GOVERNMENT OF NEPAL

MINISTRY OF SCIENCE, TECHNOLOGY AND ENVIRONMENT

DEPARTMENT OF HYDROLOGY AND METEOROLOGY

DRAFT REPORT

Study of Climate and climatic variation over Nepal

Submitted by: Nepal Hydrological and Meteorological Research Centre and Consultancy Pvt. Ltd.

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1. Award of Job

As per the agreement signed between the Department of Hydrology and Meteorology, and Nepal Hydrological and Meteorological Research Center & Consultancy P. Ltd. for consulting services on **'Study of Climate and Climatic Variation over Nepal'**, the consultant is pleased to submit this **Draft report.**

This report contains introduction, activities, objectives, scopes of work, methodology, and result and discussion.

2. Background:

2.1 Introduction

Nepal extends from 26°22’ to 30°27’N in latitude and 80°04’ to 88°12’E in longitude. The country is approximately 885 km from east to west, and the north-south width varies from 130 km to 260 km. Within this range, the altitudinal variation is from approximately 60m above mean sea level in the southern plain (called Terai) to the Mount Everest (8848m) in the northeast. Out of 147,181 km2, the total area of the country, about 86% is comprised of hilly and mountainous regions, with the remaining 14% as flatland.

Rapid changes in altitude and aspect along the latitude, creates a wide range of climatic conditions in Nepal. As a consequence, within a span of less than 200 km Nepal encounters almost all types of climates, subtropical to alpine/arctic. The temperature in Nepal varies mainly with topographic variations along south-north direction. Eighty percent of the precipitation in Nepal comes in the form of summer monsoon rain and winter rains are more common in the western hills. As the occurrence of monsoon rains is dominant in the temporal distribution of precipitation, the season can be defined as: monsoon (June to September), post-monsoon (October to November), winter (December to February), and pre-monsoon (March to May). The climate of Nepal is mainly characterized by altitude, topography and seasonal atmospheric circulations.

Statistical analysis of historical digitized climate data is essential for understanding the present-day climate, climate change, natural climate variability, extreme events, etc. at station level. It also helps us to understand the degree of local climate forcing in different locations in the country. This information would also be helpful for vulnerability and impact studies in different sectors, which are having probable impact due to climate change at different levels.

2.2 Objective

The main objective of the work is to study the general climate and its long term change over Nepal based on observational data set. In addition, the potential stations which can be utilized for long term climatological studies will be identified.

2.3 Scope of Services

- Review of climatological studies over Nepal.
- Reviewing the quality of available climatological data of DHM and identifying the potential stations which can be utilized for long term climatic variation studies.
- Preparation of data availability table for all the stations of Nepal.
- Preparation of normal climatological statistics and extreme values of all the stations of Nepal based on long term data set.
- Development of country average, district average annual and seasonal air temperature and rainfall data set based on direct arithmetic averaging and with spatial interpolation.
- Generating Gridding data set of normal monthly, seasonal and annual precipitation and air temperature data and preparation of maps based on this.
- Air temperature and precipitation trend analysis of Nepal and for major representative climate stations of Nepal. Mapping of temperature and rainfall trend for each seasons.
- Monsoon onset, retreat and duration variation studies.

2.4 Physiography

Nepal is divided into five major physiographic regions: Terai plain, Siwalik hills, middle hills, high hills and high mountains (consisting of the main Himalayas and inner Himalayan valleys). Fig.1 depicts the physiographic map of the country.

Terai: Terai in Nepal is the northern limit of Indo Gangetic plain which extends nearly 800 km from east to west and 30 to 40 km north to south with elevation ranging from 60 to 200 masl. It is generally flat at with minor relief caused by river channel shifting and down warping of the basin.

Siwalik: Commonly known as Churia hills abruptly rises from Terai and ends with the beginning of the middle hills range. The elevation of the Siwalik ranges from 200 to 1,500 masl. The Siwalik which covers nearly 13 per cent of the total area of the country is generally characterized by low terraces and alluvial fan with steep topography. The region is very much prone to landslides, mass wasting and debris flow which contributes significant amount of sediment load to major rivers in Nepal.

Middle hills: Middle hills are also known as the Mahabharata range. The elevation of middle hills ranges from 1,000 to 2,500 masl and extends throughout the length of the country. In many places the range is intersected by antecedent rivers such as the Koshi, the Gandaki, the Karnali and the Mahakali. These rivers are the source of water originating from north of this range which drain to the south. It is the first great barrier to the monsoon winds that produces heavy precipitations on itssouthern slope due to orographic effects.

High hills: This region lies further north of middle hills whose elevation ranges from 2,200 to 4,000 masl. It has an average width of 50 km and extends from east to west in the form of a strip. The high hills, consisting of low hills, river valleys and tectonic basins exhibit a mature landform. This region has cool temperate climate.

Mountains or the Himalayas: The hills of high mountains rise slowly to the north and make up the snow capped high Himalayas. The elevation ranges from 4,000 to 8,848 masl. The main north-south flowing

rivers originating from northern side of the Himalaya have dissected this range forming some of the deepest gorges in the world – 5,791 m deep gorge in the Kali Gandaki valley. The region is mostly occupied by glaciers, snow peaks, rocky slopes, talus and colluvial deposits. It has an extremely rugged terrain with steep slopes and deep valleys.

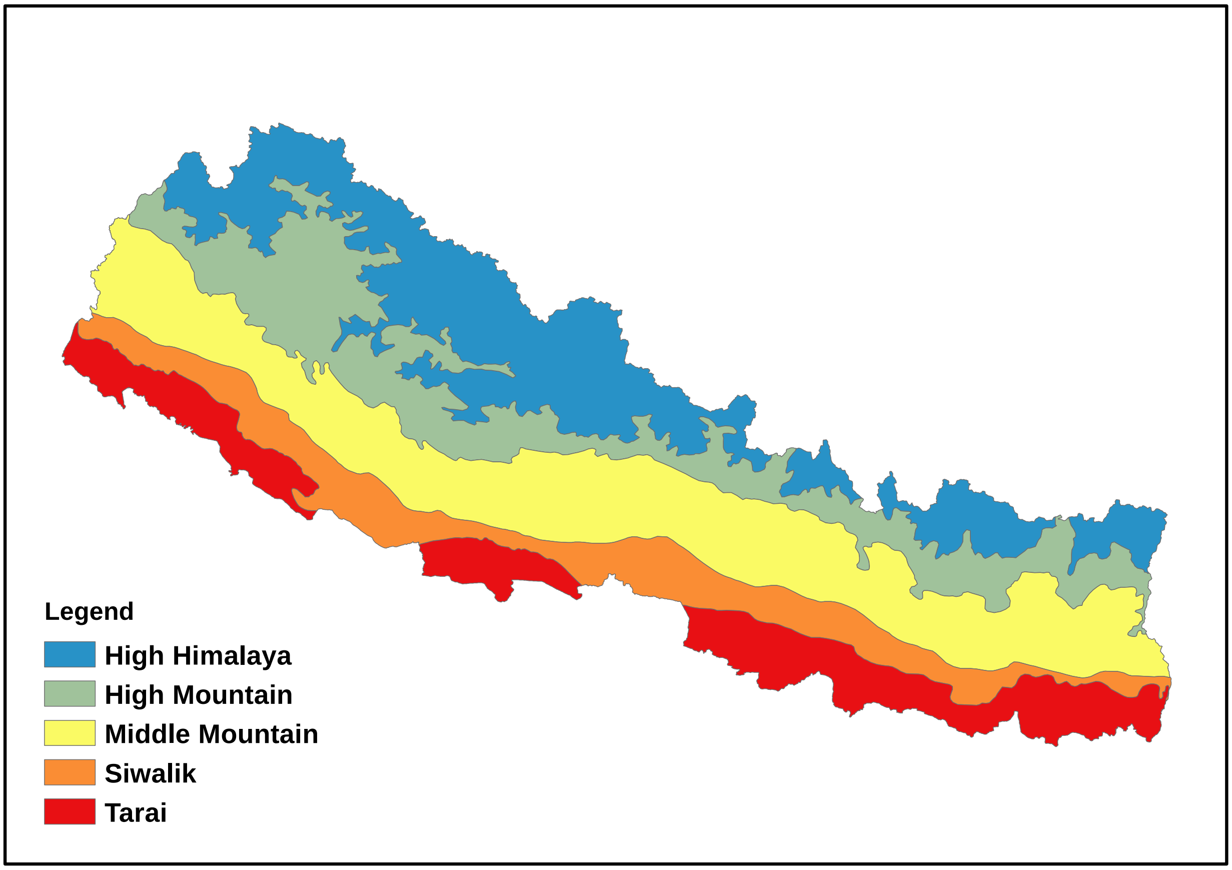

Figure 1: Physiographic regions of Nepal

2.5 Seasons

Winter (December -February):

The winter season (December to February) is dry and cold with clear sky. However, few spell of rain in association with the western disturbances which have their origin in the Mediterranean generally do occur during these months. The winter rain, highest in the northwest region decreases in amount in both southward and eastward direction. At higher elevation the winter rain falls as snow. Morning fog and frost are common in valleys and hilly areas. The lowest temperature reaches either in December or January.

Spring (March-May) or Pre Monsoon:

During March to May, the country experiences occasional pre-monsoon thunder shower activity associated with thermal convection due to increasing insolation combined with the orographic effect. An occasional hailstorm also occurs during these months. The pre-monsoon precipitation activities are

more frequent in the hilly regions rather than the southern plain of Terai region. Day time temperature in the southern plains of the country even reaches beyond 40°C.

Summer (June-September) or Monsoon:

This is the monsoon season. Monsoon normally starts in the second week of June and reaches full development in July. Monsoon is the main source of precipitation, which enters the country from eastern part of Nepal. As the monsoon enters Nepal, topography plays an important role for the distribution of precipitation ranging from about 150 mm to over 5000 mm per annum. Physiographic parameters such as elevation with windward and leeward orientation, and exposure to rain bearing winds greatly influence the precipitation. About 80% of the annual precipitation falls during this period. Analysis of data shows that July is the wettest month. Most of the days during monsoon are generally cloudy and rainy. But most of the precipitation occurs during the night. Heavy rain, incessant rain and periods of dry spell are common during this season. Most of the time dry spells occur (break in monsoon) in between extending for more than a week. Floods and landslides are the most common weather related disasters caused by the heavy precipitation in this season. However, because of the altitudinal variation and orientation of the topography, considerable variation in precipitation is observed from place to place resulting in some places susceptible to floods and some places vulnerable to drought.

Autumn (October-November) or Post Monsoon:

In October the country receives few spell of post-monsoon rain similar in character to the pre-monsoon one but the frequency is low and rapidly decrease with the progress of the season. Generally, November is the driest month. This season is best suited for the tourists due to excellent visibility for the panoramic view of the great Himalayas.

3. Methodology and Data

3.1 Data

Meteorological station network maintained by the Department of Hydrology and Meteorology (DHM), Government of Nepal is utilized for this study. This network of observation stations is irregularly distributed; denser on the southern lowlands and thinner over the complex terrain of northern mountainous region of Nepal. This irregular network creates an information gap, which ultimately hinders development plans and projects. With spatial interpolation techniques the observed meteorological data is transformed into high-resolution regular grid fields. The below map shows the stations of DHM, number of stations by type and regional distribution of stations. Available meteorological data from the date of establishment has been utilized in this study. For normal calculation, standard 1971-2000 or 1981-2010 period are selected with data availability for at least 25 years in between those period. Trend analysis of air temperature and precipitation is for the period of 1971-2012. Meteorological variables evaporation, sunshine have limited data therefore they are not included in normal calculation. The district average precipitation and air temperature statistics are based on data availability for at least 10 years and for high altitude stations only at least 5 years. The data of 4 stations of EVK2CNR (an Italian research institute) is also used in order to cover the high altitude area climate.

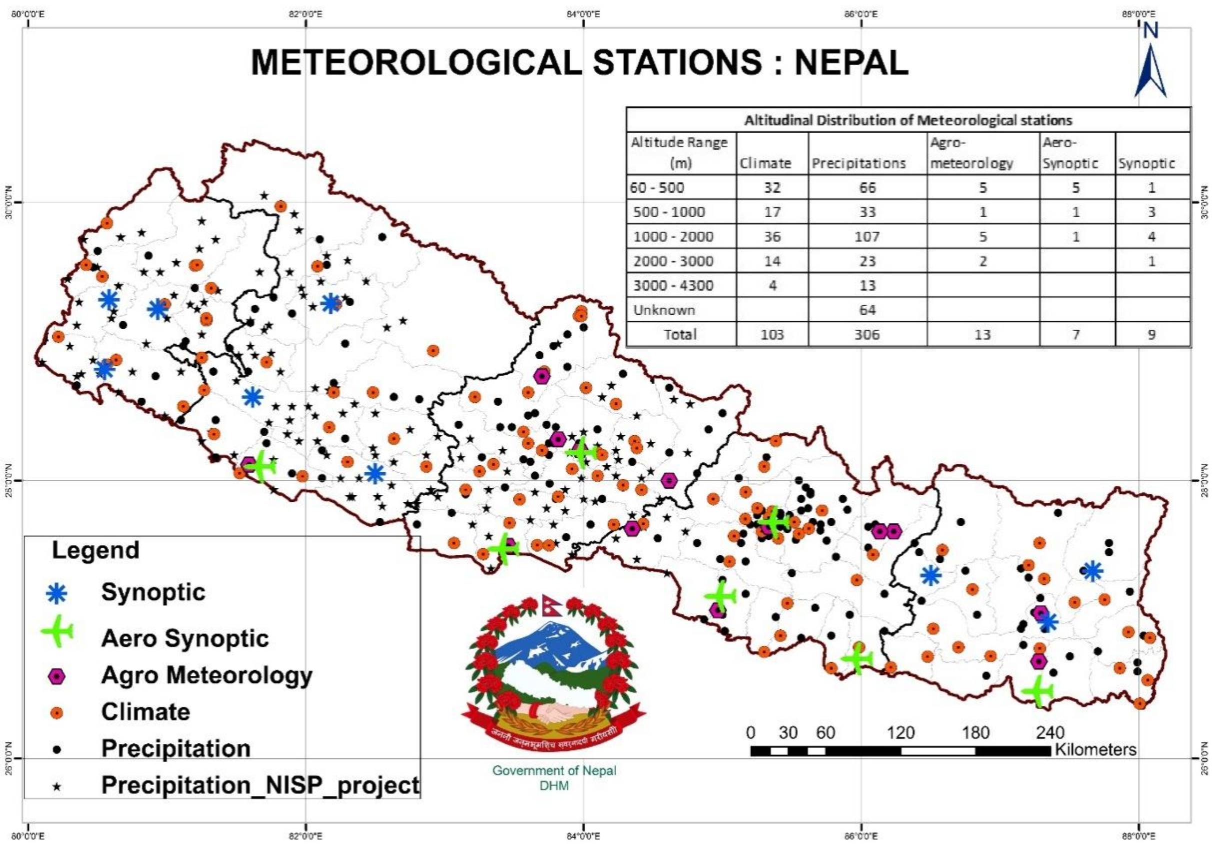

Figure 2: Distribution of Different Stations over Nepal.

Table 1 : Distribution of Stations in DHM regional offices.

Regional Office	Total stations	Precipitation	Precipitation NISP	Climate	Agro-meteorology	Synoptic	Aero-Synoptic
Mid and Far West development region	173	36	99	30	1	6	1
Western	121	38	45	31	5	0	2
Central	92	54	6	24	5	0	3
Eastern	52	28	0	18	2	3	1
Total	438	156	150	103	13	9	7

Table 2: Parameters observed in different station types

Station Type	Numbers	Parameters observed	Obs. Frequency	Time of Obs.	Remarks
Precipitation	306	P	Once	03 UTC	
Climate	103	T, P, R.H.	Twice	03, 12 UTC	
Agro-meteorological	13	T, P, R.H., E, S, Ts, Ws	Twice	03, 12 UTC	

Synoptic	9	T, P, R.H., S, Ws, Wd, C, V, PW, Pr	Three hourly	00 to 12 UTC only	
Aeronautical (aero-synop)	7	T, P, R.H., S, Ws, Wd, C, V, PW, Pr	Hourly	0 to 12 UTC only	only Kathmandu airport 00-23 UTC
Details: P= Precipitation, T= Air Temperature, R.H.= Relative Humidity, E= Evaporation, S= Sunshine Hour, Ts= Soil Temperature, Ws= Wind Speed, C= Cloud Type and Height, V= Visibility, PW= Present Weather/Past Weather, Pr= Atmospheric Pressure					

Source for table and map: DHM

3.2 Methodology:

Data from the stations are compiled in monthly, seasonal and annual statistics. Normal calculation is carried out for the period of 1981-2010 and 1971-2000.

Based on the available precipitation and air temperature data, spatial interpolation of seasonal precipitation and air temperature variables and extreme variables were carried out in R-Software using Universal kriging function with consideration to elevation in 1km*1km grid. Here, elevation is considered because it is the dominating factor for air temperature variation and precipitation are also influenced with it. The output data is in 1km*1km grid.

After that data is exported to Arc GIS 10 and maps are prepared. Zonal statistics function is used to get the seasonal values of precipitation and air temperature district wise and for whole country.

Due to low correlation with altitude for precipitation and air temperature trend only ordinary universal kriging in 10km*10km grid is utilized.

4. Result and Discussions:

4.1 Variation of mean parameters

4.1.1 Precipitation

The spatial variation of precipitation has been analyzed from the observations of 1961 to 2012. Only the stations with the data available for at least 10 years out of these years are used. However, in order to cover high altitude areas above 3000m stations with data for at least 5 years are also used.

Nepal’s precipitation is affected by two major air movements. The highest rain occurs when monsoon comes from the Bay of Bengal. The western disturbances during the winter season affects mostly the western parts of the country and results in snowfall in the high mountains and the Himalayas. The interaction of the complex topography with monsoon and westerly weather systems results into high variation in spatial distribution of precipitation. The windward side of the mountains receives more precipitation while the leeward side receives less.

The mean annual precipitation of Nepal was found to be around 1800mm with the highest annual precipitation recorded in Lumle of Kaski District with mean annual precipitation of about 5500mm. The lowest precipitation site is recorded in Upper Mustang Dhiee, Lomanthang area of Mustang District with mean annual precipitation of less than 150mm. Both of these highest and lowest precipitation sites of the country are in Annapurna area.

The three highest precipitation pocket areas - southern slope of Makalu range in eastern development region, Southern slope of langtang range in central development region and south of the Annapurna range in western development region were observed in the country. Similarly, two lowest precipitation pocket areas - Manang and Mustang, were observed at the leeward side of the Annapurna range. Fig.3 shows the seasonal contribution of precipitation in percentage over Nepal.

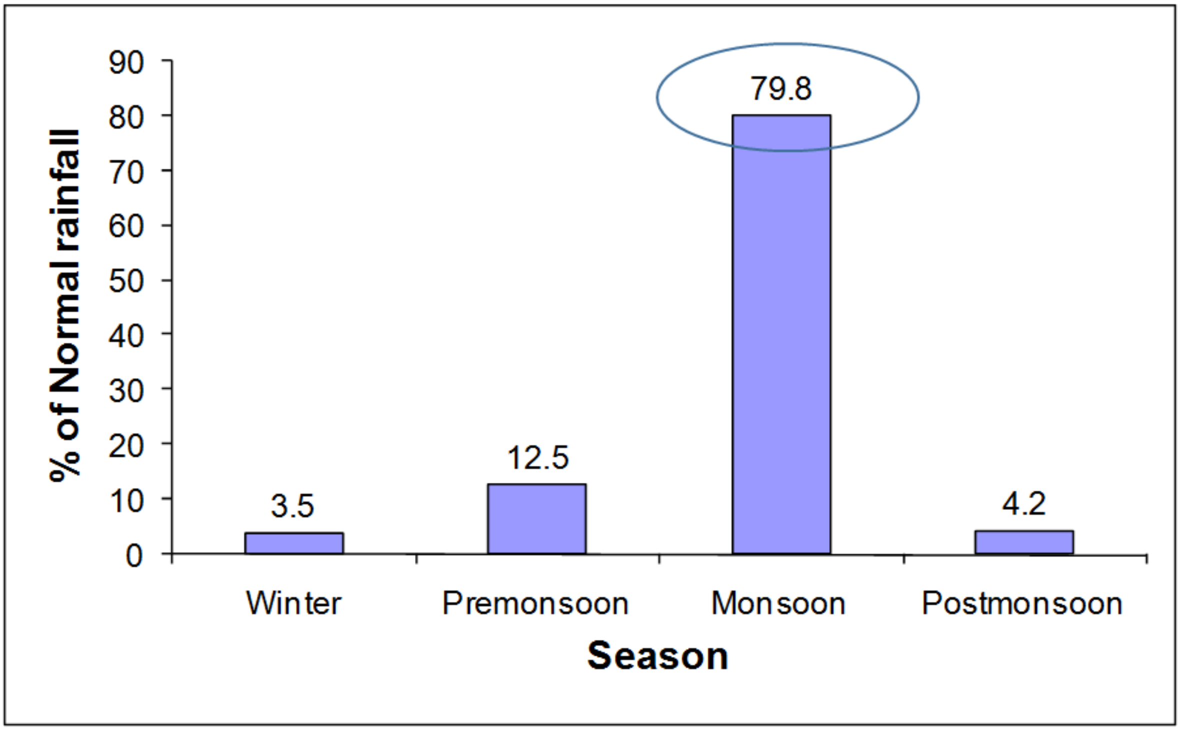

Figure 3: Seasonal contribution (Percentage of annual precipitation) over Nepal.

a. Annual precipitation:

Mean annual precipitation varies from less than 150mm to above 5000mm. Since monsoon precipitation is the largest contributor of annual precipitation, the spatial pattern of annual precipitation follows monsoon precipitation pattern (Fig. 4).

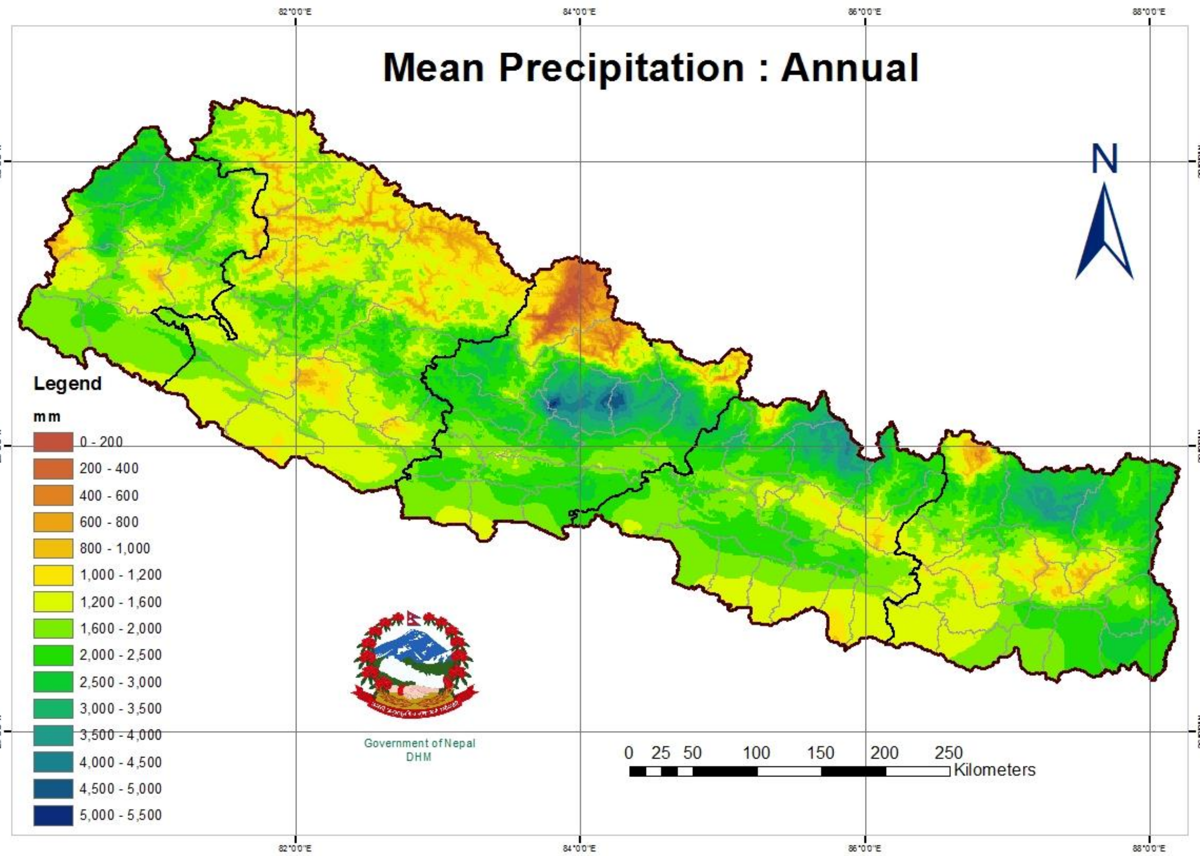

Figure 4: Mean Annual Precipitation variation over Nepal

b. Winter Precipitation:

Winter (December - February) is the driest season contributing 3.5 percent of the total annual precipitation. The western disturbances results in most of the winter precipitation in the country. The winter precipitation is high in far western development region and low in southern parts of central and eastern development regions. The prominent high and low precipitation pocket areas observed in the other seasons remained the same in this season as well. The rainfall during this season varied between less than 20 mm to over 200 mm (Fig. 5).

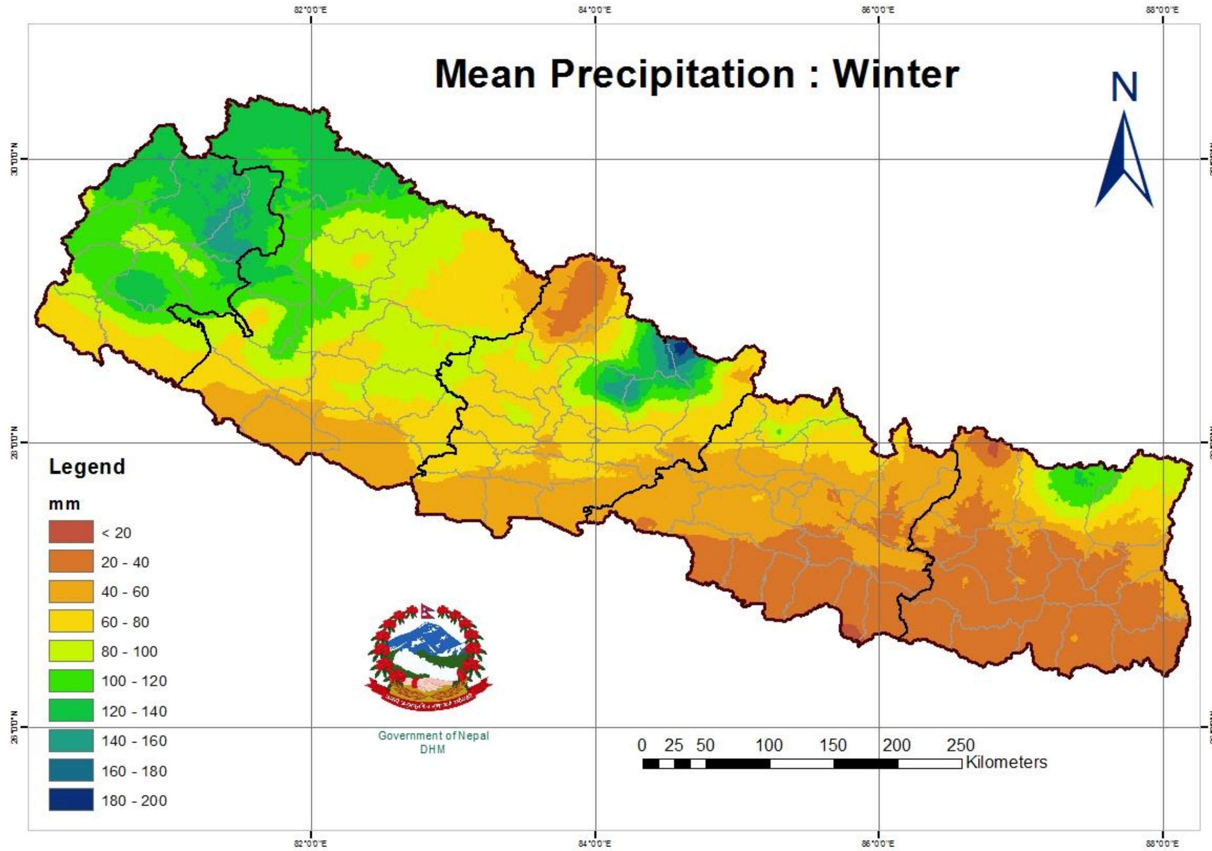

Figure 5: Mean Winter precipitation variation over Nepal

c. Pre-Monsoon Precipitation:

Pre monsoon season received 12.5 percent of the total annual precipitation which is the second highest precipitation season after monsoon. The western disturbance and locally developed thundershowers results in pre-monsoon precipitation.

During the pre-monsoon months March, April and May, the precipitation amount generally increases compared to winter with more precipitation in east Nepal compared to west. The precipitation varied from less than 50mm to over 900mm in this season (Fig. 6).

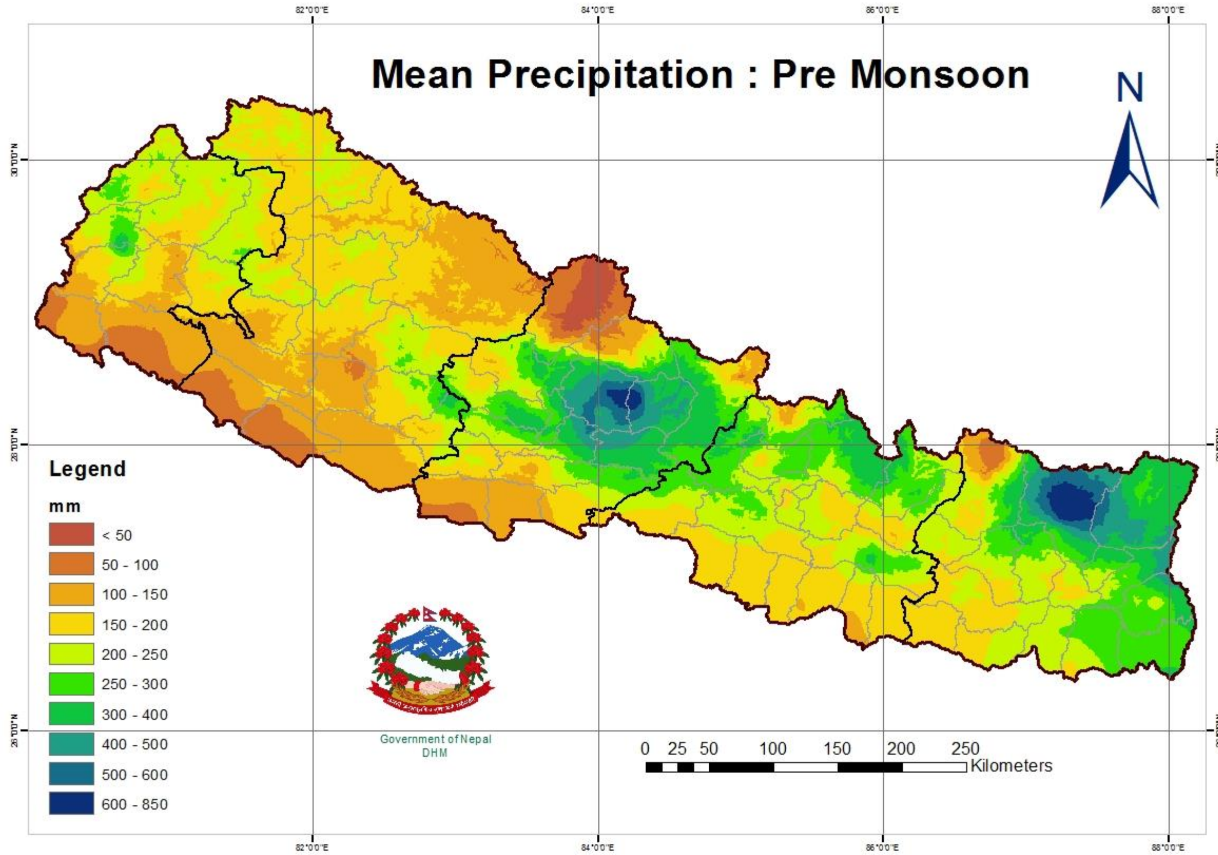

Figure 6: Mean Pre-Monsoon precipitation variation over Nepal

d. Monsoon Rainfall

Monsoon normally starts from the second week of June (10 June) and retreats in the fourth week of September (23 September). Monsoon is the wettest season and is the main source of precipitation in Nepal. Monsoon season contributes on an average 79.8 percent of the total annual precipitation of the country. The effect of monsoon is prominent in the eastern half of the country. The western half especially the northern parts of mid-western development region are generally drier compared to the eastern half. Like in pre monsoon season, the high precipitation pocket areas in monsoon season are Kaski, Sindhupalchok and Sankhuwasabha Districts. The driest regions – Mustang, Manang and Dolpa receive less than 150 mm while the wettest region Kaski receives more than 4,500 mm of rainfall during the monsoon season (Fig.7).

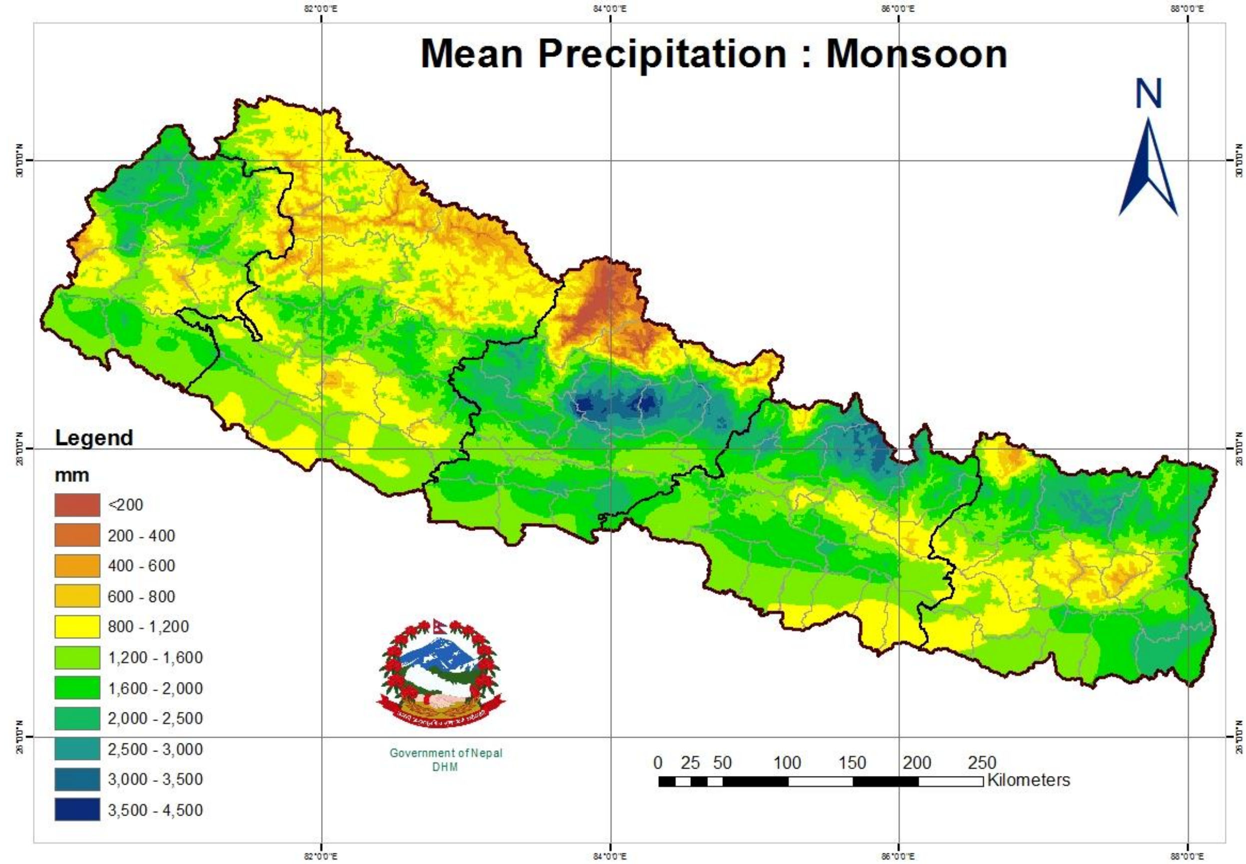

Figure 7: Mean Monsoon precipitation variation over Nepal

e. Post Monsoon Precipitation:

October and November is the post monsoon season. During this season, the country receives an average of 4.2 percent of the total annual precipitation. The character of the precipitation is similar to the pre monsoon rain. November receives the lowest precipitation of the year. The spatial distribution of precipitation is similar to the pre monsoon and monsoon seasons with low precipitation ranging from less than 25 mm in the western half of the country and to over 230 mm in the eastern half of the country (Fig. 8).

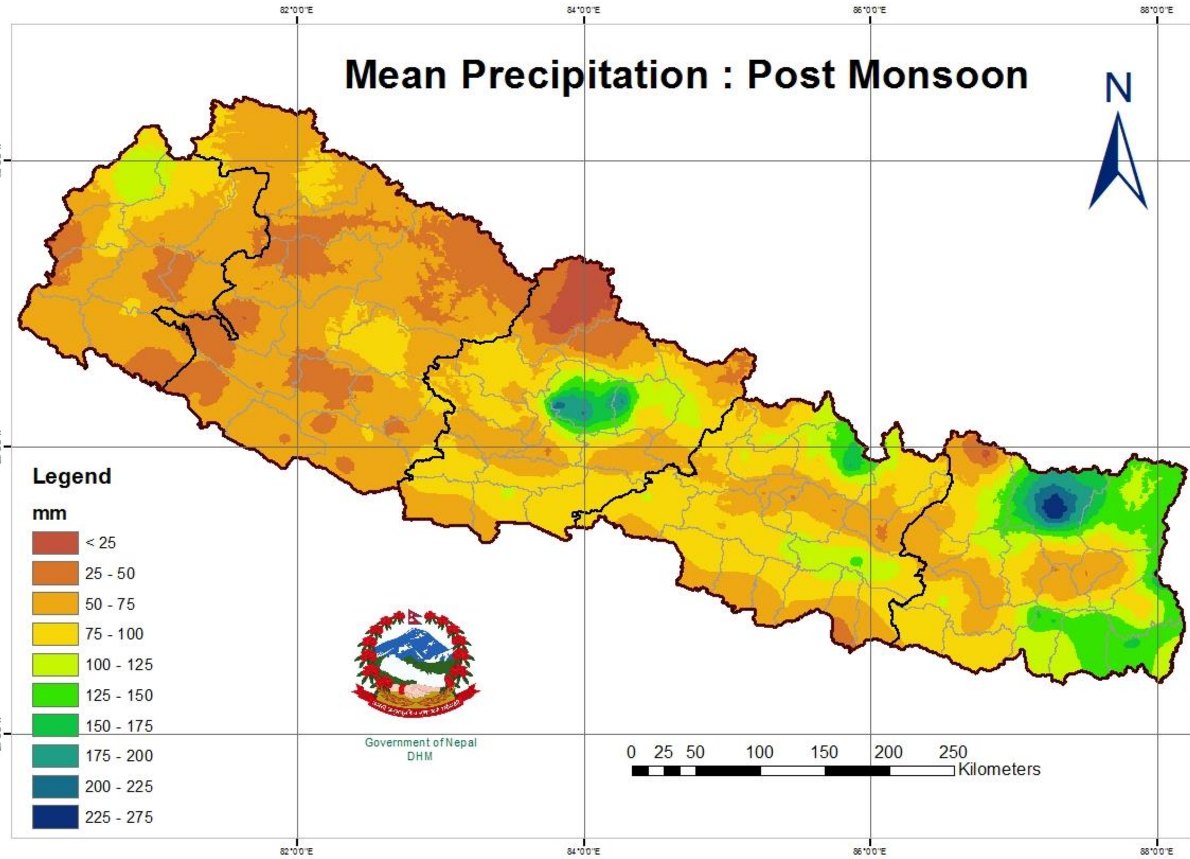

Figure 8: Mean Post-Monsoon precipitation variation over Nepal

4.1.2 Temperature Pattern:

In Nepal, temperature is lowest during winter (December - January) and increases as spring advances due to increase in solar insolation. However, the arrival of monsoon rain checks the increase in temperature making generally May or early June the hottest months. The temperature starts decreasing from October and reaches the minimum in December or January. Temperature is directly related to season and altitude of the location. The hottest part of the country is the southern Terai belt and the coldest part lies in the high mountain or the Himalayas in the north.

a. Maximum Temperature Pattern

Altitude is the guidance factor in the spatial variation of temperature. Therefore, the mean maximum temperature pattern follows the topographical variation of the country.

In annual maps, it is shown that the mean annual maximum temperature is more than 30°C recorded over the southern plains of the Terai while it is below 0°C in the Himalayan range. The pattern for the mean annual minimum temperature is very similar.

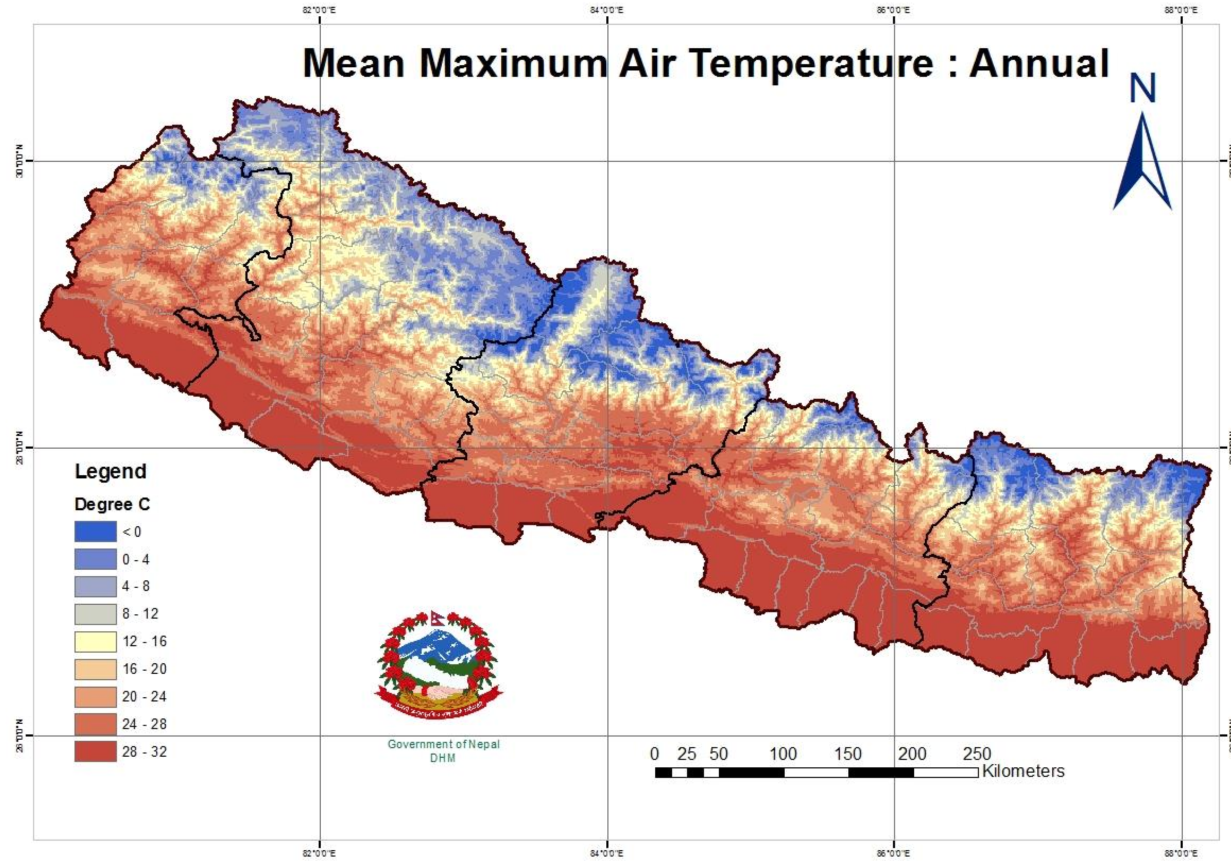

Figure 9: Mean annual Maximum air temperature variation over Nepal

b. Minimum Temperature Pattern

Mean minimum temperature pattern is similar to the mean maximum temperature pattern. Mean minimum temperature varied between above 16° C - 20° C in Terai to less than -8° C in the northern parts of the country.

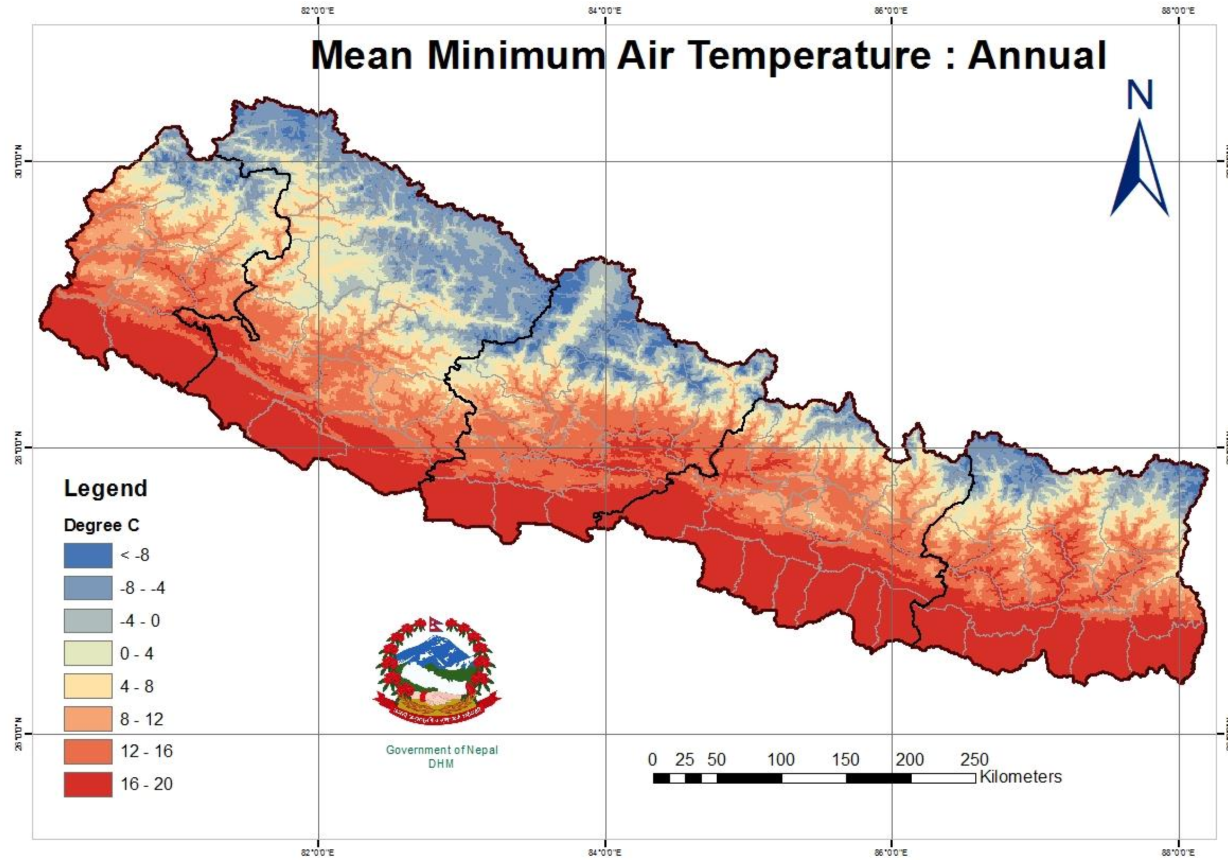

Figure 10: Mean annual Minimum air temperature variation over Nepal

The seasonal mean maximum temperatures are highest in the pre-monsoon (MAM) reaching as high as 36^{o}C along the southern tips of central Nepal. The lowest seasonal mean minimum temperatures are recorded in winter (DJF) over northern high mountainous region, where the minimum temperatures are below -10°C. In between these two extreme conditions, monsoon (JJAS) in Nepal is slightly warmer than post-monsoon season (ON) in both maximum and minimum temperatures. During the monsoon season (JJAS), the warmest region with maximum temperature above 32°C is found over the southern plains, similar to annual distribution. In most parts of Nepal monsoon season maximum temperature is above 22°C, except in the northern narrowest belt of highest elevation. The winter (DJF) and pre-monsoon (MAM) seasons have a larger latitudinal temperature gradient compared to monsoon (JJAS) and post-monsoon (ON) seasons. During all seasons, the western Terai experience a slightly lower maximum temperature than the eastern Terai, indicating a more cloudy condition in the west than the east due to the influence of western disturbances.

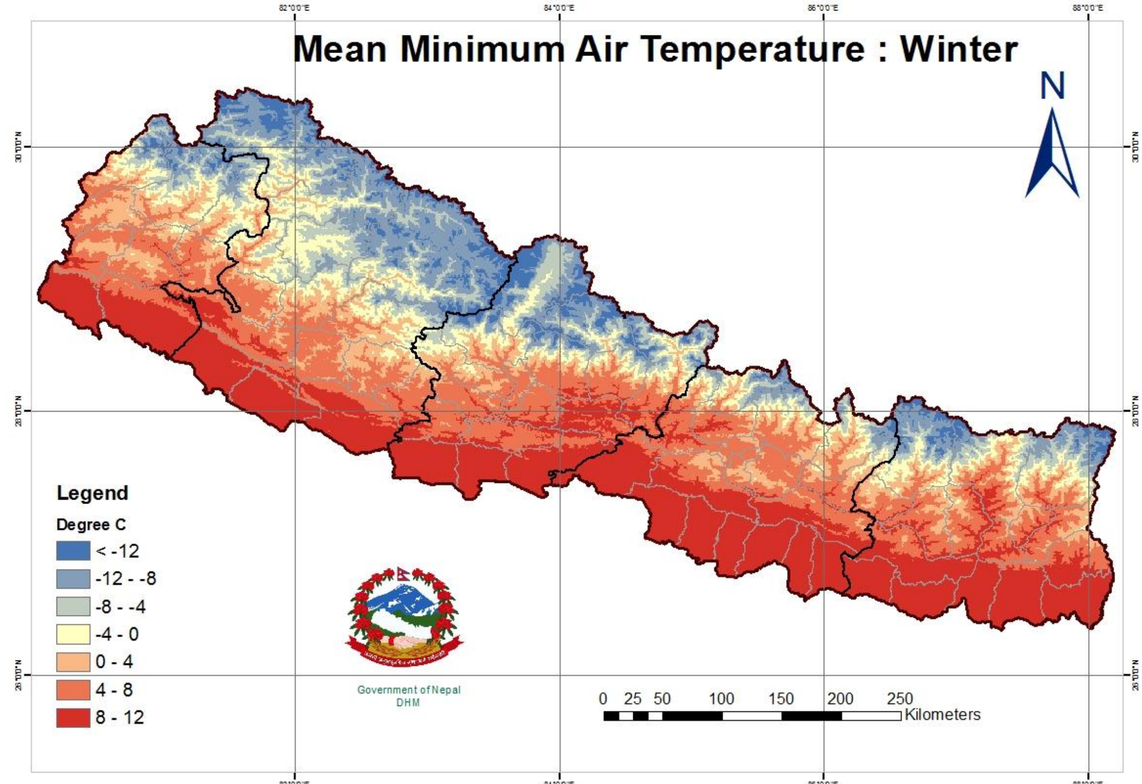

Figure 11: Mean winter Minimum air temperature variation over Nepal

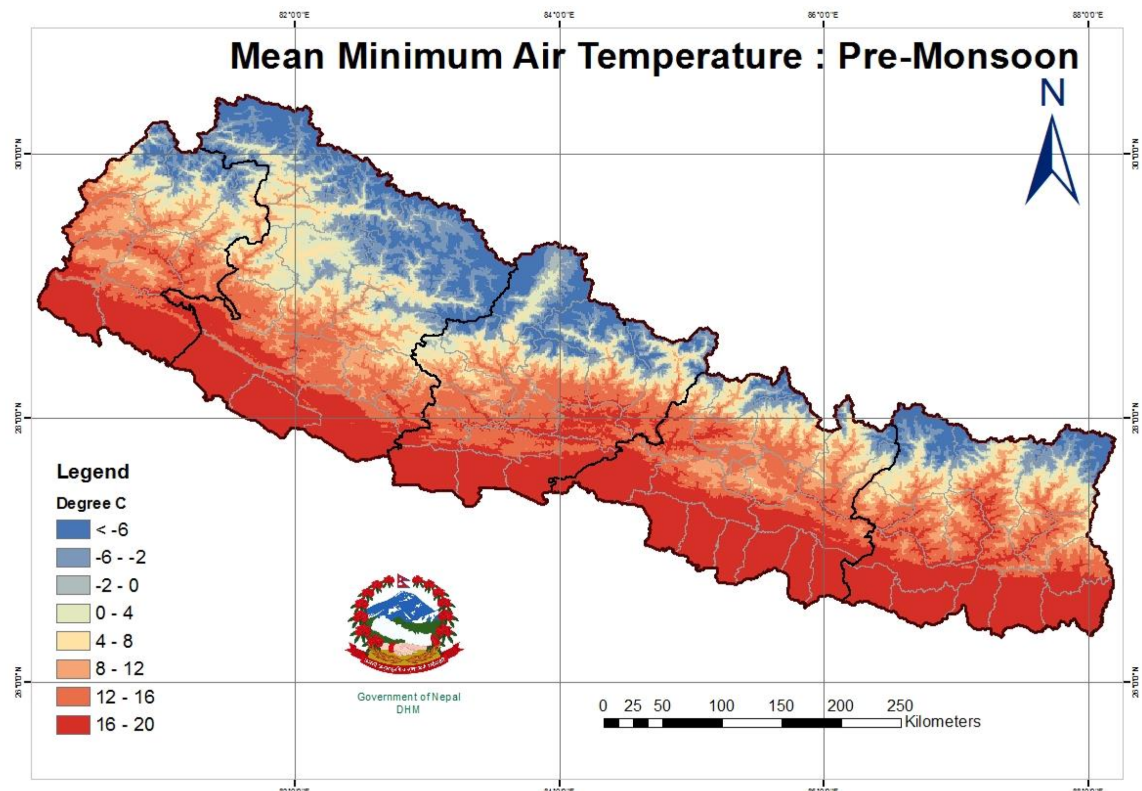

Figure 12: Mean Pre-monsoon Minimum air temperature variation over Nepal

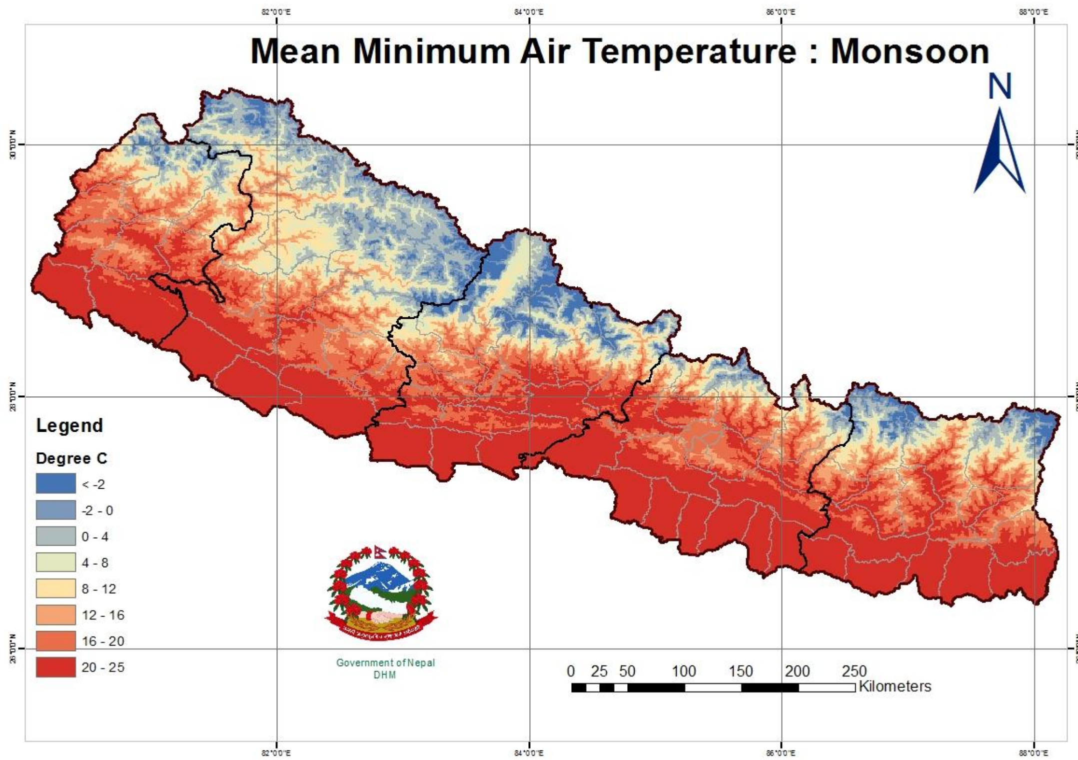

Figure 13: Mean Monsoon Minimum air temperature variation over Nepal

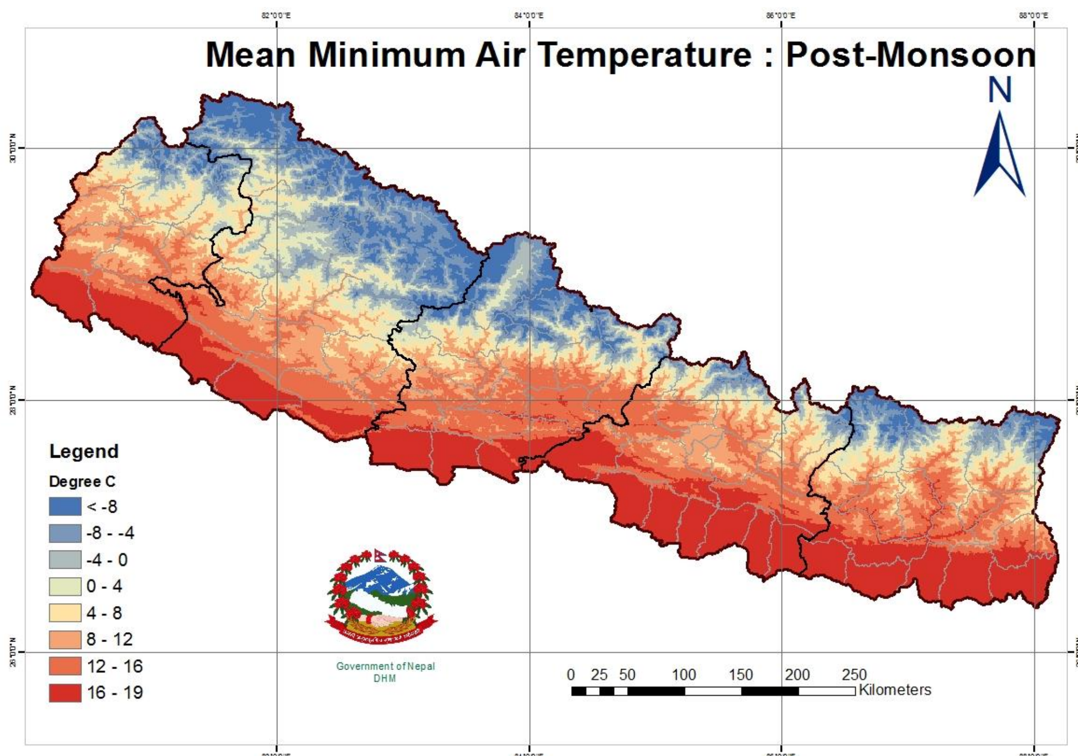

Figure 14: Mean Post monsoon Minimum air temperature variation over Nepal

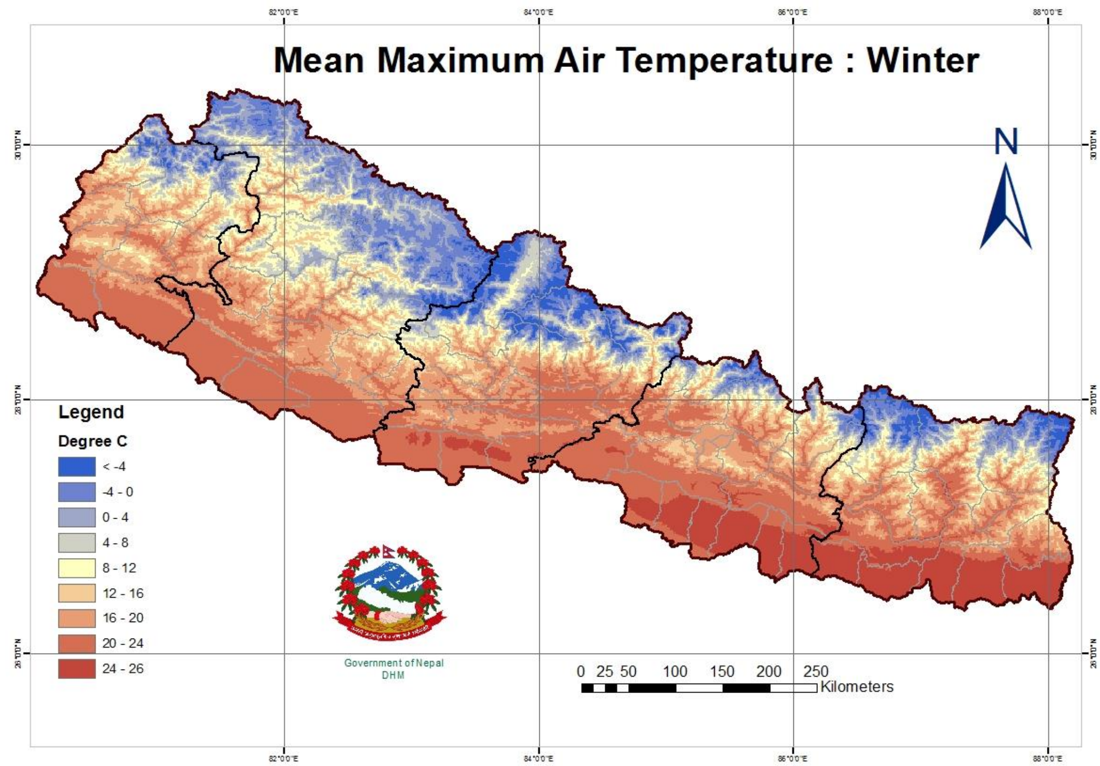

Figure 15: Mean Winter Maximum air temperature variation over Nepal

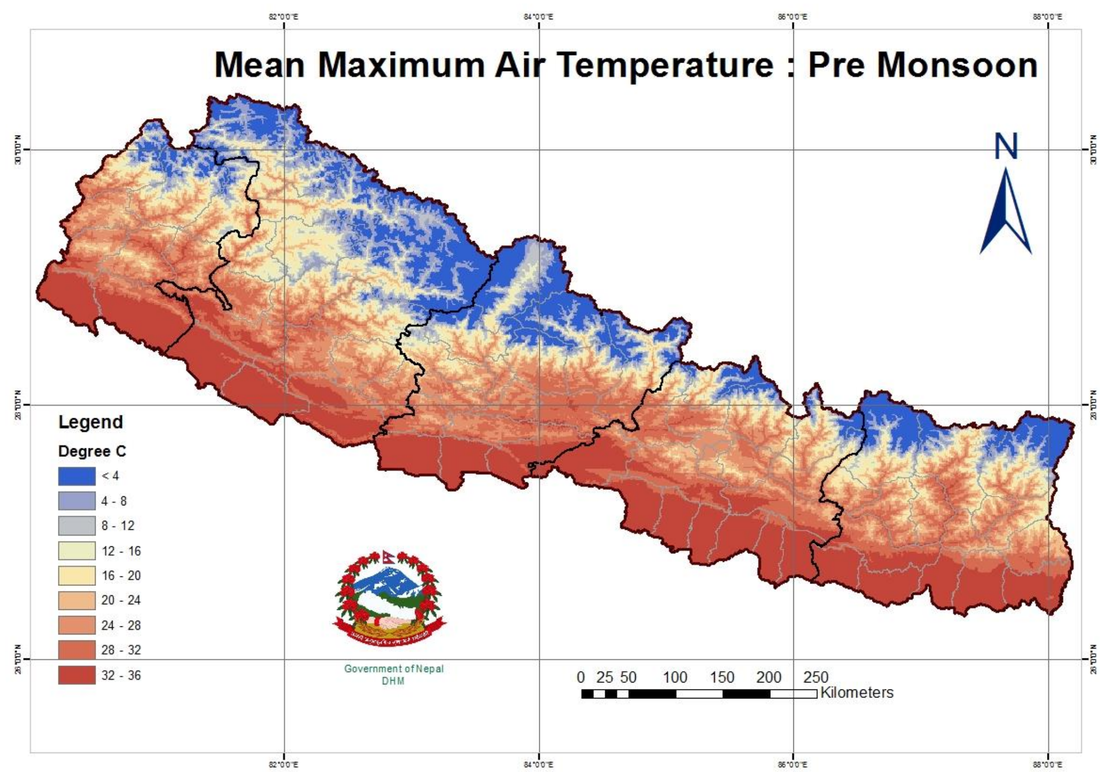

Figure 16: Mean Pre-Monsoon Maximum air temperature variation over Nepal

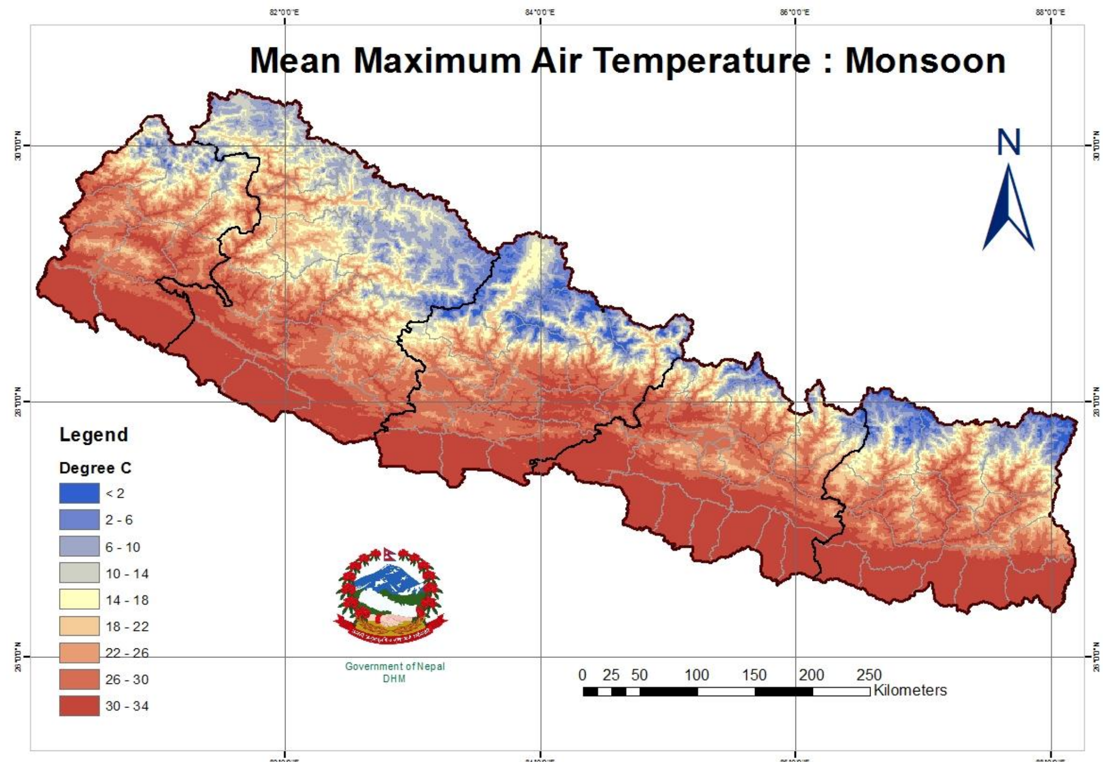

Figure 17: Mean Monsoon Maximum air temperature variation over Nepal

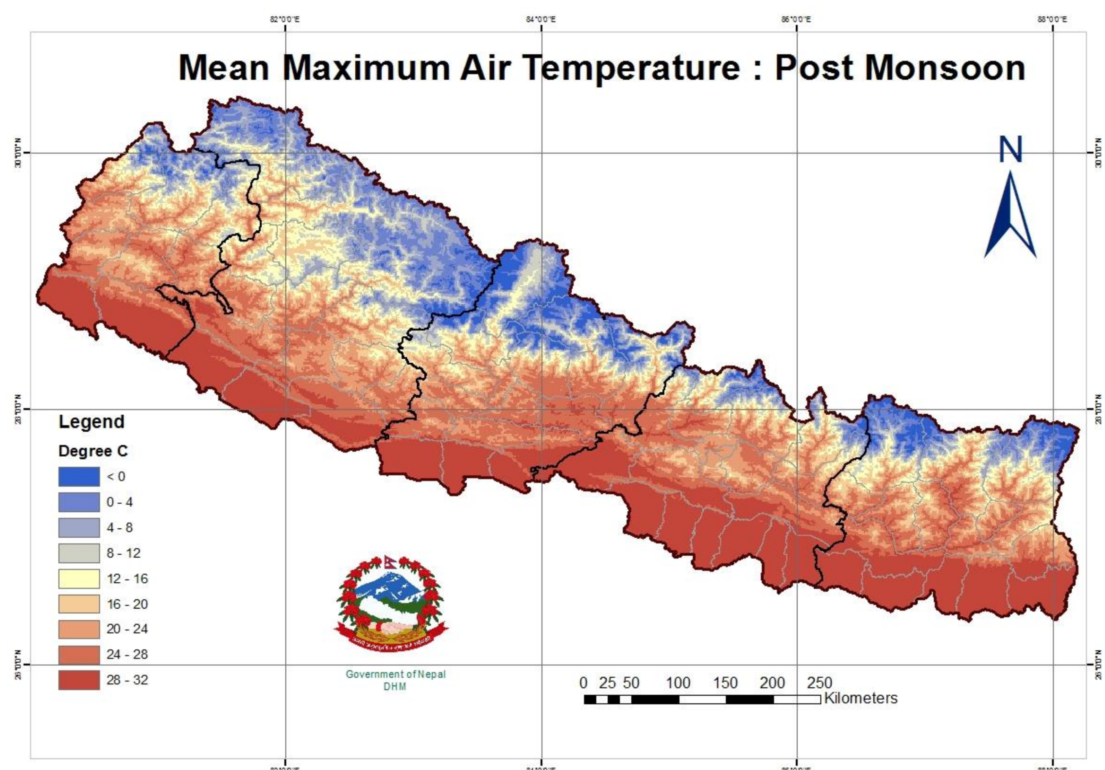

Figure 18: Mean Post Monsoon Maximum air temperature variation over Nepal

4.2 Extreme Distribution:

24 hour accumulated Extreme precipitation is higher over Churia range (Fig. 19). The value is of the order of more than 400mm/day in the Churia where as it is below 100mm/day in mustang region. Extreme air temperature variation follows the altitudinal pattern with extreme minimum temperature low over high altitude and extreme maximum temperature high over low altitude (Fig. 20 and 21). Extreme maximum temperature are more than 40°C in Terai Plains and extreme minimum temperature are less than -20 °C in mountain tops. The station wise extreme values are presented in annex 5.

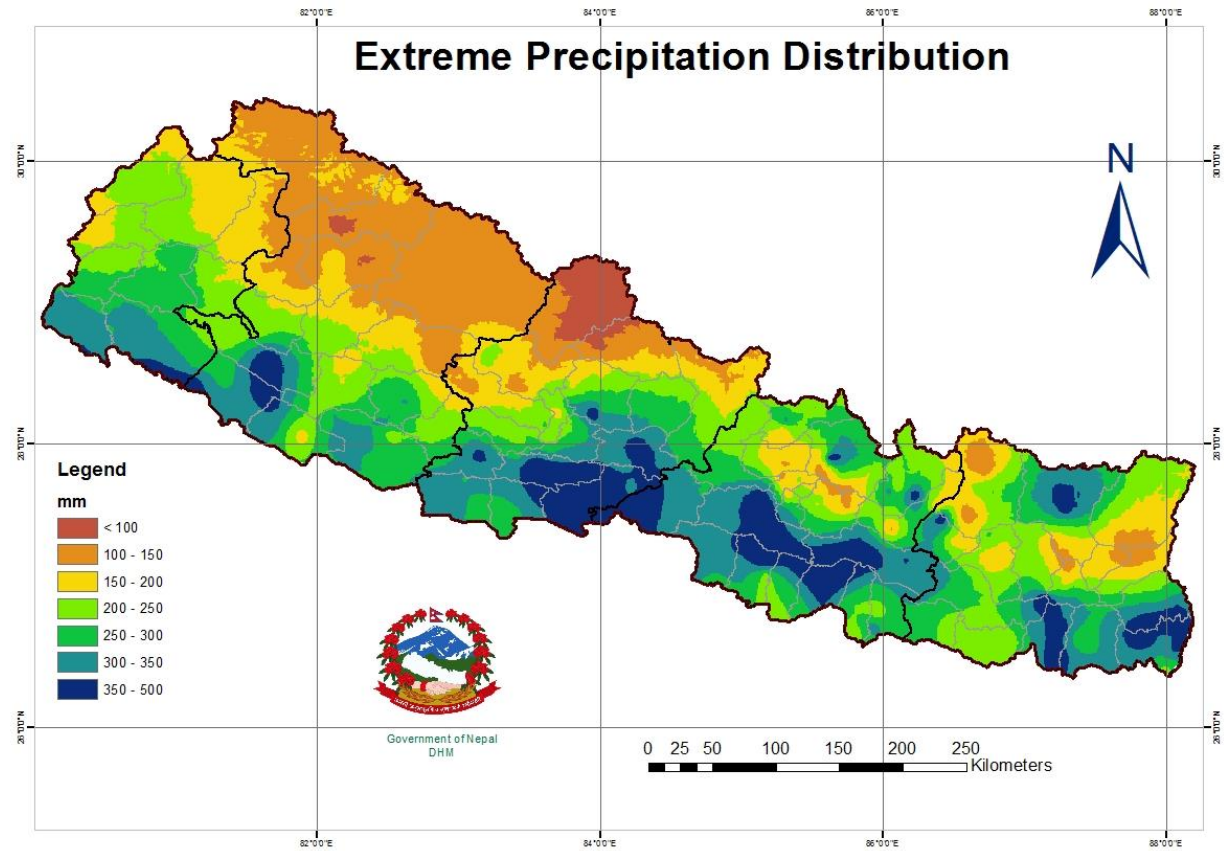

Figure 19: Daily extreme Precipitation variation over Nepal

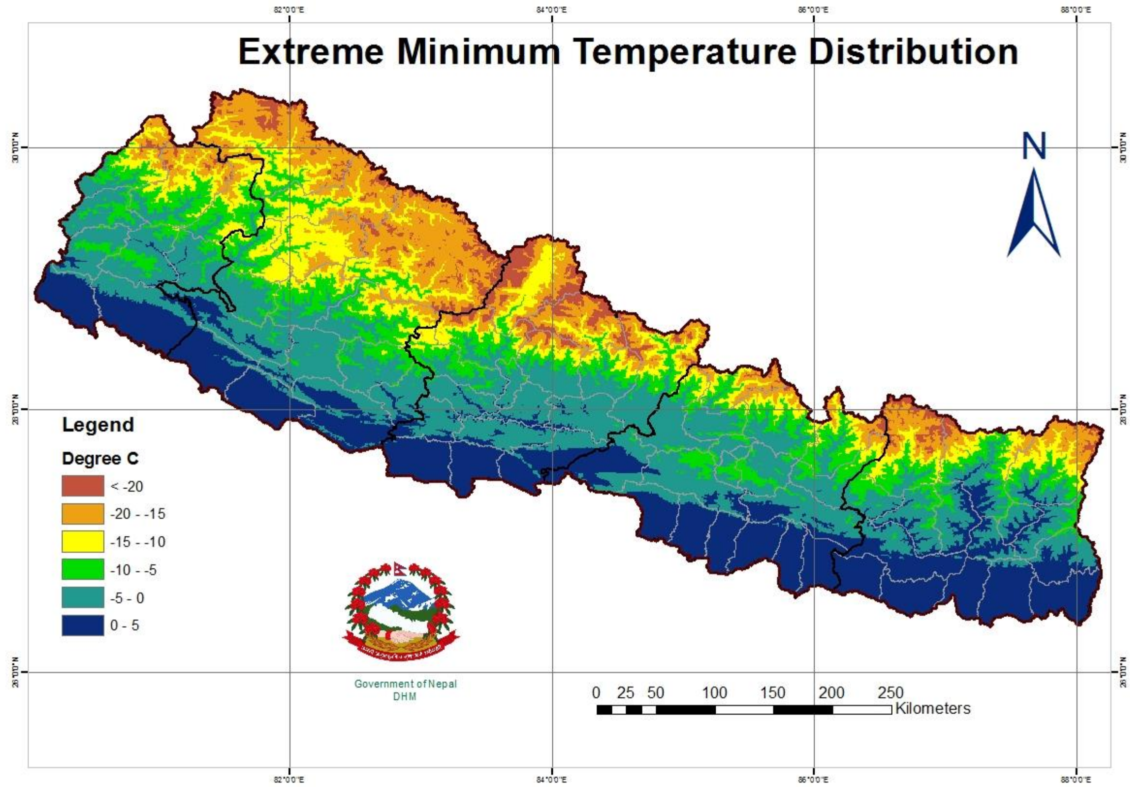

Figure 20: Daily extreme minimum temperature variation over Nepal

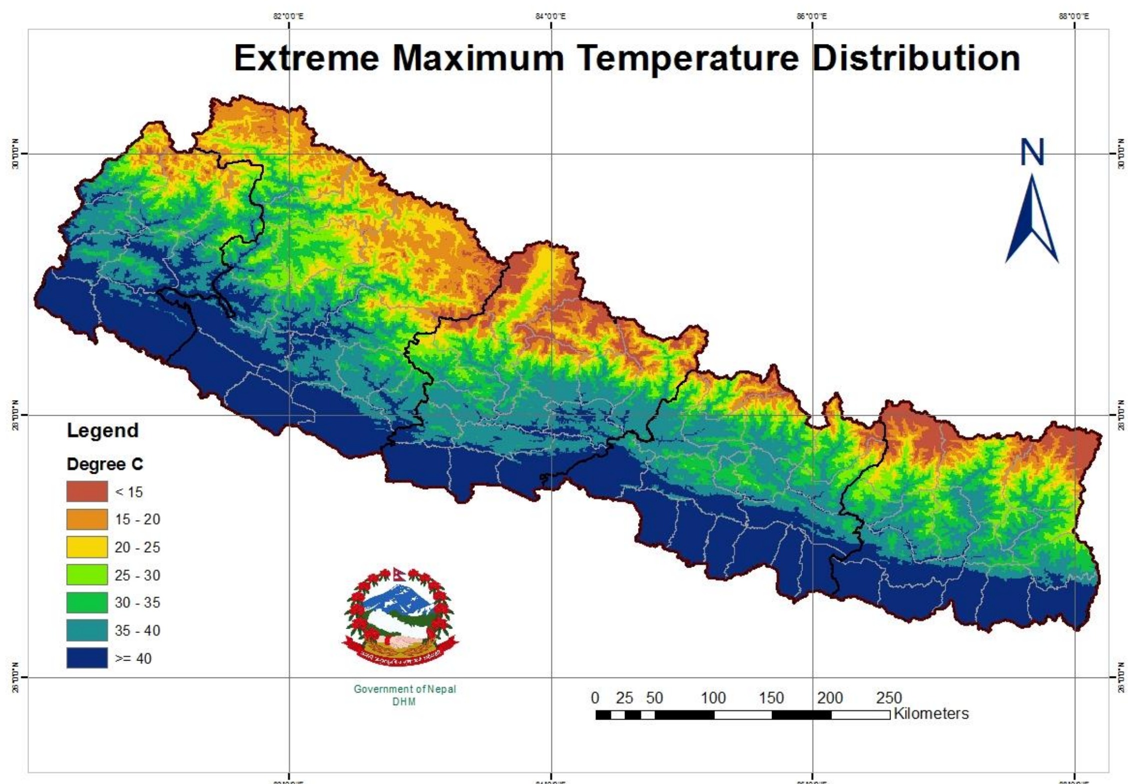

Figure 21: Daily extreme maximum temperature variation over Nepal

4.3 Temperature Trend:

Seasonal and annual time series of surface maximum and minimum temperature trend for the period 1971-2012 for the entire country is analyzed and plotted on annual and seasonal basis. The statistical values of these time series are summarized in in the annex 1.

The linear trend analysis in this report is considered as a monotonic increase or decrease in the average value of the parameter that is observed between the beginning and end of the period (1971-2012). However, due to the fact that most stations show gaps in their dataset for the period 1971-2012, and thus do not provide a continuous time series, the discussion of the trend analysis will be limited to a few locations. Furthermore, stations with unusually high or low trend are further analyzed and removed from the spatial after homogeneity testing and identification of shift of station of some significant change in observation. The example of these stations are Dhankuta, Chame, Dunai, Dailekh etc.

The trends, in general, are found higher in maximum than in minimum temperature. The spatial maps for trend analysis are prepared at 10km with universal kriging and without considering to the elevation as there was no direct relation with elevation for trend.

a. Mean Annual Maximum temperature Trend:

The spatial pattern of mean maximum temperature trend is in increasing trend almost in the entire country except in a few isolated places of southern Terai region (Fig. 22).

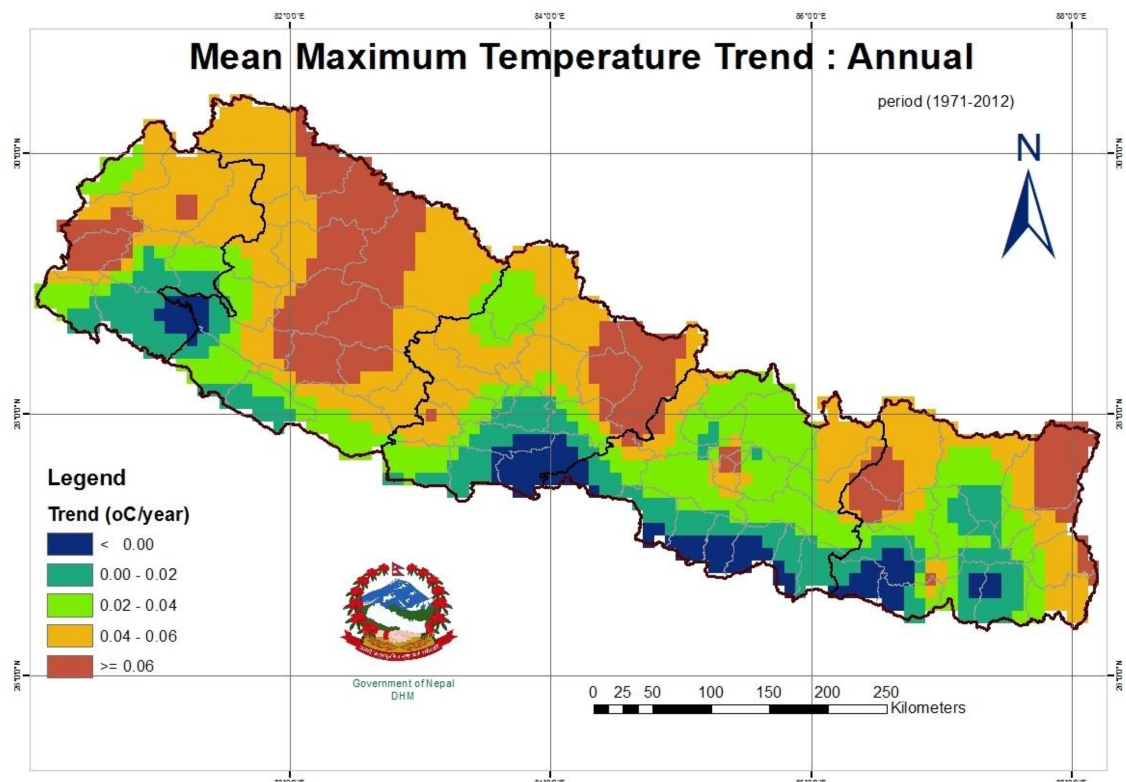

Figure 22: Mean annual Maximum temperature trend

b. Seasonal Maximum Temperature Trend:

Maximum temperature is in increasing trend in most places during all the seasons. However, significant decreasing trend was observed in Terai region during winter season. The reason for this decreasing trend in maximum temperature in winter season is due to the cold wave and resulting foggy conditions during winter months (December and January) along the northern stretch of Gangetic plain including the

Terai region of Nepal. This fog episode has become more prominent and persistent during the last decade or so. Warming has been observed more in the north than in the south of the country. The post monsoon season represented high increasing trends with low decreasing trends compared to the rest of the seasons.

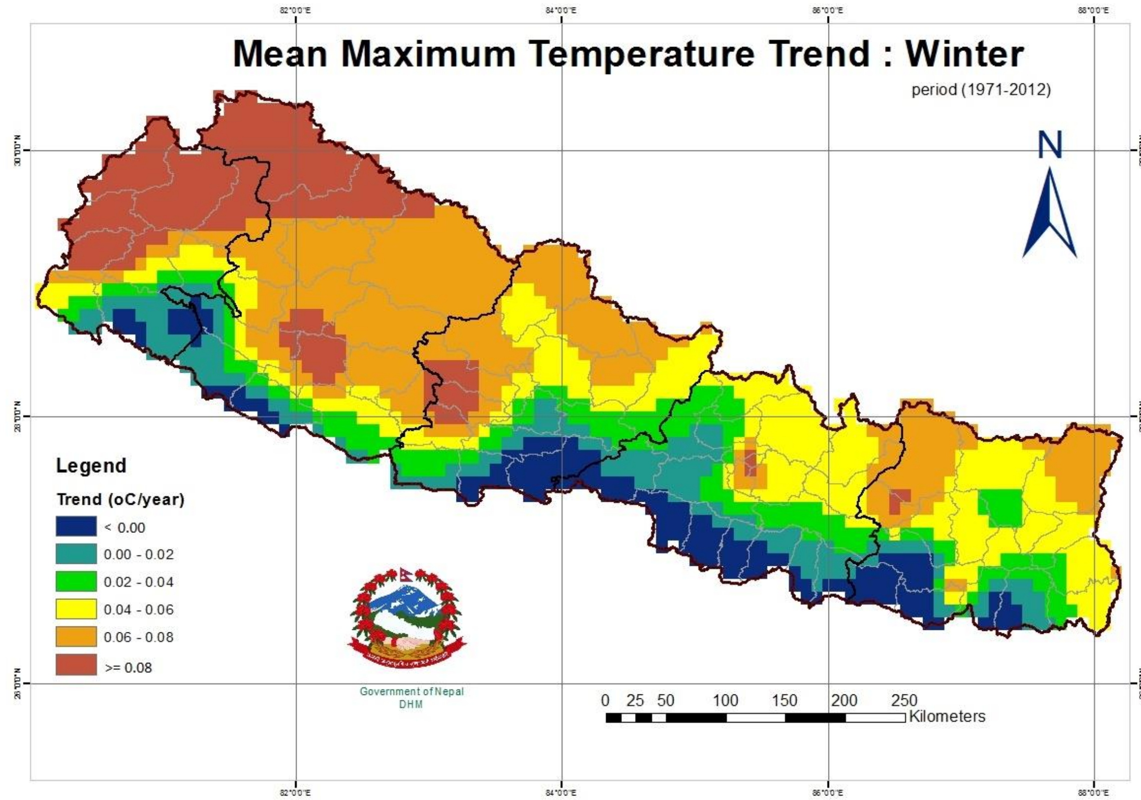

Figure 23: Mean Winter maximum temperature trend

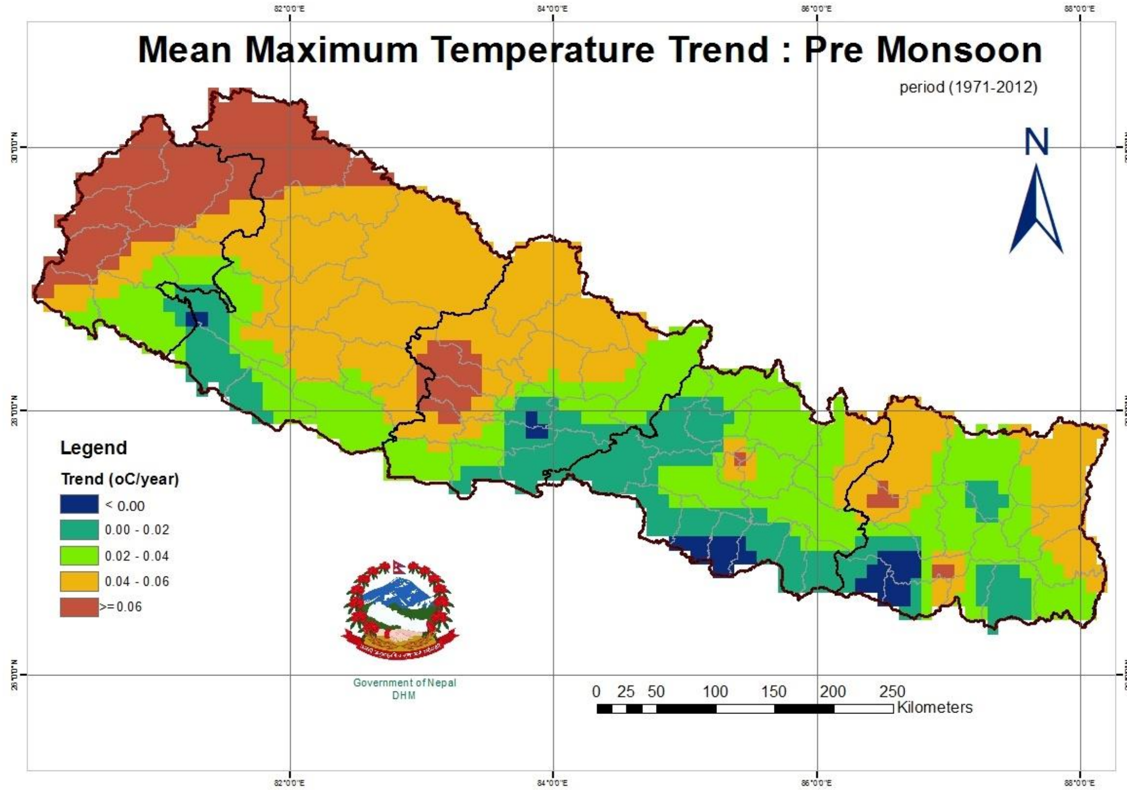

Figure 24: Mean Pre-Monsoon maximum temperature trend

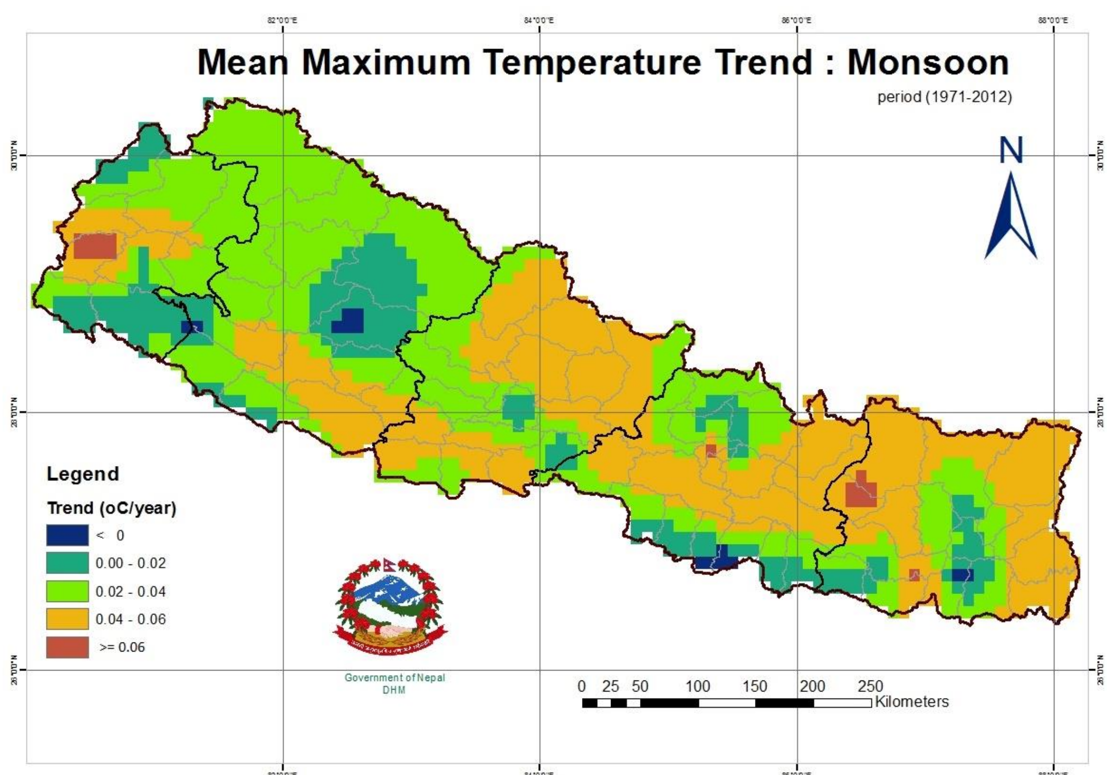

Figure 25: Mean Monsoon maximum temperature trend

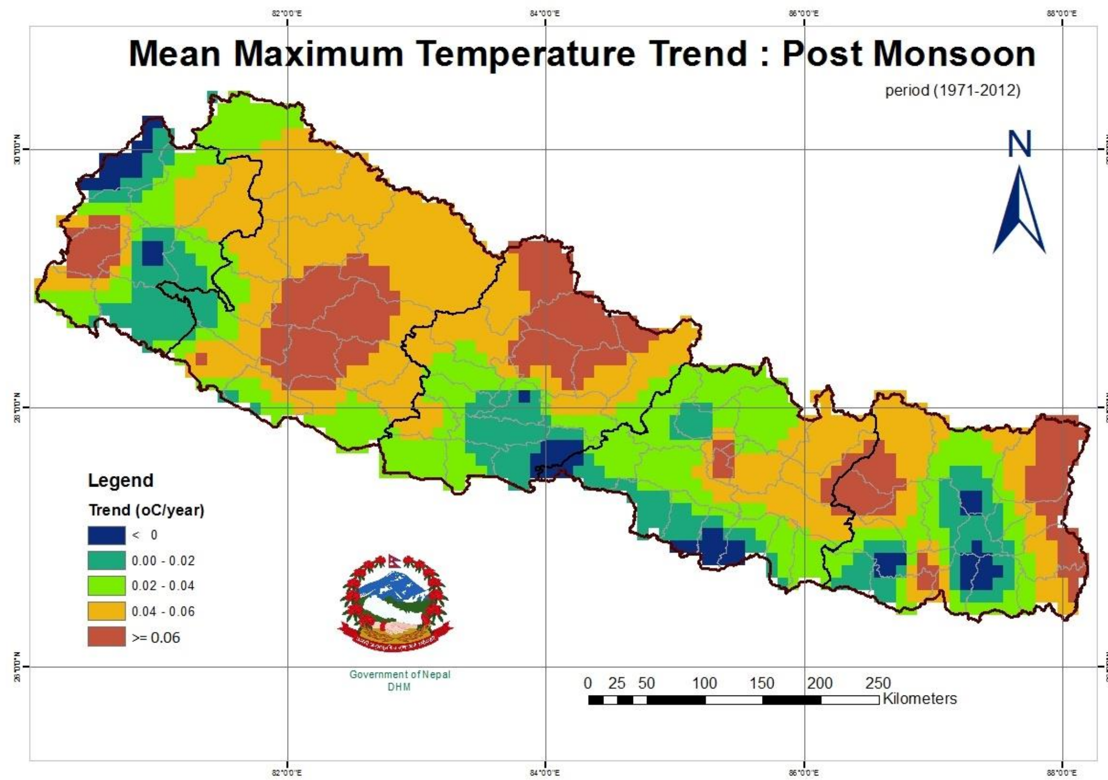

Figure 26: Mean Monsoon maximum temperature trend

c. Mean Minimum Temperature Trend:

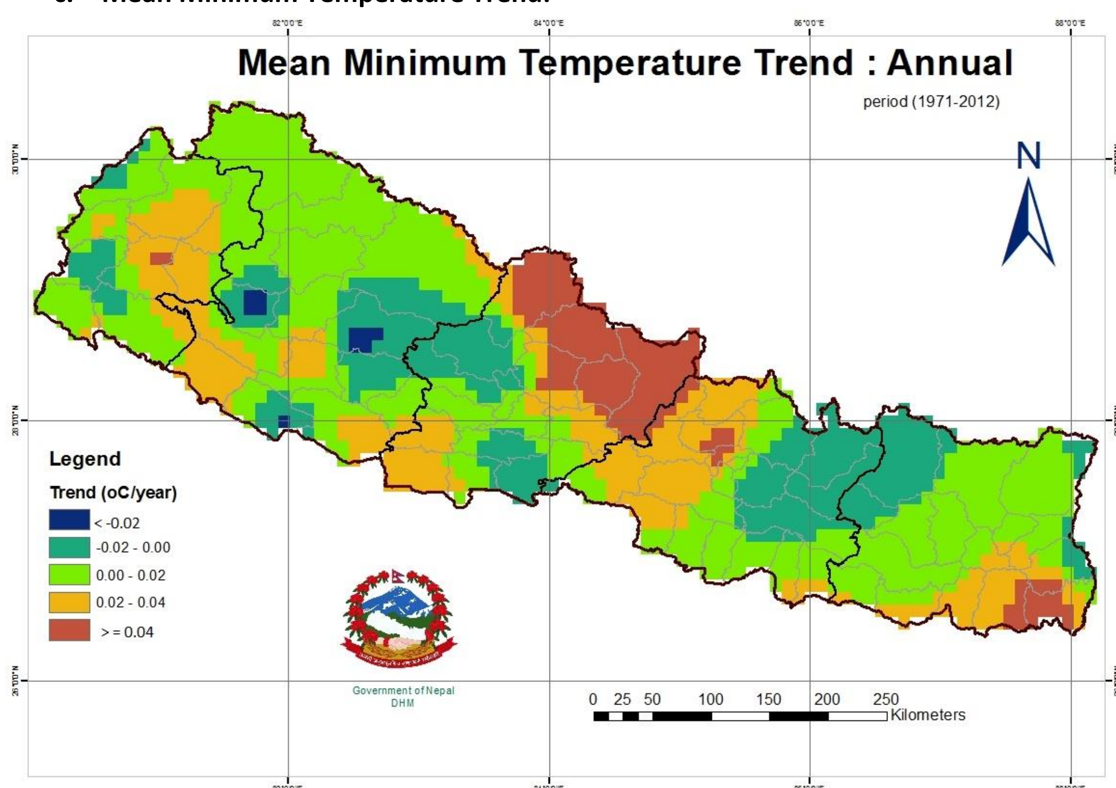

Figure 27: Mean Annual minimum temperature trend

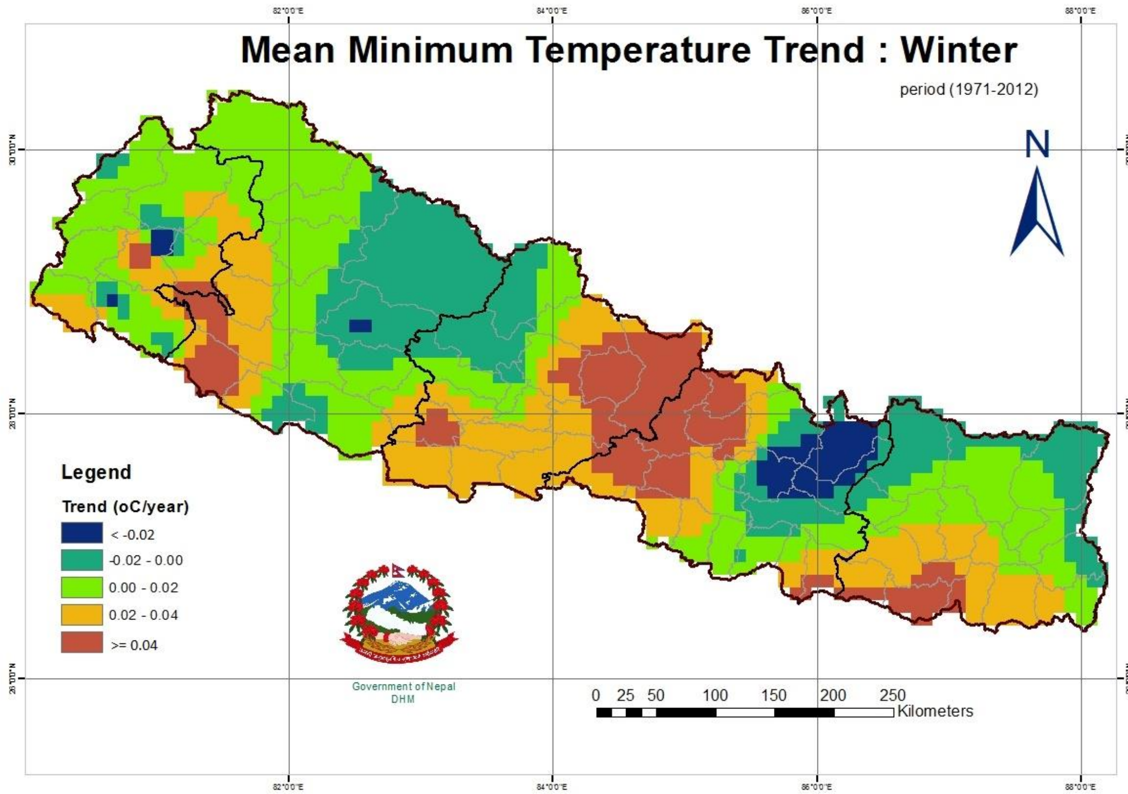

Figure 28: Mean winter minimum temperature trend

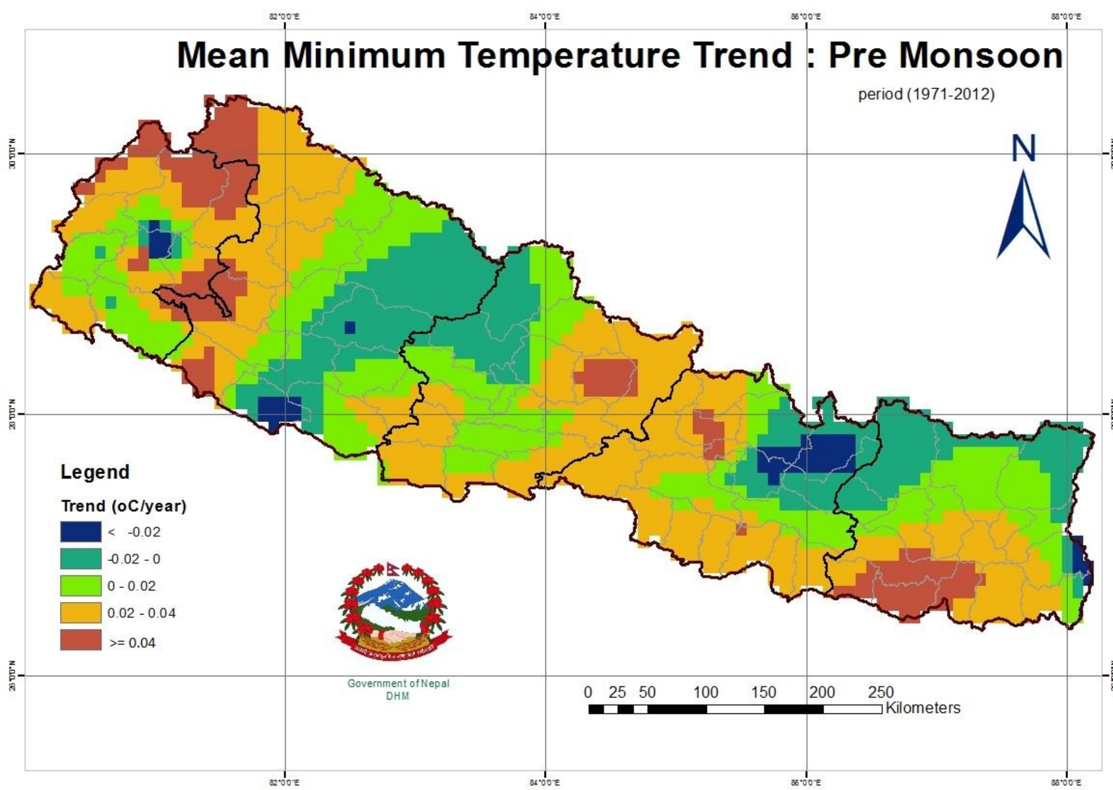

Figure 29: Mean pre monsoon minimum temperature trend

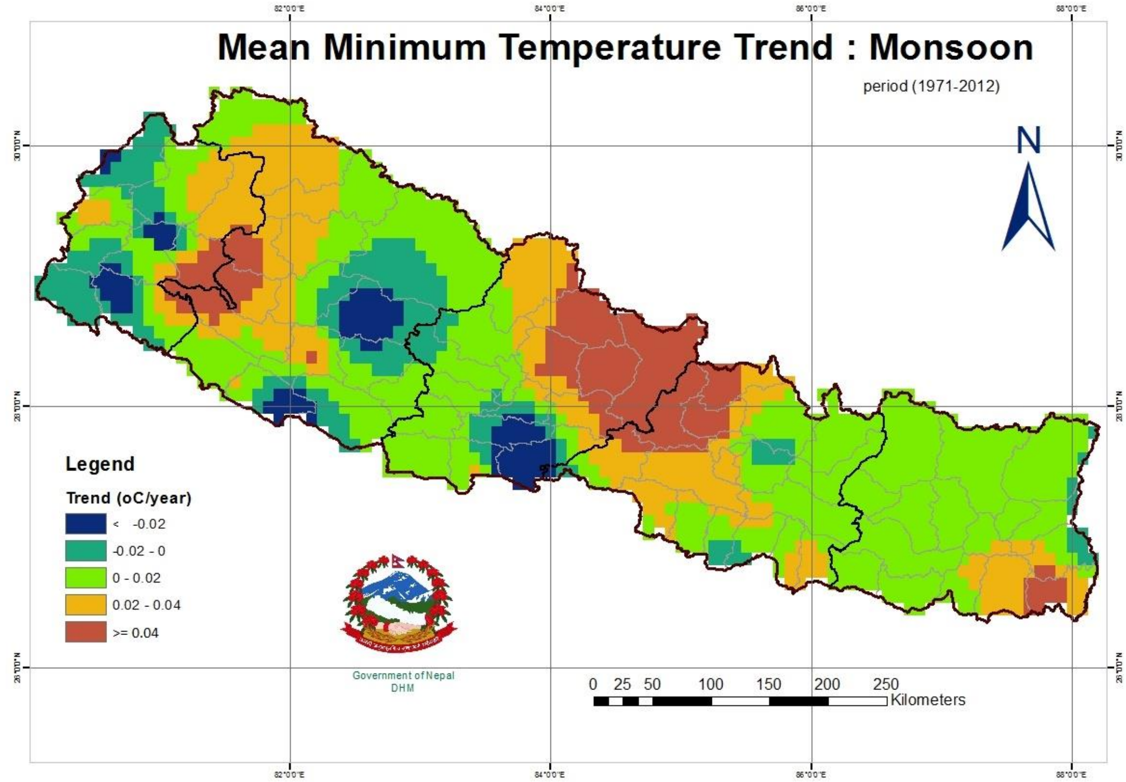

Figure 30: Mean monsoon minimum temperature trend

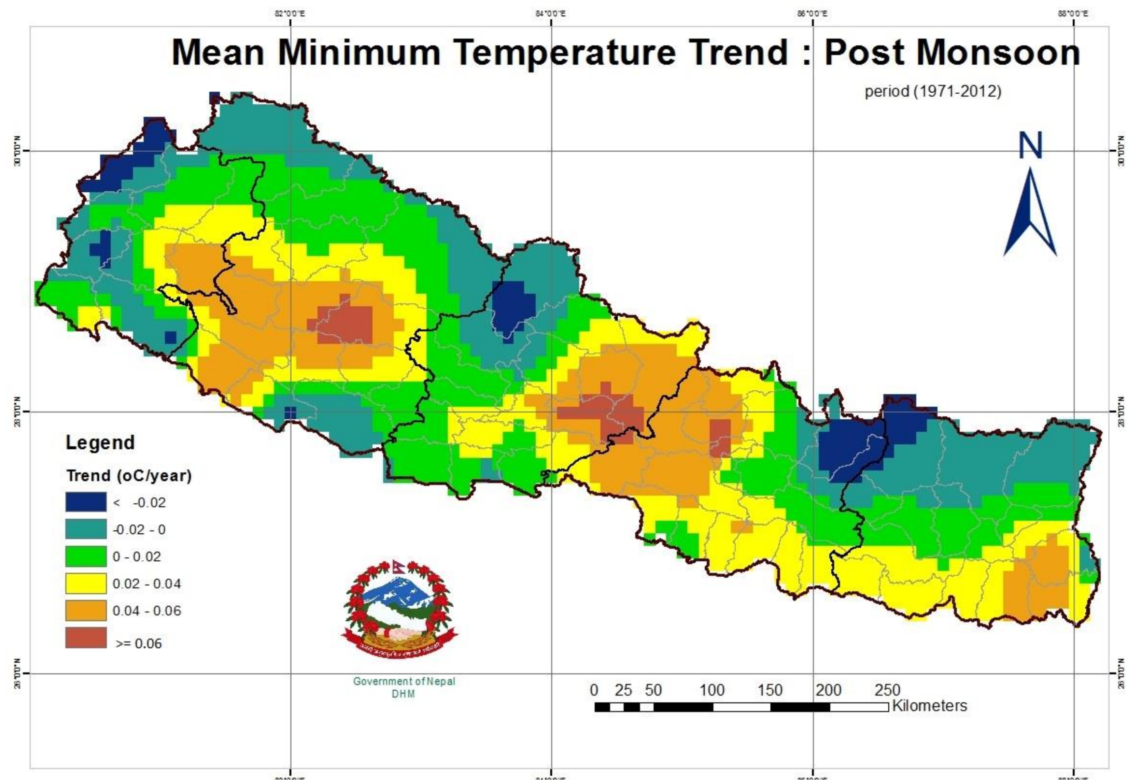

Figure 31: Mean post monsoon minimum temperature trend

4.4 Precipitation trend

a. Annual Precipitation trend

Precipitation trend has been calculated and plotted based on data from 1971-2012. Overall, eastern, central, western and far western development regions illustrated positive trend in annual precipitation (Fig. 31). Some small pocket areas observed over 30 mm/year increase in annual precipitation and decreasing trend of 40mm/year. However, most of the mid-western development region showed decreasing annual precipitation trend.

The spatial maps for trend analysis are prepared at 10km with universal kriging and without considering to the elevation as there was no direct relation with elevation for trend.

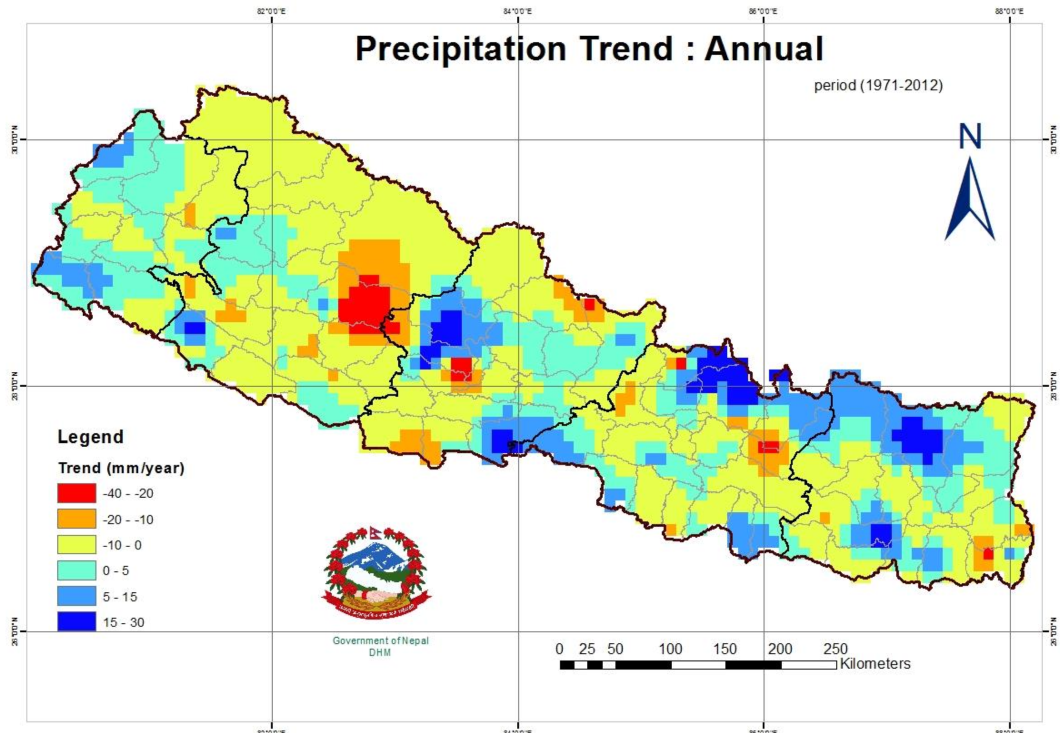

Figure 32: Annual precipitation trend

b. Seasonal Precipitation Trend:

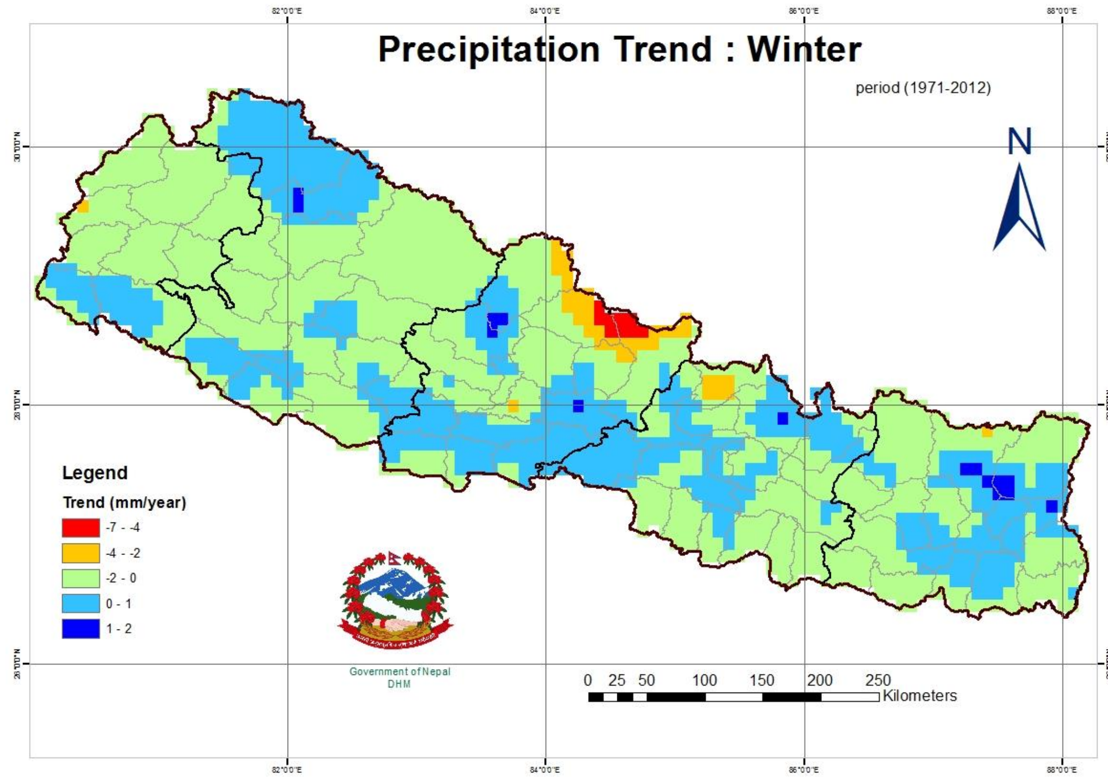

Figure 33: Winter precipitation trend

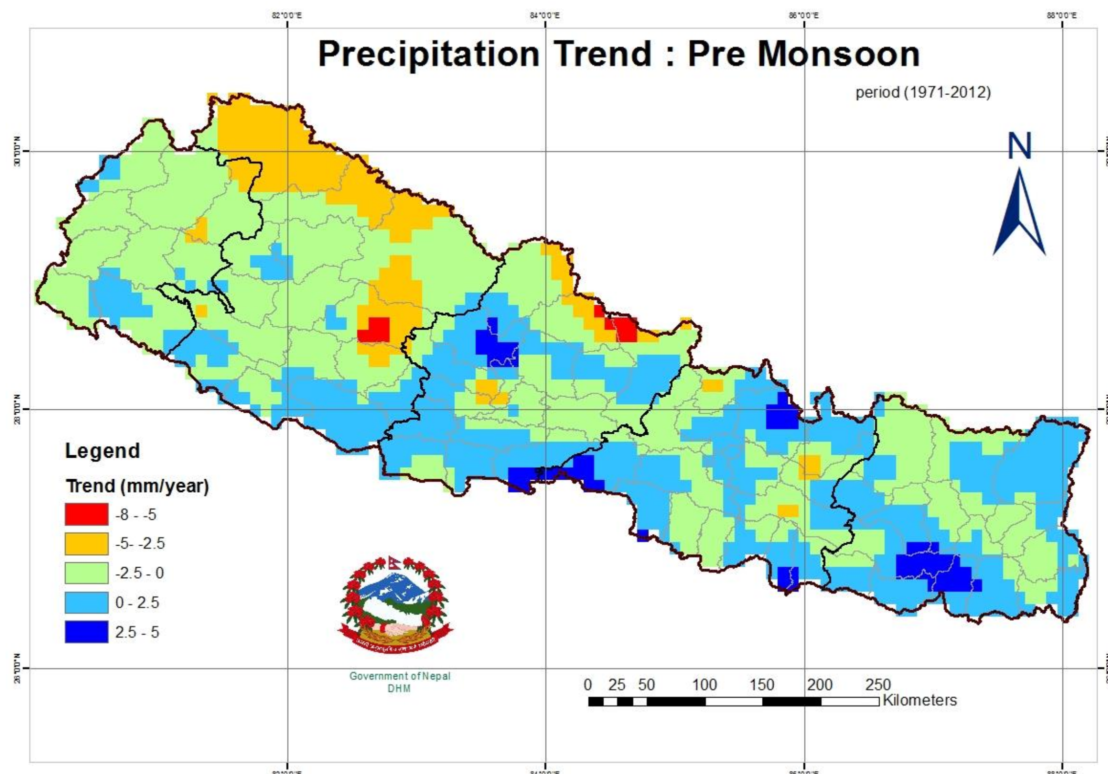

Figure 34: Pre Monsoon precipitation trend

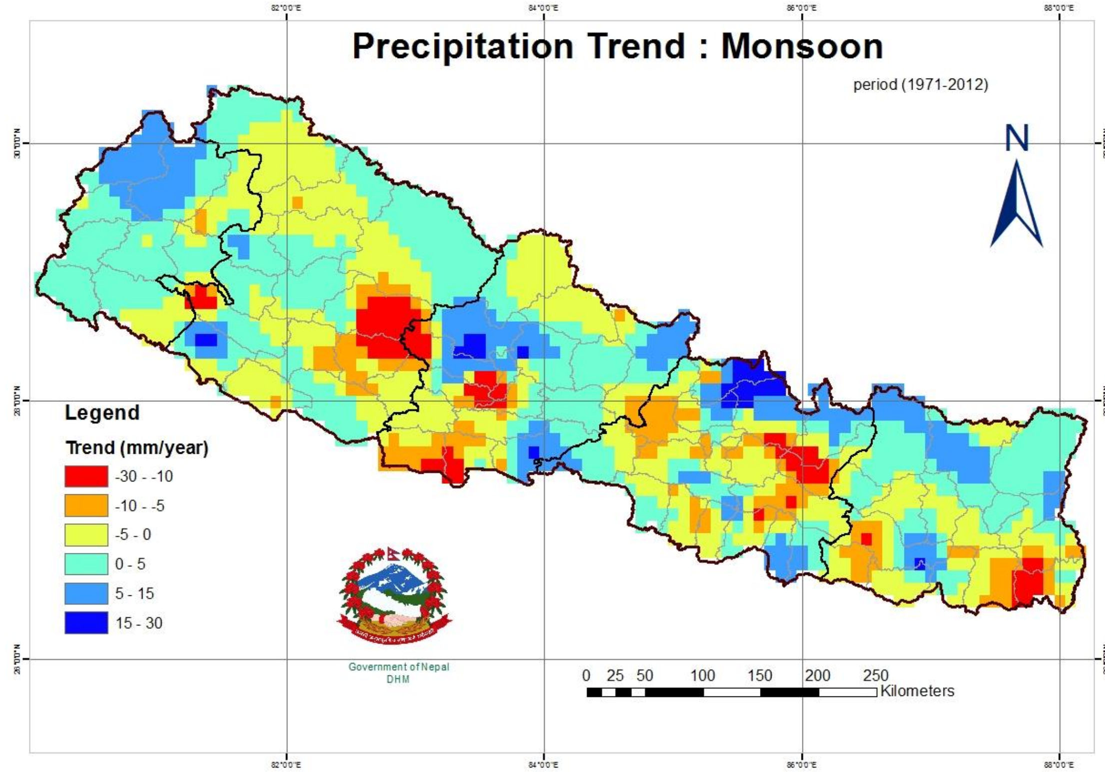

Figure 35: Monsoon precipitation trend

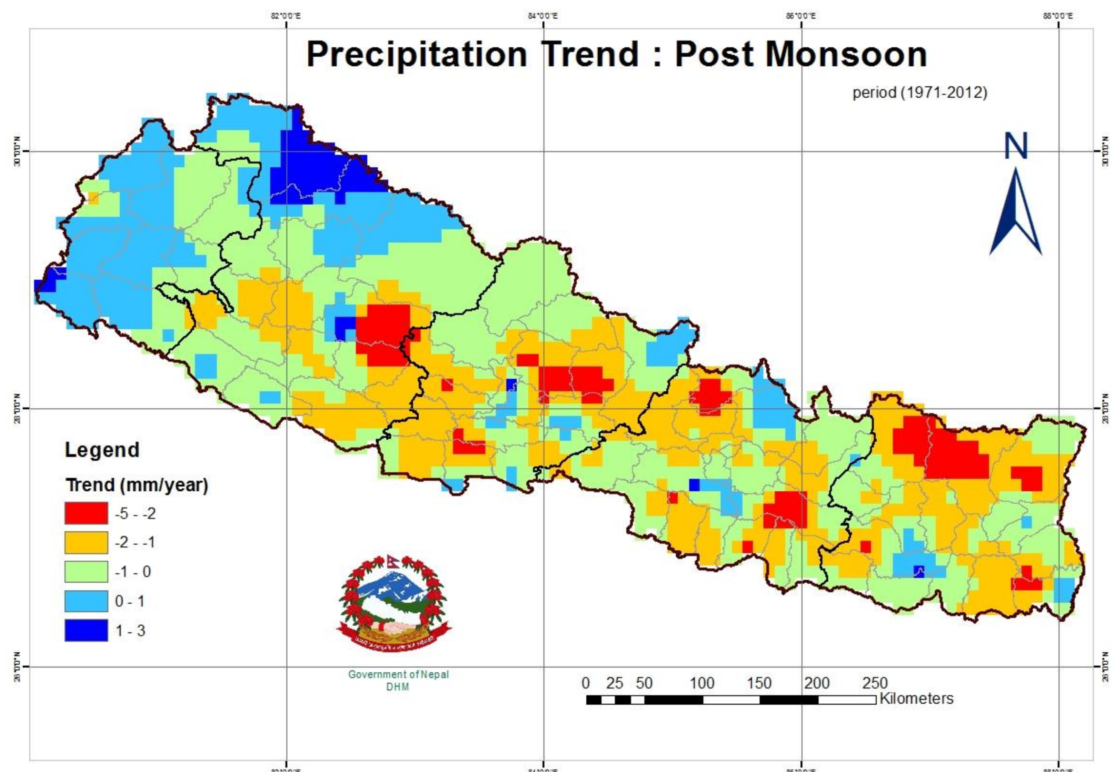

Figure 36: Post Monsoon precipitation trend

Table 3: Trend of annual Precipitation and maximum and minimum air temperature statistics

Parameters	Maximum Temperature Trend (^oC)			Minimum Temperature Trend (^oC)			Precipitation trend (mm/year)		
Region	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Terai	-0.02	0.05	0.02	-0.01	0.04	0.02	-14.9	19.8	-1.3
Siwalik	-0.02	0.07	0.02	-0.03	0.05	0.01	-16.3	26.8	0.6
Middle Mountain	-0.01	0.11	0.04	-0.04	0.05	0.01	-35.0	28.7	-2.3
High Mountain	0.02	0.07	0.05	-0.03	0.05	0.01	-42.5	31.1	0.2
High Himalaya	0.04	0.06	0.05	-0.01	0.02	0.01	-6.1	17.2	6.6
Country	-0.02	0.11	**0.04**	-0.04	0.05	**0.01**	-23.0	24.7	**0.7**

The average trend of mean annual maximum temperature over Nepal is 0.04 oC/year where as minimum temperature trend is only 0.01 oC/year. The mean annual minimum temperature trend is higher in low altitude Terai and Siwalik range and lower in High altitude region while the trend pattern is reverse in mean annual maximum temperature with higher in high altitude region and lower in low lying Terai plains.

4.5 Reviewing the station data quality.

Air temperature and rainfall data available from all the stations of Nepal for the period of 1961-2012 were compiled in annual time series. For maximum, minimum air temperature and precipitation data set, the monthly average and sum values were at first computed for each month with following WMO guidelines (at least 80% or 25 days of data availability in a month for average computation of air temperature and complete non missing data for precipitation sum) after that mean or sum of annual values for each year were computed only if data were available for all 12 months.
The data availability years on timer period 1961-2012, 1971-2012, 1981-2012 and 1991-2012 were compiled in tabular format. A general annual trend of maximum and minimum air temperature and rainfall parameters were calculated. In a remarks section station remarks with suspect of change in location are also indicated. A set of criteria as mentioned below were developed to categorize the station based on data availability.

Categorization criteria for stations

A = Missing years not > 5 in between 1971-2012. **AB =** Established after 1980 and without missing data.
B = Missing years not > 5 in between 1981-2012. **BC =** Established after 1990 and without missing data.
C = Missing years not > 5 in between 1991-2012 and data availability in overall more than 20 years.
C2 = Missing years not > 5 in between 1991-2012 and data availability in overall less than 20 years.
D = Data availability of 13- 16 years in between 1991-2012 and in overall more than 20 years.
D2 = Data availability of more than 13-16 years in between 1991-2012 and in overall less than 20 years.
E= Data availability of 10-12 years in between 1991-2012.
F= Data availability of less than 10 years in between 1991-2012. **No** = Not in operation as temperature station now.

For all these three parameters, the stations data availability, trend and category were computed and presented in tabular format in annex 2.

Table 4: Summary of number of stations in different category for different parameters

Category	Number of stations in Category		
	Minimum Temperature	Maximum Temperature	Precipitation
A	12	10	110
AB	3	3	1
B	22	21	55
BC	4	1	20
C	13	19	25
C2	4	2	9
D	20	16	43
D2	4	10	9
E	8	10	57
F	36	35	104
NO	23	22	57
Total	149	149	490

4.6 Data Availability tables.

Data availability for all the meteorological parameters are compiled in monthly tabular format. Due to the huge volume of data set suitable graphical representation tools could not be developed. The details of the data availability is presented in **annex 3**. Air temperature based parameters in monthly format is considered as available if 25 days of data is available but for precipitation monthly sum is calculated only if there is no missing days in the month.

4.7 Normal:

The normal values of precipitation and air temperature based parameters are calculated following WMO climate guidelines (Guide to climatological practices third edition) for normals calculation. It clearly mentions normal should be calculated only when values are available for at least 80% of the years of record, with no more than three consecutive missing years. No missing monthly normals are permitted in the calculation of annual normals. The climatological normal values are presented in annex 6.

4.8 Seasonal and annual district wise precipitation and air temperature statistics

Based on the available precipitation and air temperature data, spatial interpolation of seasonal precipitation and air temperature variables were carried out in R-Software using kriging with consideration to elevation in 1km*1km grid. Here, elevation is considered because it is the dominating factor for air temperature variation and precipitation are also influenced with it.
After that data is exported to Arc GIS 10 and then zonal statistics function is used to get the seasonal values of precipitation, air temperature district wise and for whole country. These are presented in annex 4. Value for the Nepal is presented in table 5.The annex table contains the maximum, minimum and average value of the precipitation or air temperature for each district wise.

Table 5: Nepal Precipitation and Air Temperature Statistics based on mean values

Parameter Name	Statistics	Mean Maximum Air Temperature (°C)	Mean Minimum Air Temperature (°C)	Mean Precipitation sum (mm)
Annual	Min	-21.0	-22.6	100.0
	Max	31.3	19.5	5317.8
	Mean	22.4	11.4	1858.4
Winter	Min	-23.6	-25.4	12.9
	Max	25.3	11.5	191.4
	Mean	16.5	4.0	65.6
Pre-Monsoon	Min	-23.1	-24.1	7.0
	Max	35.2	20.5	836.6
	Mean	24.3	11.6	218.4
Monsoon	Min	-16.8	-18.8	83.0
	Max	34.3	25.7	4500.0
	Mean	25.6	17.4	1496.7
Post Monsoon	Min	-20.9	-24.4	7.1
	Max	31.0	19.1	264.5
	Mean	21.8	10.0	77.8

4.9 Monsoon onset, retreat and duration variation studies

From the long-term data, the mean summer monsoon onset date for Nepal is June 10 and the withdrawal date is 23 September. There was no significant trend on the summer monsoon arrival but there was a significant trend toward delay in departure (about a half day per year), therefore, the duration of the monsoon is increasing at the rate of five days per ten years (Fig. 36).

Table 6: Monsoon Onset and Retreat Day of Nepal

Year	Onset day	Retreat Day	Duration of Monsoon days	Year	Onset day	Retreat Day	Duration of Monsoon in days
1968	17-Jun	21-Sep	96	1992	21-Jun	19-Sep	90
1969	2-Jun	28-Sep	118	1993	8-Jun	28-Sep	112
1970	16-Jun	30-Sep	106	1994	10-Jun	23-Sep	105
1971	10-Jun	13-Sep	95	1995	4-Jun	2-Sep	90
1972	18-Jun	26-Sep	100	1996	31-May	18-Sep	110
1973	14-Jun	27-Sep	105	1997	14-Jun	23-Sep	101
1974	19-Jun	21-Sep	94	1998	13-Jun	3-Oct	112
1975	16-Jun	18-Sep	94	1999	11-Jun	8-Oct	119
1976	9-Jun	21-Sep	104	2000	6-Jun	25-Sep	111
1977	18-Jun	18-Sep	92	2001	3-Jun	25-Sep	114
1978	8-Jun	16-Sep	100	2002	15-Jun	19-Sep	96

1979	24-Jun	4-Sep	72	2003	16-Jun	30-Sep	106
1980	12-Jun			2004	9-Jun	1-Oct	114
1981	23-Jun	11-Sep	80	2005	20-Jun	2-Oct	104
1982	27-Jun	20-Sep	85	2006	1-Jun	29-Sep	120
1983	24-Jun	29-Sep	97	2007	7-Jun	9-Oct	124
1984	11-Jun	20-Sep	101	2008	10-Jun	17-Oct	129
1985	17-Jun	26-Sep	101	2009	23-Jun	15-Oct	114
1986	12-Jun	5-Oct	115	2010	17-Jun	1-Oct	106
1987	14-Jun	26-Sep	104	2011	15-Jun	7-Oct	114
1988	11-Jun	9-Sep	90	2012	16-Jun	28-Sep	104
1989	11-Jun	2-Oct	113	2013	14-Jun	19-Oct	127
1990	12-Jun	30-Sep	110	2014	20-Jun	7-Oct	109
1991	9-Jun	19-Sep	102				

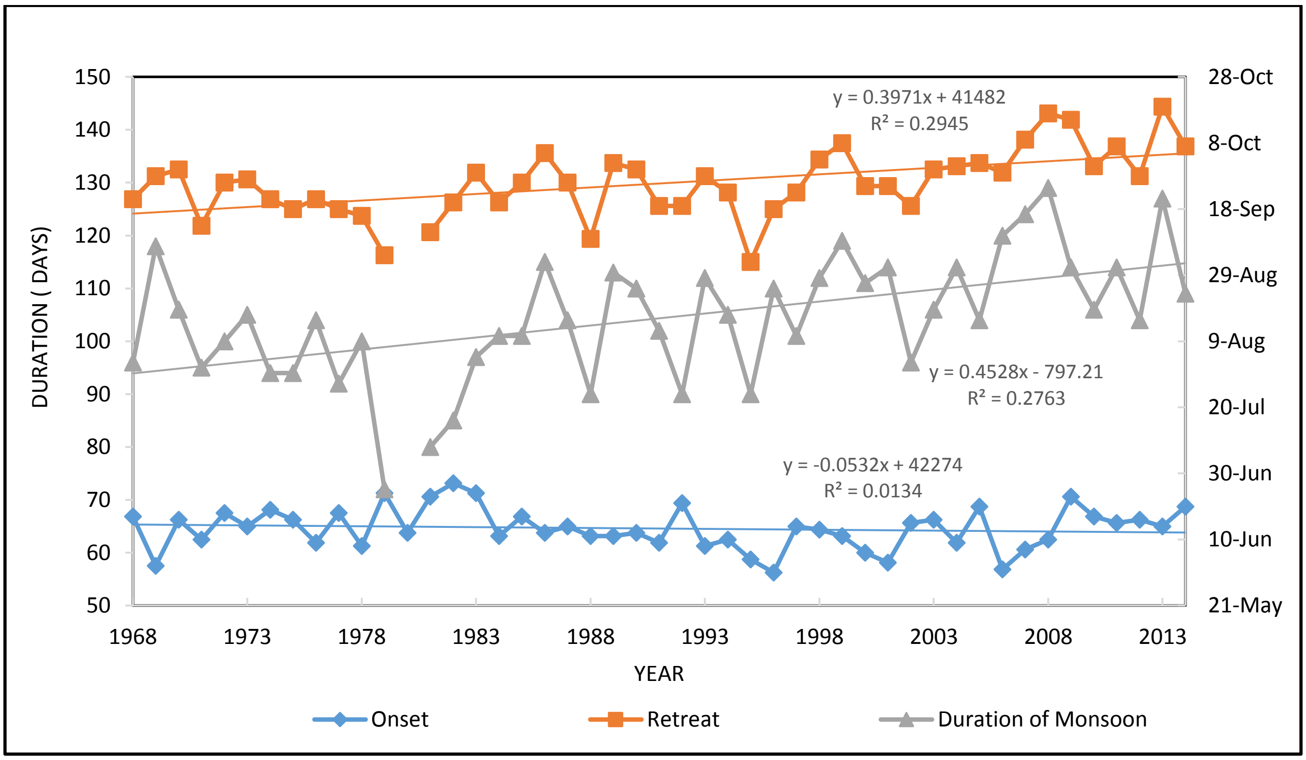

Figure 37: Monsoon Onset, retreat and duration of monsoon

4.10 Review of previous studies:

Baidya et al. (2007) studied the extreme temperature and precipitation pattern over Nepal. Decreasing trend in the cool days and cold nights increasing trend in the warm nights have been identified. Similarly, the precipitation extremes show increasing trend in total and heavy precipitation events. It indicates that it is likely to have more intense precipitation in future. For very wet days and very heavy precipitation days , most of the stations below 1500 m show increasing trend while decreasing trend is observed above 1500 m.

In case of the total annual precipitation (PRCPTOT), it has been observed that most of the stations below 1500 m show increasing trend whereas above that level the trends are not clearly defined.
The conclusion of the research is more weather related disasters; for example, floods and landslides can be expected in future.

Similarly, Shrestha et al. (1999) identified the average warming in annual maximum temperature between 1977 and 1994 with the rate of 0.06 °C/yr. The warming is found to be more pronounced in the high altitude regions of Nepal such as the Middle Mountain and the High Himalaya, while the warming is significantly lower or even lacking in the Terai and Siwalik regions. Warming in the winter is more pronounced compared to other seasons. The studies on analyses of the temperature records of Kathmandu for the period of 1921-1994 showed a similar temperature trend as that of 24 – 40°N of the earth, i.e. a general warming trend till 1940s, a cooling trend during 1940s-1970s and a rapid warming after the mid 1970s (Shrestha, 2001, p.93; Shrestha et al., 1999, p. 2781).

The study on precipitation variability by Shrestha et al. (2000) for 1948-1994 showed significant variability on annual and decadal time scales and did not find the Distinct long-term trends in precipitation records. The all-Nepal monsoon record was highly correlated with the Southern Oscillation Index (SOI) series. However, Sharma et al. (2001a, p.157) found an increasing trend in observed precipitation data from Koshi Basin in eastern Nepal but the trend widely varied in seasons and in sites.
Another study based on the precipitation records from 80 stations for the period 1981-1998 across Nepal revealed that the hills and mountains in the north showed positive trends while the plains in the south were experiencing negative trends (MOPE, 2004, p.72).

A general increasing trend in temperature has been found over Nepal based on data from 1976 - 2005. The maximum temperature was found to be increasing at a greater rate (0.05° C/year) than the minimum temperature (0.03° C /year). A decreasing trend was found in maximum temperature in Terai region during winter season. Mean annual maximum temperature in Terai belt reached above 30° C which gradually decreased towards North. In Siwalik range, the mean maximum temperature varied between 26° to 30° C. The mean maximum temperature ranged between 22° to 26° C in the middle hills regions and reached below 22° C in the high hills and the Himalayas or the mountains (PAN, 2009).
Analysis of various statistics of precipitation and air temperature including trend for the period of 1971-2009 and future projection 2030-2060 for Nepal was also carried out by Asian disaster preparedness centre (ADPC) in collaboration with DHM.

5. Conclusions:

This work contributed to the analysis of climatological data of Nepal. This output led to expansion of high resolution climate information in time and space over the whole country. Summary of this information is made available through maps and tables in this report. As expected the topography and monsoon are of major influence on the temperature and precipitation climatology in Nepal. Still data gaps exist in most meteorological records, which potentially affect the trend analysis, but not the mean climatology and natural variability analysis.
The mean minimum and maximum temperatures show clear a seasonal cycle. For both temperatures the spatial distribution over the country follows the topography; the highest temperatures are recorded in the Terai and Siwalik regions and the lowest temperatures in the High Himalaya regions.

The precipitation pattern is dominated by the presence of the monsoon circulation and its interaction with the topography. The winter (DJF) season is the driest period of the year but with a high variability, where most precipitation falls during the monsoon season (JJAS) when the variability is low. The southern flanks of the Annapurna range in the Central Middle Mountain regions are the wettest of Nepal with averaged precipitation amounts of more than 5400 mm per year. The lee side of this Annapurna range is recorded as driest region in Nepal, with annual precipitation of less than 200 mm.

Winter rain is high in far western development region and low in southern parts of central and eastern development regions. The extreme rainfall distribution is quite different from the annual and seasonal distribution. Siwalik and the tarai belt which generally receive less total seasonal rainfall compared to the middle hills received the highest 24 hour rainfall. These regions are therefore prone to landslides, flash floods and inundation. Especially, the southern parts of central and western development regions are more prone to such hazards compared to other regions as these regions get high total annual rainfall and the Churia hills in the regions are getting more intensive rainfalls.
The average annual maximum temperature over Nepal is 22.4 ^{o}C and annual minimum temperature is 11.4^{o}C. The mean annual precipitation of Nepal is 1858.4mm.

Maximum temperature is in increasing trend in large magnitude than the minimum temperature in almost all the seasons. The average trend of mean annual maximum temperature over Nepal is 0.04 ^{o}C/year where as minimum temperature trend is only 0.01 ^{o}C/year. The mean annual minimum temperature trend is higher in low altitude Terai and Siwalik range and lower in High altitude region while the trend pattern is reverse in mean annual maximum temperature with higher in high altitude region and lower in low lying Terai plains.

The data availability table from stations for different parameters will be very useful for researchers to know the availability of data and plan for their research accordingly. This will also make easier for DHM personals to engage in telling the individual about the status and availability of data. Moreover, the stations are categorized on the basis of data availability and continuity into different classes and it will be more useful to get the representative stations for climate change studies. The district wise statistics of precipitation and air temperature can serve as a valuable asset for district level planning and implementation of projects.

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