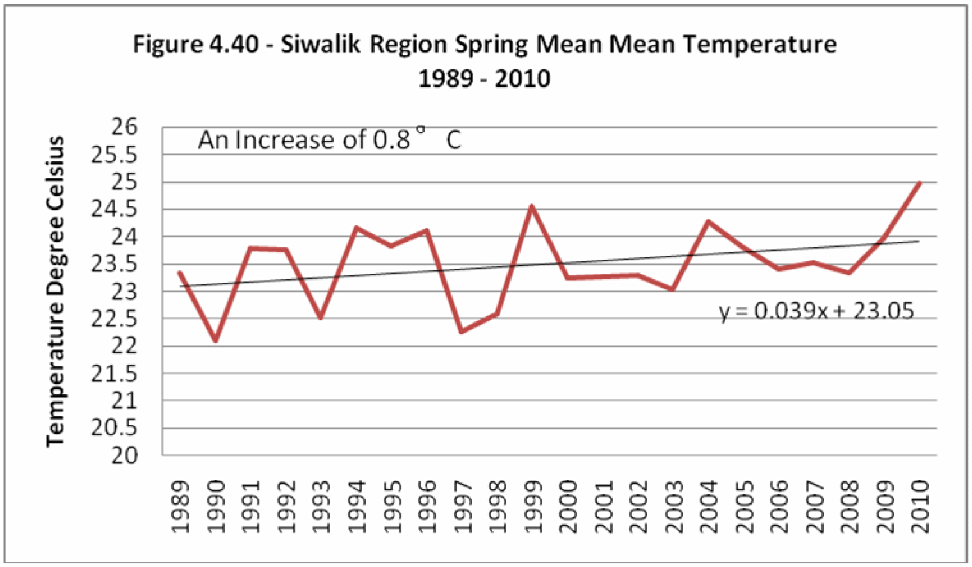
The autumn season mean mean temperature also increased at the rate of 0.7 ° C between 1989 and 2010 with 1997 being the coolest year followed by sudden increase and the warmest year 1999. See figure 4.38.



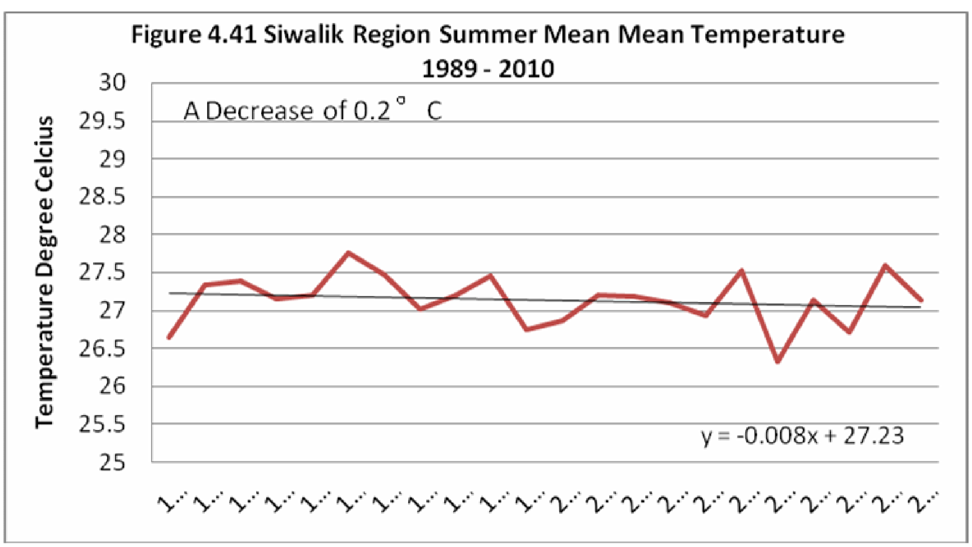
Winter season mean mean temperature also increased at the rate of 1.2 ° C confirming the second highest increasing rate among all season in this region. Although 1998 showed a high seasonal mean temperature the highest temperature trend for winter in middle mountain region was 2008. See Figure below 4.39.



The Siwalik region lies below the middle mountain region. The spring season mean mean temperature trend for this region showed an increasing rate of 0.8 ° C between 1989 and 2010. Similarly, the year 1997 was the coolest spring with sudden increase in the mean temperature in 1999 and 2010 saw the warmest spring in the Siwalik region of Nepal. See figure below.



Moreover, the summer mean mean temperature in the Siwalik region decreased by 0.2 ° C from 1989 to 2010. In this region, 2006 experienced the coolest summer season and 1994 the warmest season.



Also in the Siwalik region, 1997 experienced the coolest autumn in the 22 years period and the warmest year was 1995. The autumn season mean mean temperature increased by 0.08 between 1989 and 2010.

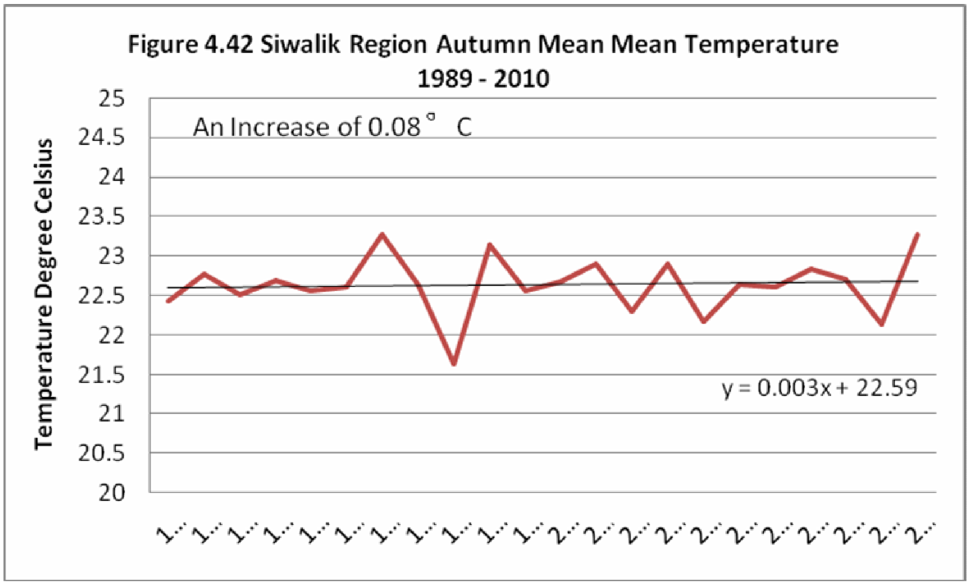


Figure 4.42 Siwalik Region Autumn Mean Mean Temperature 1989 - 2010

The winter season mean mean temperature in the Siwalik region of Nepal increased by 0.7 °C. However, 2008 winter season was the warmest winter in the period of study and 1996 was the coolest with 1997 also comparatively a cold winter.

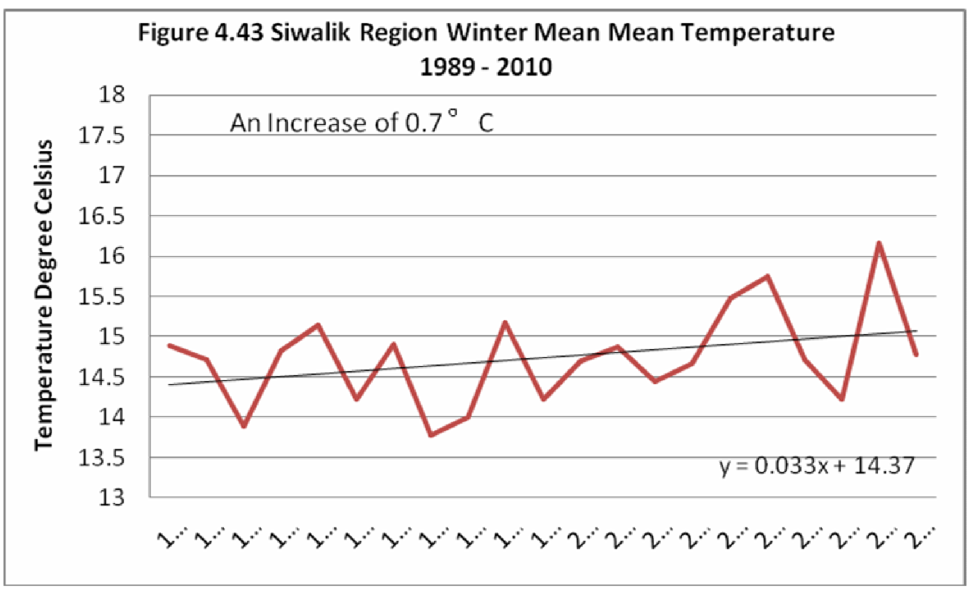
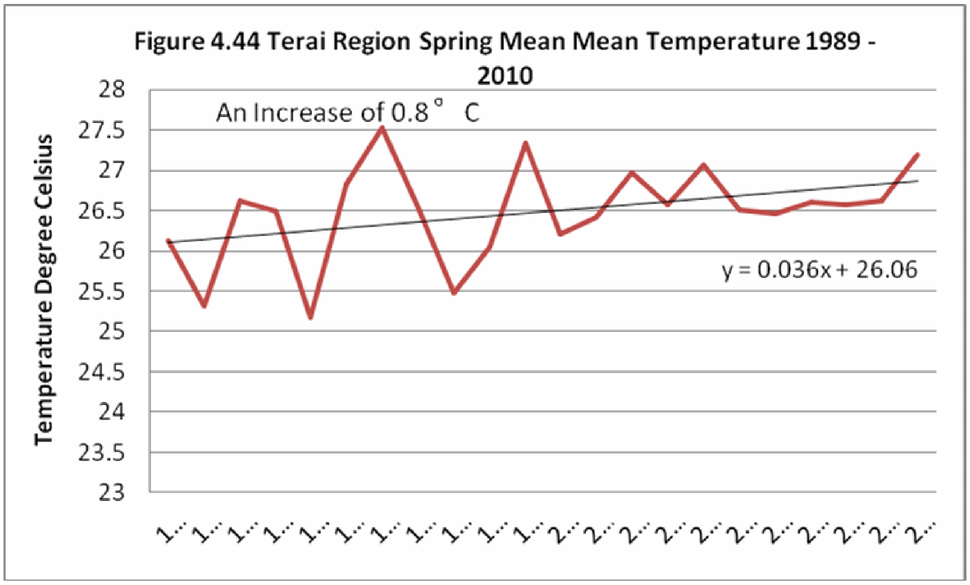
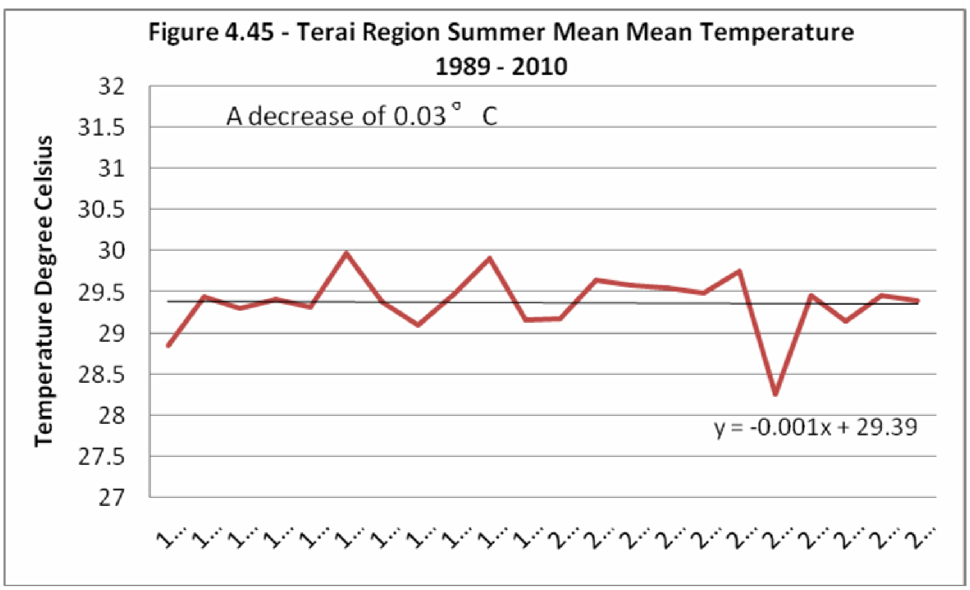


Figure 4.43 Siwalik Region Winter Mean Mean Temperature 1989 - 2010

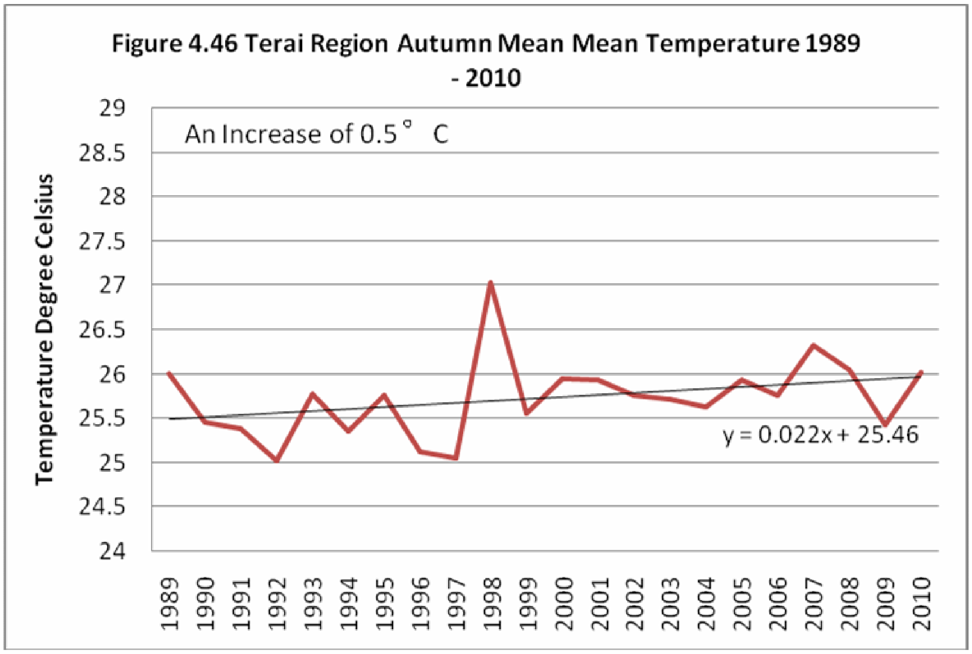
Terai Region the warmest region in Nepal close to India experienced the warmest spring in the year 1995 and coolest spring in 1993 with an overall increasing trend in the seasonal mean mean temperature of 0.8 ° C between 1989 and 2010.



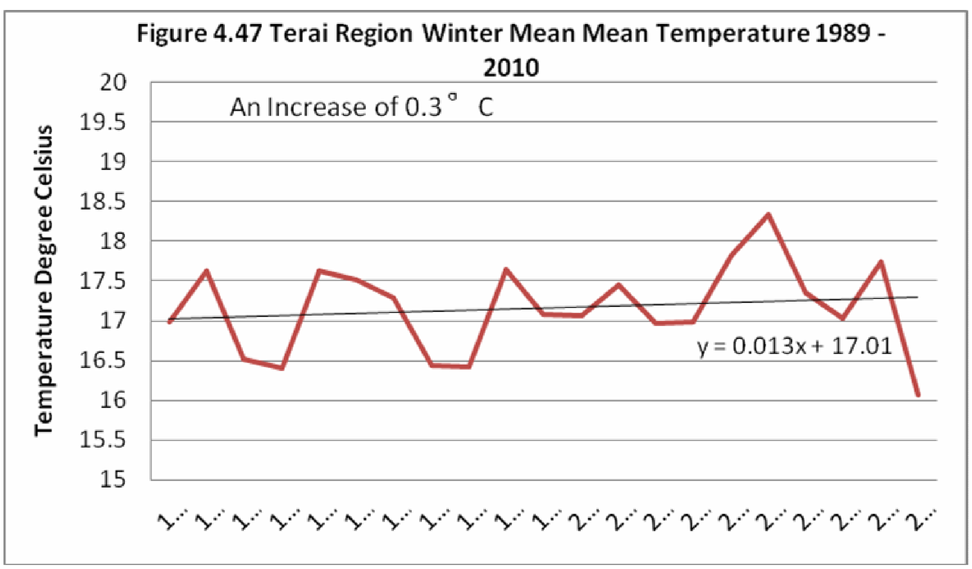
The summer mean mean temperature in Terai Region of Nepal with an evidence of decrease in the temperature of 0.03 ° C between 1989 and 2010 proved to be decreasing in the summer seasonal temperature trends in the Terai Lowland Region of Nepal.



Similarly, the autumn mean mean temperature in the Terai Region of Nepal increased by 0.5 ° C between 1989 and 2010. Moreover, again in this region 1998 experienced the warmest autumn season in the 22 years period and 1997 the coolest autumn followed by 1992.



Furthermore, the winter in the Terai region became warmer by 0.3 ° C between 1989 and 2009. The coolest winter was experienced in 2009 and the warmest in the year 2005 in the Terai region of Nepal. 1997 and 1998 like other regions and seasons was comparatively cool and warm respectively in this region too.



CHAPTER FIVE: DISCUSSION

5.1 Annual Temperature Trends

According to results from analysis of daily maximum, minimum and mean temperature of Nepal from 1989 – 2010, the running mean temperatures certainly shows an increasing trend. Maximum running temperature on daily basis shows the most significant increase over the 22 years. In the research by Shrestha et al. (1999), they found out that the maximum temperatures in Nepal are increasing at a significant rate. They also found that the annual mean temperatures had been increasing at the rate of 0.06 °C between 1977 and 1994. In this study, the results show that the annual maximum mean temperatures in Nepal have increased by 0.4°C between 1989 and 2010. Similarly, annual mean and minimum temperatures have increased by 0.7 °C and 0.2 °C respectively. See Figure 5.1, 5.2 and 5.3. It can be said that the annual mean temperature of Nepal has increased by 0.7 °C between 1989 and 2010.

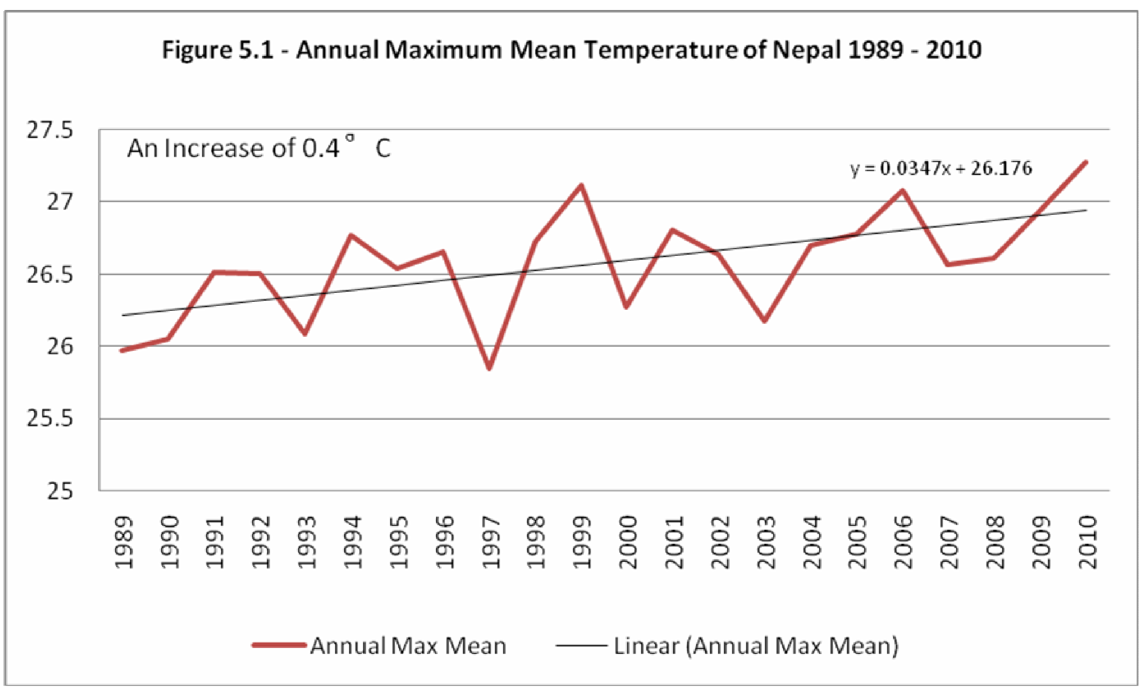


Figure 5.2 - Annual Minimum Mean Temperature Nepal 1989 - 2010

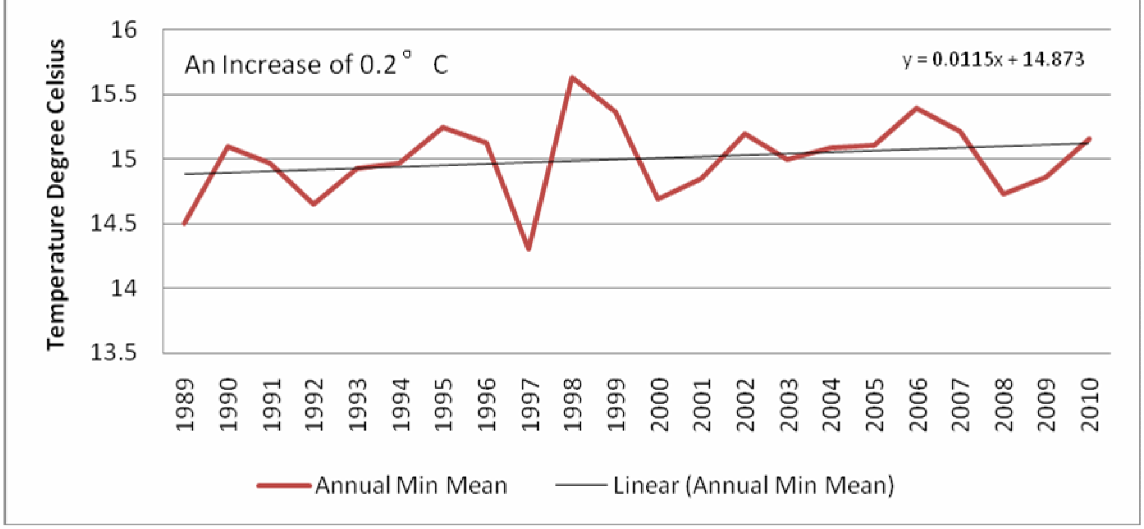
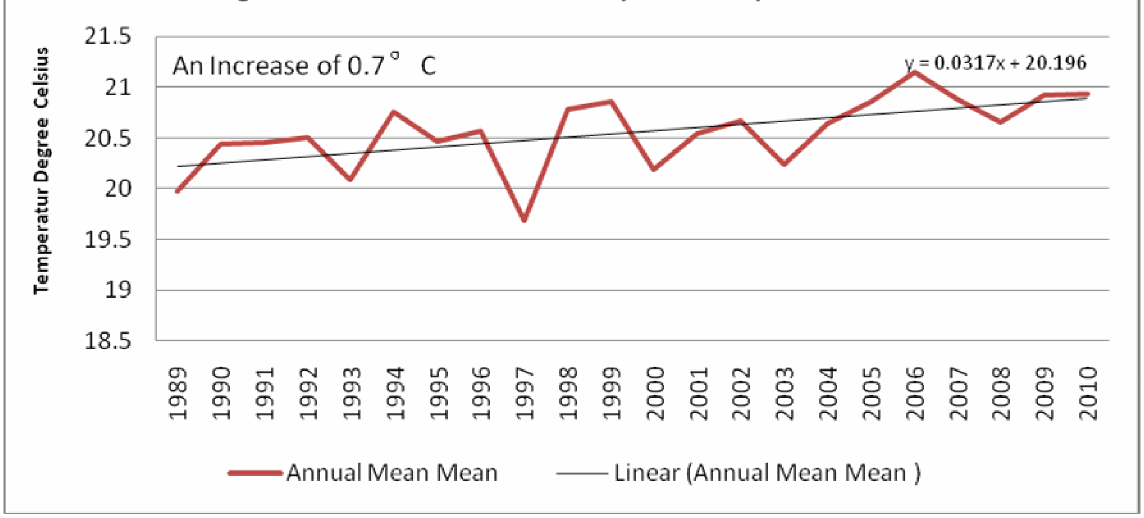


Figure 5.3 - Annual Mean Mean Temperature Nepal 1989 - 2010



Moreover, results from the maximum mean and minimum mean temperatures also shows that 1998 and 1999 were the warmest years in the last 22 years. Furthermore, the annual mean mean temperature was highest during the year of 2006 between 1989 and 2010 whereas, 1997 was the coolest year. In 1998, the Tam Pokhari Lake in the Dudh Koshi basin of Nepal outburst due to ice avalanche killing many lives and more than Nepalese Rupee 156 Million worth damage was calculated. The burst of the basin occurred during September, the time of the year Nepal, when summer is just ending. The high maximum temperature during this year could be considered as one of the main factor for the moraine dam to outburst due to over topping of the lake water level resulting from melting snow from the mother glacier.

The annual standardized mean temperature anomaly, when compared with the SOI data, shows some correlation. The bars in Figure 4.6 in the previous represent annual mean mean temperature anomaly with lines representing standardized Southern Oscillation Index mean for annual average of 1989 – 2010. It is evident that years such as 1997 and 1999 have correlation with the SOI showing La Niña and El Niño episodes respectively. However, it is evident from the annual anomalies of maximum, minimum and mean temperature that after 1999, there is evidence of more warm years than before 1999, indicating increase of temperature at national level. Before 1999, there were more cold years that after the year 1999. Therefore, 1998 and 1999 were the hottest years in that period. 1997 proved to be the coolest year in the 22 years period with low maximum, minimum and mean anomaly. During this year there are no evidences of big flash floods which were originated with the outburst of Glacial Lake in Nepal. However, most GLOF during the years between 1998 and 2004 were caused by collapse of moraine dam which is holding the glacial lake. There is high probability that the moraine dam was naturally destroyed due to excessive water in the lake and the natural dam was not able to hold.

5.2 Seasonal Temperature Trends

In Nepal seasonal temperature variations are certainly positive with winters having the most temperature variations. Moreover, the minimum temperatures winters are increasing, indicating that the cold temperatures during the days in winters are becoming warmer showing an increasing trend. Moreover, spring season in Nepal has shown second highest variations in temperatures indicating that spring season in Nepal is also becoming warmer. If spring becomes warmer there are more chances of flash floods and other changes in the mountain environment due to increase in temperature. Spring season would become similar to summer season in Nepal and would result in greater rate of melting glaciers and flash flood during the year. According to the results, even though summer and autumn season does not show much variation in the temperature trends, warming of winter and spring would cause more natural calamities during the year.

When analyzing the seasonal temperature trends for each season's maximum, minimum and mean temperatures, spring season showed the highest increase in the minimum temperatures illustrating that colder temperature in spring is becoming warmer the most compared to all other seasons of the year. This could mean that there is high probability of summer to start earlier in the future. Summer season temperature trends showed less increase in the maximum and mean seasonal temperature as compared to other seasons, however, the minimum temperature in the summer showed a decreasing trend. This explains that, in summer season, the hot is getting hotter and the cold is getting cooler which may result in extreme weather conditions in Nepal during the summer season. After analyzing the mean temperatures of autumn season, it was seen that the year 1998 had the highest maximum temperature compared to all other years in that period. The discussion will be further continued in the next section of the chapter which discusses the number of hot and cold days.

5.3 Number of Hot and Cold days in Nepal (seasonal)

After analyzing the seasonal temperature trends, it was known that number of cold days in spring in Nepal has decreased by 10 % between 1989 and 2010 implying that there is lesser number of cold days in spring than 20 years ago from 2010. And at the same time number of hot days has also increase in spring season. This strongly shows that spring is certainly becoming warmer and there are more chances of early starting of summer season.

In 1998, the Tam Pokhari GLOF that occurred was during the month of September (Ives et al. 2010), however during hot days in August, the Glaciers might have melted and collected in the Tam Pokhari Lake in Dudh Koshi basin of Nepal and with additional water from the rain during September, it might have triggered the moraine dam to outburst, flooding all the water downstream. During the same year the number of cold days was also less, proving that the year 1998 was one of the warmest year in the period of 22 years between 1998 and 2010. The number of hot days during was highest during the year 1998 in autumn season also. Similarly, the number of cold days during the same year in autumn was also the lowest. This strongly indicates that high temperature trends during 1998 with increase number of hot days and less number of cold days had strongly contributed melting of the glaciers at high rate causing the glacial lake outburst flood downstream. Numbers of cold days in winters are decreasing according to the results of this study and at the same time the hot days are also increasing. Although during the winters, all the glacial lakes are frozen and there have not been any evidence of flood during the winters. However, it is important to understand the increasing temperature trends during the winter in the future will have high possible to cause the glaciers to melt after the increased temperatures reach a certain high level.

5.4 Monthly Annual Temperature Trends

Although the results showed that winter had the highest increasing trends of temperatures in Nepal between 1989 and 2010, since winter in Nepal consists of December, January and February, each month's temperatures for 22 years were also studied. The results showed that February had the highest increasing trend in temperature than any other months.

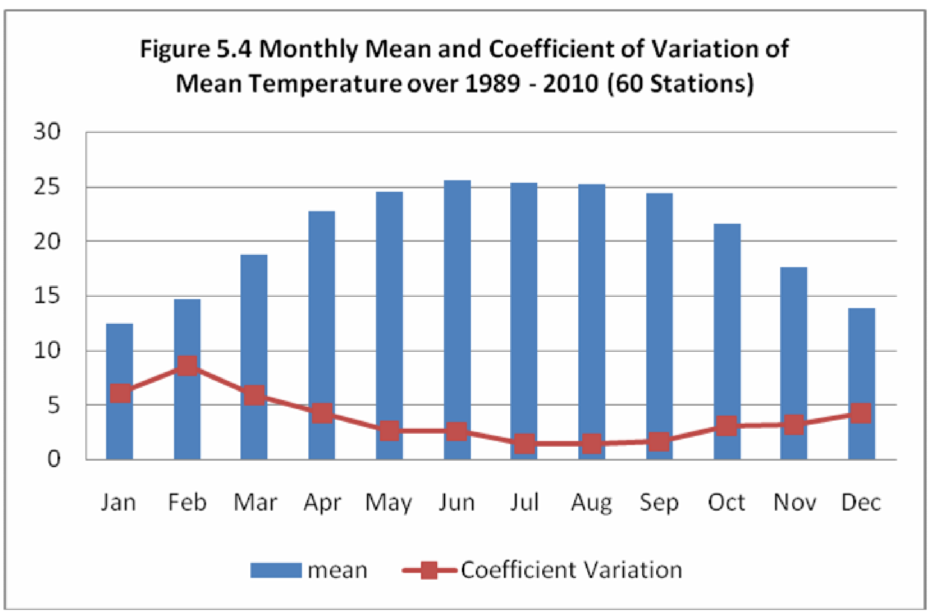
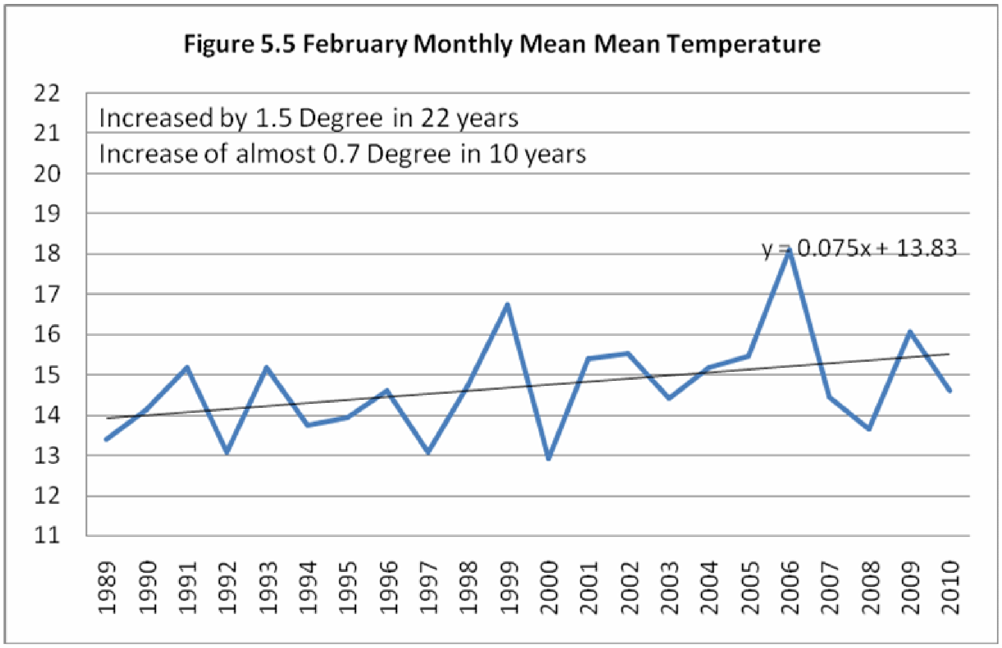
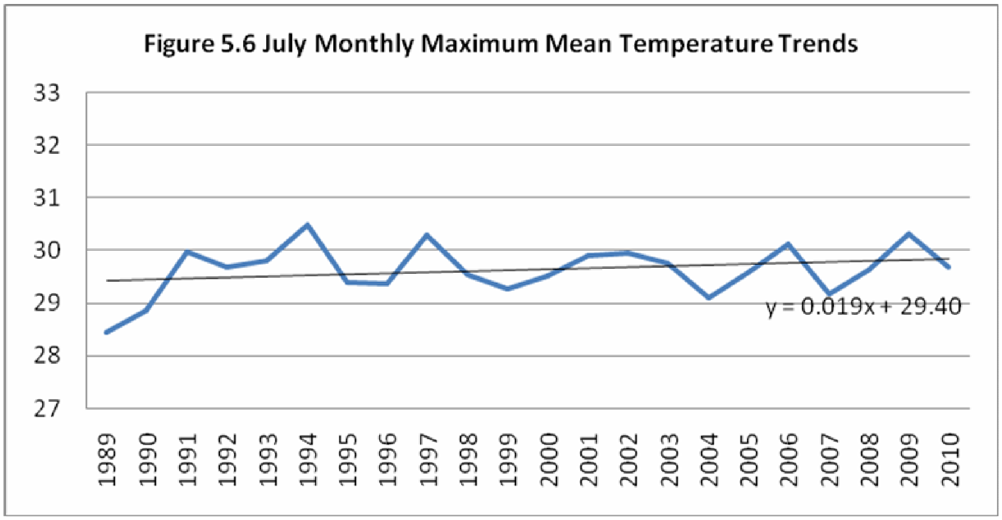


Figure Monthly Mean Mean Temperature and Coefficient Variation of Temperature increase Trends 1989 – 2010 Nepal

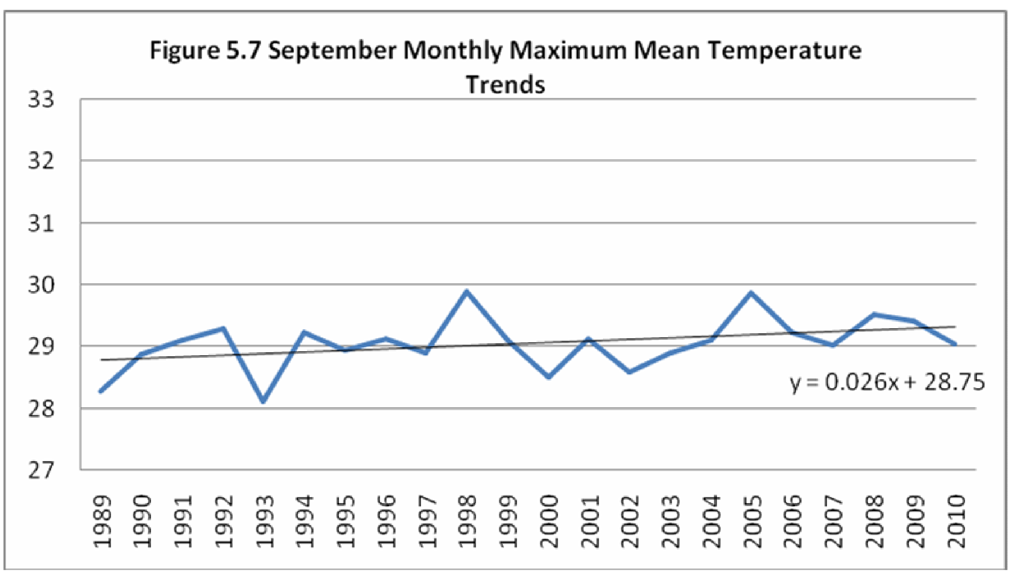
The month of February increase by 1.5°C between 1989 and 2010. This increase is very drastic and if this continues than the winter in Nepal will be warmer like spring or summer in the far future.



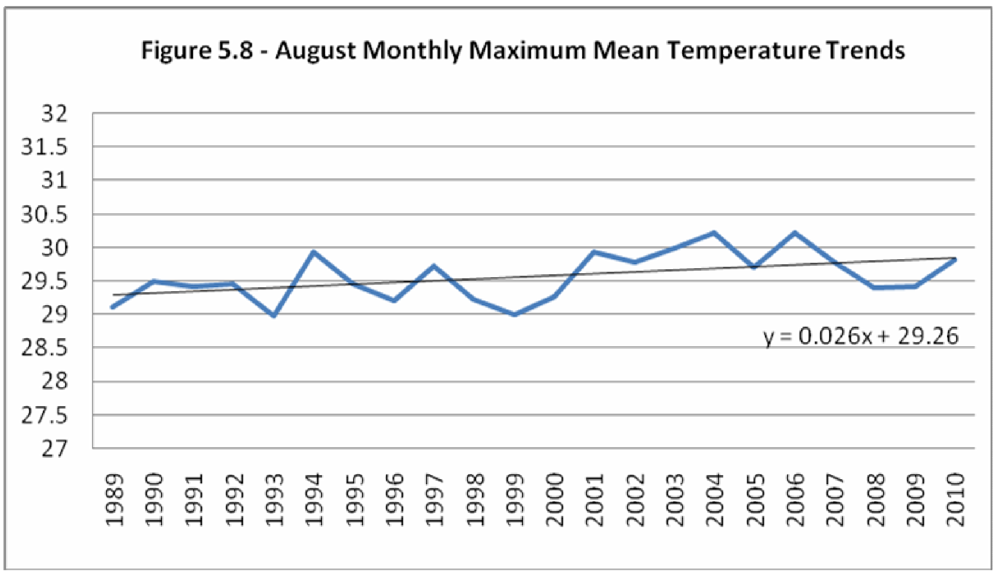
Looking back at the dates when the Glacial Lake Outburst Floods had occurred in Nepal, most events took place during the months of June, July, August and September. During these months in Nepal, the temperature is at its maximum peak and over that, these months especially September experiences heaviest rainfall during the year. In July 1991, Chubung Lake located in the Tama Koshi river outburst washing away many houses and farmlands downstream. This event occurred due to the collapsing of moraine dam of the Chubung Glacial Lake (Ives et al. 2010). According to the results of this study, the maximum mean temperature during the time of July in 1991 had reached peak. See Figure below.



Similarly, the Tam Pokhari GLOF in 1998, (discussed earlier in the paper) occurred during the September. According to the results, September 1998 had the highest maximum temperature and had reached maximum peak also. The outburst was caused by a huge boulder of ice avalanche which fell into the lake and caused the water in the lake to over flood eventually causing havoc downstream (Ives et al. 2010).



The Kabachi Glacial Lake in Nepal out broke in 2003 August and after the same year it broke again in 2004 August. The cause of this glacial lake outbreak was due to collapse of the moraine dam that is holding the lake (Ives et al., 2010). When the natural moraine dam can no longer hold the increasing water in the lake, the dam naturally outbursts flowing all the water in the lake downstream with a flash flood (Yamada, 1998). Figure 5.7 illustrates the August monthly maximum mean temperature trends between 1989 and 2010. Years 2003 and 2004 have had highest maximum temperatures for August. During the year 2003 the maximum temperature was increase when it reached the peak in 2004 and during both these years, Nepal has experienced GLOF from the same lake. Also see chapter 2 table 2.2.



5.5 Temperature Trends of Nepal based on Different Topographic Regions

Although there is a clear idea for temperature trends for the whole of Nepal, it is equally important to understand the temperature trends for different regions of Nepal because Nepal has different weather condition from north to south. Maximum mean temperature for Himalaya region was highest in the year 2006 but coolest in the year 1997, similarly for the middle mountain region of Nepal, 2006 was high but the highest was 2010 and the lowest temperature was experienced in the year 1997 as well. Also the year 1997 had lowest temperatures for Siwalik region, showing that 1997 was the coolest year in most of the region in Nepal except in the Terai region, 1993 had the lowest maximum mean temperature. In Nepal, temperature varies significant according to topography ranging from north to south but the years 1997 and 2006 had similar trend for maximum mean temperature for most region. Most importantly the highest increase in temperature trend was noticed in the Himalayan region than other regions.

For the mean temperatures, nationally, the highest increasing trend was found in the middle mountain region. The mean temperatures had increased by 1.04°C between 1989 and 2010. The least increasing trend was seen in the Himalayan region for mean mean temperature. Moreover, 1997 was the year with lowest mean temperatures for most regions in Nepal and 1999 and 2006 had highest mean temperatures for most regions.

Seasonally, for Mean temperature, spring temperature increased highest in the Himalayan region of Nepal. It increased by 2.31°C between 1989 and 2010 and 2.0°C for winter season. However, summer mean temperature decreased in most of the region by 0.3 °C in Himalayan region, 0.2°C in Siwalik and 0.03°C in the Terai region. Table 5.1 illustrates mean temperature trends in Nepal, regionally and seasonally between 1989 and 2010.

Table 5.1 Regional – Seasonal Mean Mean Temperature Trends Nepal 1989 - 2010

Region	**Seasonal**				**Annual**
	Spring (MAM)	**Summer (JJA)**	**Autumn (SON)**	**Winter (DJF)**	
Himalayas	2.31	0.3 (decr.)	0.2	2.0	0.2
Middle Himalayas	1.2	0.8	0.7	1.2	1.04
Siwaliks	0.8	0.2 (decr.)	0.08	0.7	0.4
Terai	0.8	0.03 (decr.)	0.5	0.3	0.3
All Nepal	0.89	0.1	0.3	0.79	0.7

*Winter was calculated for 1989 – 2009

* (decr.) Stands of decrease in temperature

*Temperatures in °C unit

CHAPTER SIX: CONCLUSION

6.1 Summary

Increasing temperature trend is a big threat to the world because it not only causes natural disasters but also brings about drastic changes to the natural environment. Moreover, climate change and increasing temperature trends whether due to the power of nature or manmade causes would increase significant issues especially for developing countries such as Nepal because with underdeveloped economy and low financial budget, it becomes difficult to quickly adapt to the environmental changes (Bolin et al., 1986).

In Nepal increasing in Temperature has had a major impact on the natural environment and its surroundings. With most population still depended on agriculture as major source of income, little changes in the ecosystem may cause big changes in their livelihood. Nepal is a country which is blessed with enormous mountain ranges which are called the Great Himalayas. From these mountains, a network of more than 6000 rivers flow downstream serving billions of people not only in Nepal but also in China, India and Bangladesh.

In Nepal, there are about 3,253 glaciers with a total area of 5,324 km^2 and 2,323 glacial lakes with an area of approximately 76 km^2. During the warm season these water slow flow downstream to vast network of river covering the whole country. However, recent studies show that these glaciers are melting at an alarming rate which makes the future uncertain, if all the snow in the mountains melts away. 99% of electricity in Nepal is generated through hydropower plants which rely on run off from these mountains – river network. Meanwhile, the fast retreating of glaciers have caused glacier lakes to be formed right beneath it and when the lakes cannot hold the melting snow it burst to flow downstream destroying everything on its way. Therefore, there is not only uncertainty of water availability for the future but also danger from flash flood in the near future.

Therefore it has become important to understand the temperature trends of Nepal at national as well as region scale by studying temperature data from 1989 to 2010 from a network of 60 stations covering whole of Nepal. This study has attempted to investigate the maximum, minimum and mean temperature trends of Nepal associated with not only annual trends but also seasonal and monthly temperature trends. Moreover, in this study, the analysis was further divided to topographical temperature trends for the four main topographic regions of Nepal.

6.2 Conclusion of the Study

The results from the study indicates that between the year 1989 and 2010, year 1998, 1999 and 2006 were the warmest years in the 22 year time period. Similarly, year 1997 was the year with lowest temperature trends. Moreover, maximum temperature in Nepal is increasing more significantly than the minimum temperature. Maximum temperature had increased by 0.4°C, minimum temperature by 0.2°C and the mean temperature increase by 0.7°C between 1989 and 2010.

Furthermore, winter season in Nepal has experienced the highest increasing trend in temperature followed by spring which could results in warmer winter season in future and with spring becoming warmer, summers in Nepal could start earlier. Moreover, summer is not only becoming warmer with increasing trend in the maximum temperature but with increasing trend in the minimum temperature, extreme climatic condition can be anticipated because the hot is becoming hotter and the cold is becoming colder. Likewise, February in Nepal is experiencing the highest temperature increasing trend in all maximum, minimum and mean temperatures. Therefore, in winter season, February is the most critical month with regard to high increase in temperature trends.

Regionally, Middle Mountain and Himalayan Region has experienced the highest increase in mean temperature especially during the spring season followed by winter season. Spring season in the higher region of Nepal will experience warmer temperature in the future. Likewise, the glaciers will most likely to melt at faster rate during the spring season and flash floods can be expected during this time of the year also. Most of the Glacial Lake Outburst floods have occurred in the summer season but in 2012, during May (spring) the Seti River was flooded due to GLOF from Mt. Macchapuchre, killing many people and washing away house, farmland and livestock. More GLOF during the spring season can be estimated in the future.

6.3 Suggestions and Recommendations

After analyzing the data and from the results of the study, spring and winter season in Nepal is highly recommended to study further in detail due to its high increasing temperature trends. However, even if summer season had low increase in temperature trends, it is equally important to study other factors such as rainfall, for summer because the minimum temperature in summer is increasing and the number of cold days in summer is also increasing. Extreme climatic condition can be estimated in summer in the future with maximum temperature increasing and minimum temperature decreasing. In summers, hot is becoming hotter and the cold is getting colder. Furthermore, Himalayan region is recommended to study followed by the middle mountain region due its high variation in temperatures during the past 22 years. Most glacial lakes are located in the mountain and middle mountain region where the glacier melt and is the starting point of the flash floods. Moreover, the most important cities are located in the middle mountain region such as the capital city, Kathmandu. However, the capabilities of the flash flood should not be underestimated because even if the glacial lakes are located in the high remote areas, they can cause severe impacts to long distance downstream. The GLOF in May, 2012 originated in the Mountain region, had serious impact on the city which is located in the Siwalik region of Nepal.

6.4 Future Work

Temperatures data for stations located in the high elevation is required and need to be studied for better study of the temperature trends in Nepal. Therefore, for the future work, temperature data from high remote areas of Nepal will be also be considered. Moreover, in the future work, the rainfall trends also needs to be studied to find closer relationship between the climatic condition and changing mountain environment and its impacts on the surrounding area. With the results from this study although the temperature trends of Nepal was understood for various topographic regions from north to south, but in the future work, the studying the different zones according to the river basin from east to west will be given importance because Nepal is largely divided into four river basin regions, Mahakali, Karnali, Gandhaki and Koshi. Although there are large numbers of potentially dangerous glacial lakes in the Koshi basin, with changes in the temperature trends, other basin could be increasing in numbers of these lakes. Furthermore, in the future work, other environmental impacts caused by the temperature variation will also be studied and try to make future predictions by scientifically finding the relationship between the extreme temperatures and its impacts on its surrounding environment.

List of References

Alford, D. (1992). Hydrological Aspects of the Himalayan Region. Kathmandu: ICIMOD.

Australian Government, Beaureu of Meteorology; S.O.I. (Southern Oscillation Index) Archives retrieved from http://www.bom.gov.au/climate/current/soihtm1.shtml on 2012/04/20.

Bajracharya S.R., Mool P.K. (2005). Growth of Hazardous Glacial Lakes in Nepal. *Proceedings of the JICA Regional Seminar on Natural Disaster Mitigation and Issues on Technology Transfer in South and Southeast Asia*, Sep 30 to 13 Oct 2004, pp 131 - 148. Kathmandu: Department of Geology, Tri - Chandra Campus, Tribhuvan University

Bajracharya S. R. (2008). Change in Glacial Environment of Everest Region, Nepal, ICIMOD (International Centre for Integrated Mountain Development)

Bajracharya S. R., Mool P.K. (2009). Glaciers, Glacial Lakes and Glacial Lake outburst floods Mount Everest Region, Nepal, ICIMOD (International Centre for Integrated Mountain Development)

Barnett T. P., Adam J. C., Lettenmaier D. P. (2005). Potential impacts of a warming climate on water availability in a snow-dominated region. Nature, pp 300–315.

Bolin B., Doos B. R., Jager J., Warrick R. A. (1986). The Greenhouse Effect, Climatic Change and Ecosystems. Chichester: J, Wiley, pp. 206-311

Carson B. (1985). Erosion and sedimentation processes in the Nepalese Himalaya, *Occasional paper No. 1*. Kathmandu: ICIMOD

CBS (1995). Statistical Year Book of Nepal. Kathmandu: Central Bureau of Statistics

Dyurgerov M.B. and Meier M.F. (1997). Mass balance of mountain and sub-polar glaciers: *A new global assessment for 1961-1990*, Arctic and Alpine Research, 29(4), pp. 379-391

Dyurgerov M.B. and Meier M.F. (2000). Twentieth century climate change: *Evidence from small glaciers*. Proceedings of the National Academy of Sciences 97(4):1406-1411

FAO (2004a). Compendium of Food and Agriculture Indicators 2004 – Nepal (www.fao.org/es/ess/compendium_2004/pdf/ESS_NEP.pdf accessed on Dec, 2010

Gray Vincent (2001). The Cause of Global Warming. Policy Series no. 7, Frontier Centre for Public Policy.

Haeberli, W. (1990). Glacier and permafrost signals of 20th century warming. *Annals of Glaciology*, 14, p 99-101

ICIMOD, UNEP (2007). Global Climate Change and Retreat of Himalayan Glaciers in China, India, Bhutan and Nepal,pp7-19.

ICIMOD (2012). International Center for Integrated Mountain Development, article publish on May 6th 2012, http://www.icimod.org/?q=7122 retrieved on May 12th 2012)

IPCC. (2001a). Climate Change (2001). Impacts, Adaptation and Vulnerability. *Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change.* [McCarthy, J.J., et al. (eds)]. 1032 pp.

IPCC (1996b). Climate Change (1995). Impacts, Adaptation and Mitigation of Climate Change: *Scientific and Technical Analyses*. Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change.

IPCC (2001). Climate Change (2001). The Scientific Basis. Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK.

Ives J. D. (1986). Glacial lake outburst floods and risk engineering in the Himalaya: *A review of the Langmoche disaster, Khumbu Himal, 4 August1985*, Occasional paper No 5. Kathmandu: ICIMOD

Ives J. D., Shrestha R. B., Mool P. K., (2010). Formation of Glacial Lakes in the Hindu Kush-Himalayas and GLOF Risk Assessment, ICIMOD

Kattelmann R. (1987). Uncertainty in assessing Himalayan water resources. *Mountain Research and Development*, 7(3): pp 270–290.

Malla G. (2003). Impact of climate change on water and soil health, Agriculture and Environment. MOAC, pp60-75.

Marahatta S., Dangol S., Bhawani, Gurung B. Gehendra (2009). Temporal and Spatial Variability of Climate Change Over Nepal 1976 – 2005, Practical Action Plan Nepal Office 2009

McSweeney C., New M. and Lizcano G. and Lu X. (2010). The UNDP Climate Change Country Profiles; Improving the accessibility of observed and projected climate information for studies of Climate Change in developing countries. Bulletin of the American Meteorological Soceity, 91, 157-166

Mool P.K., Bajracharya S.R., Joshi S.P. (2001a). Inventory of glaciers, glacial lakes, and glacial lake outburst floods: *Monitoring and early warning systems in the Hindu Kush-Himalayan regions* - Nepal. Kathmandu: ICIMOD

Ministry of Population and Environment (MoPE), (2004). Initial National Communication to the Conference of the Parties of the United Nations Framework Convention on Climate Change.

Nepal: Ministry of Population and Environment.

NEA (2008). Nepal Electricity Authority Corporate Plan 2008, http://www.nea.org.np/index.php?page=corporateplan retrieved on January 17th, 2011.

New M., Lister D., Hulme M., and Makin I. (2002). A high-resolution data set of surface climate over global land areas. *Climate Research, 21*.

National Planning Commission (NPC). (2005). MDG Assessment Report 2005. Kathmandu, Nepal. National Planning Commission/United Nations Development Programme

Oerlemanns J., Anderson B., Hubbard A., Huybrechts P.H., Jóhannesson T., Knap W.H., Schmeits M., Stroeven A.P., van de Wal, R.S.W., Wallinga J., and Zuo Z. (2000). Modelling the response of glaciers to climate warming. Climate Dynamics 14: 267-274.

Romilly George de Berdt and Singh Prasant Vikram Prashant, (2009). NEP: Climate Change Assessment. Strategy and Program Assessment. Asian Development Bank

Seko K. and Takahashi S. (1991). Characteristics of Winter Precipitation and its effect on glaciers in the Nepal Himalaya. *Bull Glacier Res.* 9,9-16

Shrestha A. B., Wake C. P., Mayewaski P. A. and Dibb J. E. (1999). Maximum Temperature Trends in the Himalayas and its Vicinity; An Analysis Based on Temperature Records from Nepal for the Period 1971 – 94. *Climate Change Research Center, Institute for the Study of the Earth, Oceans, and Space*, University of New Hamsphire, Durham, New Hampshire

Shrestha A. (2008). Overview on Climate Research presented at Advanced Institute on *The Asian Monsoon System: Prediction of Change and Variability*. 2–11 January 2008, East-West Center, Honolulu, Hawaii

Shrestha M. L., Baidya S. K., Sheikh M.M. (2008). Trends in daily climatic extremes of Temperature and Precipitation in Nepal. Journal of Hydrology and Meteorology, Volume 5

Singh P., Jain, S.K., Kumar N. and Singh U.K. (1994a). Snow and Glacier Contribution in the Chenab River at Akhnoor, CS (AR)-131, National Institute of Hydrology, Roorkee, India.

Stern N. (2006). The Economics of Climate Change. London: Cambridge University Press

United Nations Development Programme (UNDP). (2007). Human Development Report 2007/2008 – Country Fact Sheets – Nepal. New York: UNDP.

UNEP (2010). High Mountain Glaciers and Climate Change – *Challenge to human livelihoods and adaptation*, GRID-Arendal, Birkeland Trykkeri AS, Norway

Nepal's Initial National Communication to the conference of the Parties of the United nations Framework Convention on Climate Change, July 2004, UNEP

Vuichard, D., Zimmermann M. (1987) The 1985 catastrophic drainage of a moraine-dammed lake, Khumbu Himal, Nepal: *Cause and consequences*. Mountain Research and Development

Wanchang Z., Ogawa K., Besheng Y. and Yamaguchi Y. (2000). A monthly stream flow model for estimating the potential changes of river runoff on the projected global warming, Hydrological Processes, 14, 1851-1868.

Wessels R.L., Kargel J.S., and Kieffer H.H. (2001). Global Land Ice Measurements from Space: *Documenting the Demise of Earth's Glaciers using ASTER*. American Geophysical Union 2001 Spring Meeting, May 2001.

WECS (2010). Energy Sector Synopsis Report 2010. Water and Energy Commission Secretariat, Kathmandu, Nepal

WHO, (2007). Health System in Nepal: Challenges and Strategic Options. Country Office for Nepal. http://www.nep.searo.who.int/LinkFiles/Health_Information_HSC.pdf retrieved on 2011/10/5

WWF (2005). An Overview of Glaciers, Glacier Retreat and Subsequent Impacts In Nepal, India and China

XuDaoming (1985). Characteristics of Debris Flows Caused by Outbursts of Glacier Lakes in Boqu River in Xizang, China, 1981. Lanzhou Institute of Glaciology and Cryopedology, Academia Sinica

Xu J. C. (2008). The highlands: a shared water tower in a changing climate and changing Asia. *Working Paper No. 67*. World Agro forestry Centre.

Yamada Tomomi (1998). Glacier Lake and its Outburst Flood in the Nepal Himalaya. Japanese Society of Snow and Ice, Japan.