Climate Change and Its Implications: What Science Says and What Local People Perceive?

(Climatic Variabilities and Their Implications in Peri-urban Areas of Kathmandu Valley)

Water Security in Peri-urban South Asia: Adapting to Climate Change and Urbanization

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1. INTRODUCTION

Climate change is one of the major phenomena that have received special attention in the last decades. During the past few decades the world has been experiencing significant increase in global temperature resulting into climate change. From 1906 to 2005, the global average surface temperature increased by 0.74 [0.56 to 0.92]°C (IPCC, 2007). According to data sources compiled by the World Meteorological Organization (WMO, 2011), over the ten years from 2001 to 2010, global temperatures have averaged 0.46°C above the 1961-1990 average, 0.03°C above the 2000-09 average and the highest value ever recorded for a 10-year period. Recent warming has been especially strong in Africa, parts of Asia, and parts of the Arctic; the Saharan/Arabian, East African, Central Asian and Greenland/Arctic Canada sub-regions have all had 2001-10 temperatures 1.2 to 1.4°C above the long-term average, and 0.7°C to 0.9°C warmer than any previous decade. Climate change is expected to cause an increase in mean annual temperature up to 5 degrees Celsius in Asia by 2080 (Cruz *et al.* 2007).

Chaulagain (2006) states the climate change in Nepal is going even faster than the global average. According to the Thematic Assessment Report on Climate Change (2008) prepared under the National Capacity Self Assessment (NCSA) project, ongoing records of national temperatures since 1962 and recent analyses of these records show high inter-annual variability, and that maximum temperatures in Nepal are progressively increasing in line with global and regional records. Between 1977 and 1994, the mean annual temperature is estimated to have increased by 0.06°C, and is projected to increase by another 1.2°C by 2030, 1.7°C by 2050, and 3.0°C by 2100 (as cited in ADB, 2009). A study made by Practical Action Nepal (2009) on the temporal and spatial variability of temperature and rainfall, based on the observed meteorological data for the period 1976- 2005, shows increasing trend in temperature over Nepal. The maximum temperature was found to be increasing at a greater rate (0.05°C/year) than the minimum temperature (0.03°C/year). Days and nights are becoming warmer and cool days and nights are becoming less frequent. Rainfall extremes show an increasing trend in intense rainfall events at most recording stations. The assessment indicates that more weather-related disasters such as floods and landslides can be expected in future. Ongoing climate variability and change are projected to impact a variety of sectors in Nepal.

The report published by World Bank in 2007 mentioned that climate change will have far-reaching consequences for agriculture that will disproportionately affect poor and marginalized groups who depend on agriculture for their livelihoods and have a lower capacity to adapt. A changing climate brings many challenges in water availability and demand management and in managing the water quality changes. Agriculture, which is the only available means of livelihood for many of the poor, is one of sector which is expected to be most vulnerable to climate change. The changes in the temperature and rainfall patterns are expected to bring major changes in the farming systems and practices, which are expected to produce far reaching implications to the rural economy and livelihood of the people. Increased water demand and decreased water availability as a result of climate change may adversely affect the society and economy (Brookes *et al.* 2010). The communities have been adapting some measures to mitigate adverse impacts of climate change, based essentially on their local knowledge and resources.

Considering these contexts, this study on Climatic Variabilities and their Implications in Peri-urban Areas of Kathmandu Valley was conducted in four peri-urban areas of Kathmandu valley as a part of action research project entitled “Water Security in peri-urban South Asia: Adapting to Climate Change and Urbanization” funded by International Development Research Center (IDRC), Canada and coordinated by South Asian Consortium for Interdisciplinary Water Resources Studies (SaciWATERs), Hyderabad, India.

Problem Statement

In Nepal rain falls within four distinct seasons (Nayava, 1974) but it receivesthe major portion of annual rainfall from June to September under the influence of summer monsoon. Most of that rain may be concentrated in a few heavy falls. The monsoon rainfall is thus very important from the agricultural point of view because it is the main season for thecountry's major crop.Therefore small shifts in the large-scale weather patterns from year to year may significantly alter the amount and/or the distribution of seasonal rainfall. The rainfall in Nepal varies greatly from place toplace due to sharp topographical variations and more complex techniques are usually needed to interpret variations in rainfall. The trend analysis of maximum temperature in Nepal carried out by Shrestha *et al.* (1999) found that the average annual warming between 1971 and 1994 was 0.06°C/year. Studies show that the trends of temperature rise are not uniform in Nepal. The warming in the maximum temperature is found to be more pronounced in the high altitude regions.

Ongoing climate variability and change are projected to impact a variety of sectors in Nepal. Impacts on water resources include anticipated water shortages in dry seasons and more weather-related disasters such as floods and landslides are expected in future. Most of the climatic data analysis in Nepal has been concentrated in national level and generalized to represent the entire country. With extensive variations in topography and microclimate there is need of site specific climatic data analysis to understand the climatic variation at local contexts.

Besides, meteorological information from the scientific analysis is rarely available at the community levels in developing countries and farmers rely on their own observations and subjective interpretations (LI-BIRD undated; Gbetibouo, 2009). These interpretations are based on a longstanding experience and familiarity with seasonal patterns of rainfall and a set of local climate indicators that constitute the climatic perceptions (Dahal, 2005; Thomas*et al.* 2007; Mertz *et al.* 2009; Green and Raygorodetsky, 2010; Piya 2012). It is important to be aware of these perceptions since people frequently act on their perceptions, change their behavior, and develop strategies to cope with the changes in the short run and to adapt to the long term changes based on their dynamic and evolving knowledge, whether or not they are consistent with meteorological data (Vedwan and Rhoades, 2001; Gearheard *et al.* 2010; Speranza *et al.* 2010).

Climate change vulnerability mapping for Nepal prepared as a supplementary effort to National Adaptation Programme of Action- Nepal has ranked Kathmandu, Bhaktapur and Lalitpur districts in very high to high in the most of risk specific and combined vulnerability maps (MoEST, 2010). However, there has beenvery limited study to understand the climatic variation focusing Kathmandu valley, particularly those co-relating the climatic data analysis to the local perceptions. Considering the context, this study has analyzed the hydro-meteorological data from seven different hydro-meteorological stations of Kathmandu valley for the observed trend of change, persistence and anomalies. Alongside it has captured locally perceived changes in a wide range of attributesclimatic parameters and triangulated the findings from two broad research areas. Thus the study can be expected to contribute to better understand the changing climate in Kathmandu valley with the findings of hydro-meteorological data analysis, the local peoples' perception on the changing climate and implication of changes on livelihood and other natural resources.

Research questions

1 How has the climate of the Kathmandu Valley been changing over time on the basis of available hydro-meteorological data?
2 Whatchanges have the local people perceived in the local climate?
3 What the literatures remark on the implications of changes in climatic indicators and how the local people have perceived such implications?

Objectives

The overall objective of this study is to understand the climate change trend and variabilities and their implications in peri-urban areas of Kathmandu valley. The specific objectives that are set to achieve this overall objective are stated hereunder:

- To analyze the time series changes in climate records from the Kathmandu valley.
    - To identify increasing and decreasing trends in temperature,
    - To identify increasing and decreasing trends in rainfall,
    - To identify the significant monthly and seasonal shift in temperature and rainfall,
    - To identify the highest rainfall intensity and the driest seasons,
    - To identify the highest and the lowest temperature extremities,
- To understand the perception of local people on changes in various climatic indicators at local level,
- To understand the peoples' perceptions on impacts of changes in climatic indicatorson water, agriculture and other natural resources and livelihood of local people.

2. CLIMATIC DATAAND HYDRO-METEOROLOGICAL STATIONS

2.1 Hydro-meteorological Stations

The hydro-meteorological data were collected from seven different stations within Kathmandu Valley. These stations were selected based on their proximity to the study sites across where the climatic perceptions were captured.The maximum distance between the stations is less than 25 kilometers, the maximum difference in height is 208 meter (between Panipokhari and Changunarayan). The stations Tribhuwan International Airport (TIA) and Panipokhari are situated within urban core of Kathmandu City. Khumaltar lies in the newly built urban area of Patan (Lalitpur). The stations Godawari, Changunarayan and Sankhu are situated the furthest away from the urban center.

Changunarayan station, located at the hilly areas of Bhaktapur district and Naikap station of Kathmandu district is in the proximity of Jhaukhel and Matatirtha Village Development Committee (VDC) respectively whereasthere is no station close to the Lubhu and Dadhikot VDC. However, station in Khumaltar andTIA are comparatively closer to these VDCs rather than other stations in Kathmandu valley.

The hydro-meteorological records wereanalyzed on a daily, weekly, monthly and annual basis using statistical software R. An overview of these field sites can be found in table 1 and 2 whereas figure 1 shows the location of different stations and selected research sites within the Kathmandu valley.

Table 1: Summary of Hydro-Meteorological Records Used in Analysis

Index No.	Station	Location (Deg. Min.)		Altitude (m) Amsl
		Latitude	Longitude	
1029	Khumaltar	$27^0$40’	$85^0$20’	1350
1030	TIA	$27^0$42’	$85^0$22’	1337
1022	Godawari	$27^0$35’	$85^0$24’	1400
1039	Panipokhari	$27^0$44’	$85^0$20’	1335
1059	Changunarayan	$27^0$42’	$85^0$25’	1543
1035	Sankhu	$27^0$45’	$85^0$29’	1449
1076	Naikap	$27^0$41’	$85^0$15’	1520

Table 2: Available climate variables and covered period per station

Index No.	Station	Period of Meteorological Records				
		Rainfall	Temp.	Humidity	Evaporation	Wind speed
1029	Khumaltar	1967 - 2009	1967 - 2009	1976 - 2009	1968 - 2008	1999 - 2008
1030	TIA	1968 - 2009	1968 - 2009	1968 - 2009	1969 - 2008	1993 - 2008
1022	Godawari	1953 - 2009	1972 - 2009	1976 - 2009		
1039	Panipokhari	1971 - 2009	1971 - 2009	1976 - 2009		
1059	Changunarayan	1971 - 2009				
1035	Sankhu	1971 - 2009				
1076	Naikap	1997 - 2009				

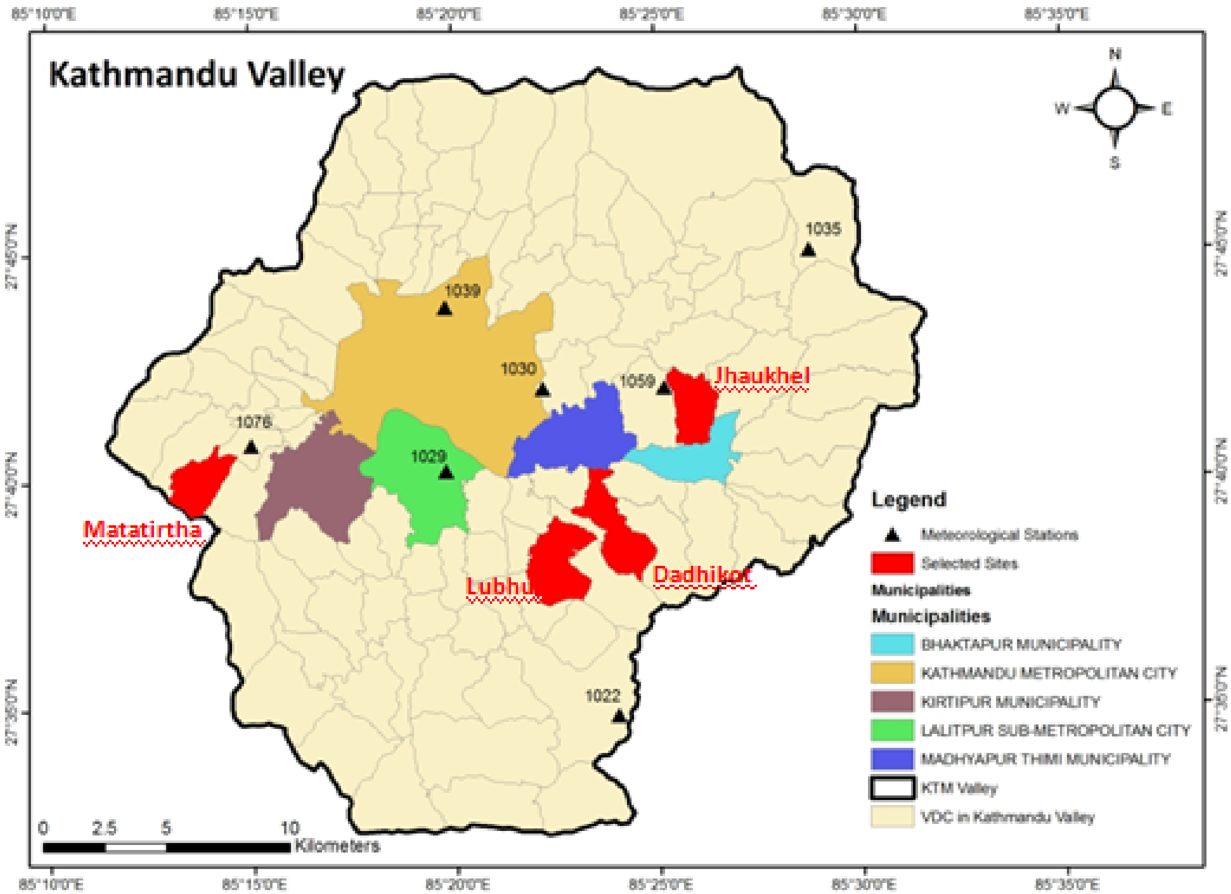


Figure 1: Location of Hydro-Meteorological StationsUsed in the Analysis and Research Sites

2.2 Climatic data

Temperature

The data availability for temperature varied across the stations. The data of Khumaltar was available for 43 years, for TIA it was 42 years, Panipokhari for 39 years and Godawari for 38 years. For every station the daily minimum and daily maximum temperature was available. The minimum temperatures were measured between 4.00 AM and 5.00 AM and the maximum temperatures were measured between 1.00 PM and 3.00 PM.

Rainfall

Similarly the rainfall records vary in length across the stations. Godawari had a rainfall record of 57 years. Khumaltar 43 years, TIA 42 years, and Changunarayan, Sankhu and Panipokhari had record length of 39 years. For Naikap stationonly 13 years of data is available. According to the World Meteorological Organization (WMO, 1966), 40 year of data is necessary for robust climate analysis. This criterion was met for all stations except Naikap. This should be taken into consideration when analyzing the results. The available data for rainfall contained the letter 'T' for Traces when rainfall was less than 0.05 mm per day. For the analyses 'T' is replaced with 0.05. This can, in some situations, lead to some small over estimations.

Evaporation

PAN-evaporation data were measured only at two stations; Khumaltar and TIA. For Khumaltar, data had a large gap between 1986 and 2001 and for TIA, a large data gap existed in the period 1983-1998.

3. RESULTS AND DISCUSSION

3.1 HYDROMETEOROLOGICAL DATA ANALYSIS

In this section the results of the hydro-meteorological analyses carried out on rainfall, temperature, and evaporation data has been presented and discussed.

3.1.1 Temperature

A deviation-plot from temperature was drawn to get a first sight on the temperature in the Kathmandu valley. The temperature over 43 years in Khumaltar is shown in figure 2. The line shows the 5 year moving average, and it is striking that the minimum as well as the maximum temperature in and outside monsoon season seem to have increased the last years. This signal is stronger in the non-monsoon period. Shrestha *et al.* (1999) found a constant or decreasing trend in temperature for the period 1960-1976 and an increasing trend after the mid '70. This pattern is also recognizable in figure 2.

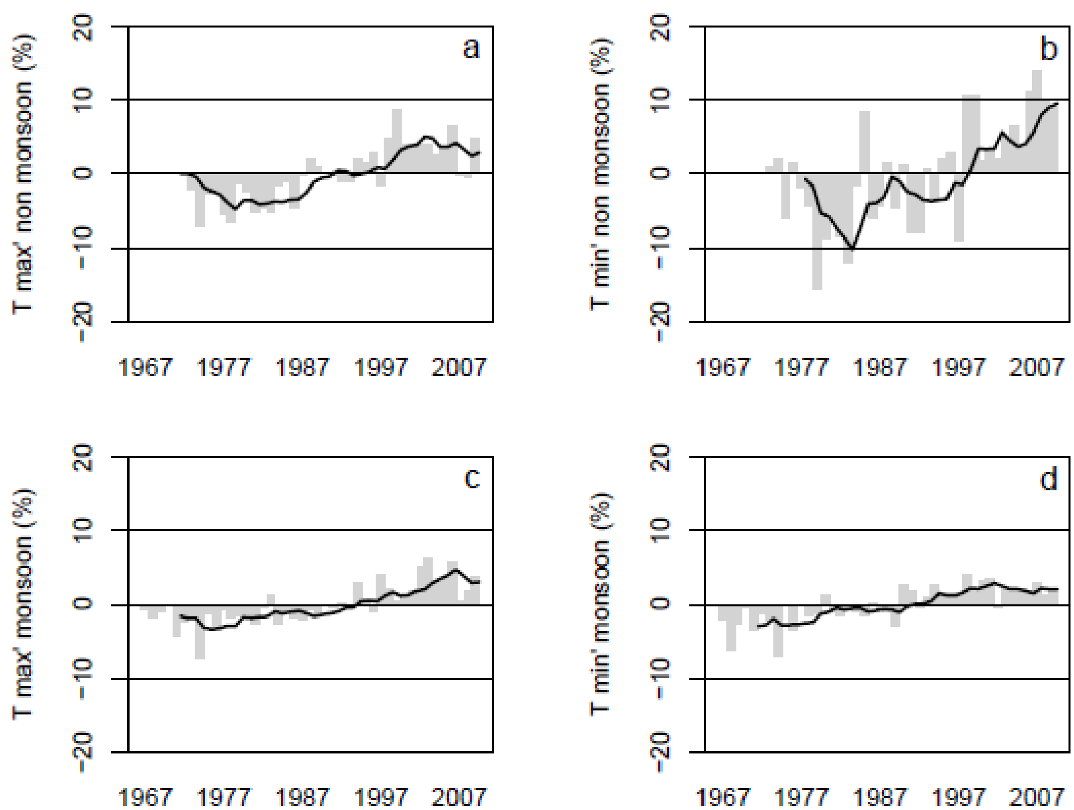


Figure 2: Deviation from long term annual mean max. (a and c) and mean min. (b and d) temperature in non-monsoon (a and b) and monsoon (c and d) period in Khumaltar, expressed in percentage. The line gives the 5 year moving average.

An overview of the temperature-deviation plots for the other stations is given in annex 1. Comparing the graphs of all the stations, it was found that there is difference between the stations in long term annual average temperature. Godawari had an annual average temperature of 16.7°C, whereas the long term annual average temperature in TIA is 18.6°C. Khumaltar and Panipokhari are in between with respectively 17.8°C and 18.4°C. These differences can be caused by differences in altitude or a difference in surrounding environment.

3.1.1.1 Indices

The trend in the three different indices that were calculated with the temperature data will be described below.

a. Number of days below 0°C

For every year, the numbers of days that Tmin was below 0°C were counted.The details of the slope of the trend line and the regression (R^2) values are given in table 3. For all the stations, the number of days with Tmin < 0°C seemed to have decreased quite drastically, especially in Khumaltar and TIA.

Table 3: Slope of trend line through number of days < 0°C

Station	< 0°C	R^2
Khumaltar	-0.30	0.14
TIA	-0.28	0.26
Godawari	-0.01	0.05
Panipokhari	-0.13	0.01

The five years moving average for the number of days with temperature < 0°C per year is shown in figure 3. It clearly shows the strong downward pattern in Khumaltar and TIA. The weakest signal was in Godawari. This is striking; TIA and Khumaltar are two stations situated in urban area, whereas Godawari is the station furthest away from the urban core. This gave the idea that there might be an urban heat island effect. This effect is more pronounced in minimum temperature (Mitchell, 1961), and might therefore very well be visible in the number of < 0°C-days.

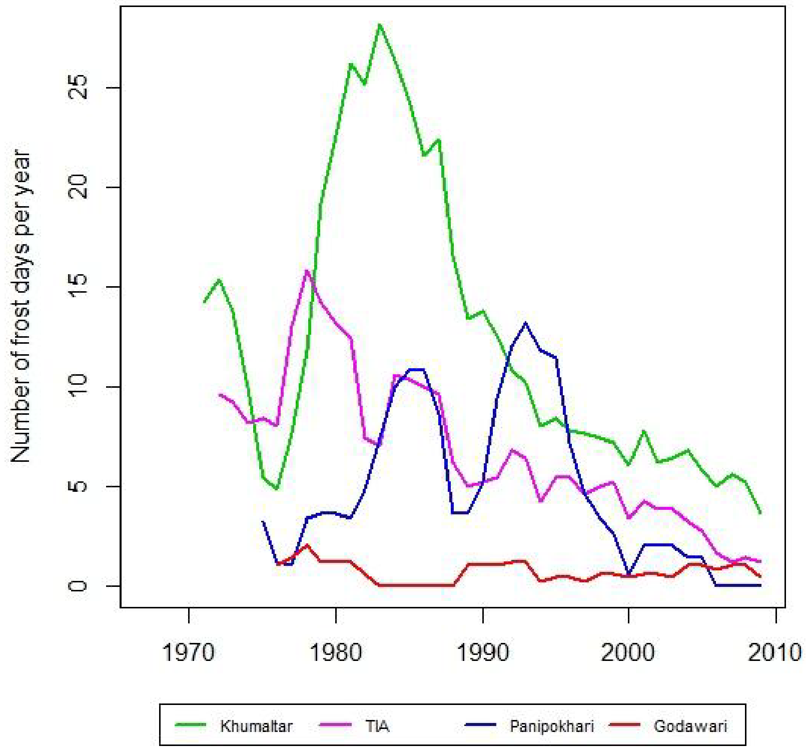


Figure 3: Five years moving average for the number of days with temperature < 0°C per year.

b. Number of hot days per year

For every year the numbers of days that maximum temperature was above 30°C were counted. In table 4 it can be seen that the number of hot days had increased in all four stations. This signal is particularly strong for TIA, with a yearly increase of 1.52 hot days (and a high R^2). Figure 4 shows the five year moving average of the number of hot days for all four stations. The increase is clearly visible and in strong contrast with the decrease in the number of days with < 0°C. It is also striking that again station Godawari, the station furthest away from the urban core, is showing the lowest increase.

Table 4: Slope of trend line through number of hot (>30°C) days

Station	>30°C	R^2
Khumaltar	0.32	0.20
TIA	1.52	0.66
Godawari	0.08	0.13
Panipokhari	0.73	0.27

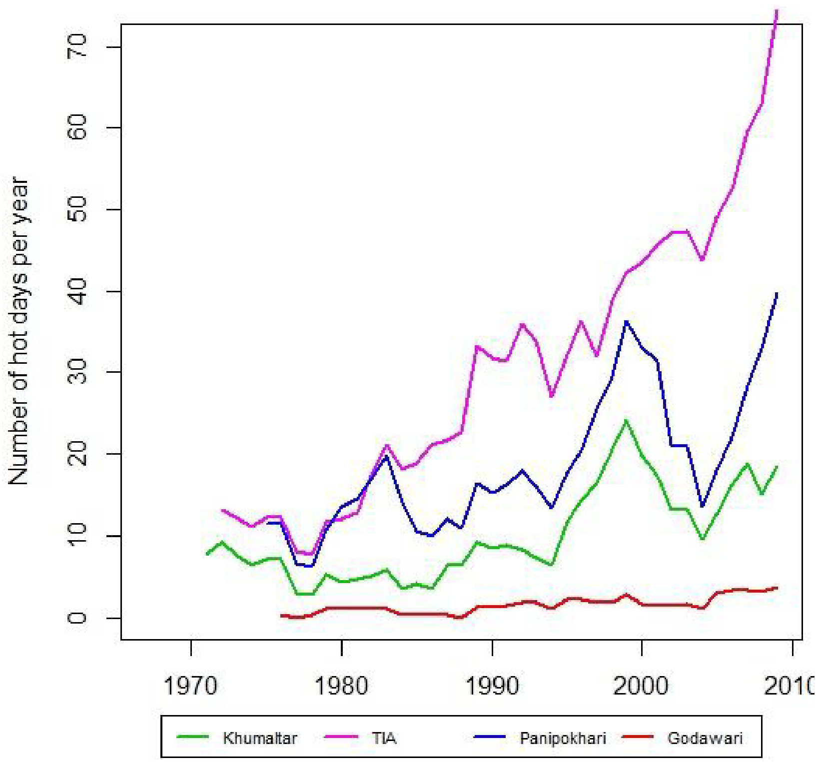


Figure 4: Five years moving average for the number of days with temperature >30°C per year.

c. Yearly maximum and minimum temperature extremes

The most extreme temperature measurements per station per year were considered based on daily data. It is found that the yearly maximum value ofmaximum daily temperature (Max Tmax) have increased in all four stations. The minimum value of maximum temperature (Min Tmax) measured also seems to have increased for all four stations, which might imply that the coldest day of the year have become warmer and the warmest day of the year have become warmer. On average, the minimum value of minimum temperature (Min Tmin) and the maximum value of minimum temperature (Max Tmin) also both had become warmer, although this signal was less clear and not visible for all stations. The slopes of the linear trend line through the four aforementioned temperature extremes are given in table 5 below.

Table 5: The slope of the trend line through the most extreme temperatures per year for the whole record period

Station	Max Tmax[1]	$R2$	Max Tmin[2]	$R2$	Min Tmax[3]	$R2$	Min Tmin[4]	$R2$
Khumaltar	0.02	0.05	-0.01	0.02	0.10	0.24	0.03	0.08
TIA	0.06	0.27	0.02	0.12	0.03	0.02	0.06	0.19
Godawari	0.03	0.12	0.04	0.20	0.06	0.16	-0.01	0.01
Panipokhari	0.04	0.13	-0.01	0.00	0.11	0.28	0.05	0.19
Average	0.04		0.01		0.08		0.03	

Baidya *et al.* (2008) found comparable results for stations all over Nepal: an increase in warm nights and warm days and a decrease in cool nights and cool days. They showed an increase of 0.071 in the maximum of the daily maximum temperature (Max Tmax), increase of 0.008 in the minimum of the maximum temperature (Min Tmax) andincrease of 0.031 in boththe maximum of the minimum temperature (Max Tmin) and minimum of the minimum temperature (Min Tmin) which are in the same range as found in this study, but here a stronger increase in the lowest of both minimum and maximum temperatures is found.

3.1.1.2 Trend analysis

The results of the different trend analyses that were carried out are discussed below.

a. Linear trend analysis per month

The monthly averaged minimum and monthly averaged maximum temperature of succeeding years were plotted and a linear trend line was fitted to ascertain the trend in minimum and maximum temperature per month. The details of the slope of the trend lines through the monthly average maximum and minimum temperatures are given in table 6 whereas the R^2-values for every month for every station for both temperatures are given in table 7.

Table 6: Slope of trend line through monthly mean of Tmax (top) and monthly mean of Tmin (bottom)

Months	Khumaltar		TIA		Godawari		Panipokhari	
	Tmax	**Tmin**	**Tmax**	**Tmin**	**Tmax**	**Tmin**	**Tmax**	**Tmin**
January	0.06	0.02	0.10	0.05	0.09	0.00	0.06	0.04
February	-0.01	0.07	0.11	0.09	0.08	0.03	0.02	0.09
March	-0.01	0.10	0.08	0.07	0.05	0.01	0.04	0.06
April	0.03	0.05	0.07	0.04	0.05	-0.01	0.06	0.06
May	0.03	0.08	0.05	0.03	0.04	0.01	0.07	0.02
June	0.03	0.05	0.06	0.02	0.04	0.02	0.04	0.07
July	0.03	0.06	0.05	0.02	0.04	0.03	0.03	0.01
August	0.02	0.08	0.05	0.03	0.04	0.04	0.04	0.03
September	0.03	0.07	0.08	0.03	0.07	0.04	0.06	0.08
October	0.04	0.08	0.09	0.05	0.07	0.01	0.05	0.12
November	0.05	0.05	0.08	0.06	0.09	-0.01	0.06	0.09
December	0.02	0.07	0.07	0.08	0.09	0.01	0.05	0.11

Except for two months in one station (February and March in Khumaltar), all the months showed an increase in monthly averaged maximum temperature. This signal was the strongest in TIA (on average 0.07), and the lowest in Khumaltar (on average 0.03). The increase was on average the lowest for the months June, July, August (all three with an average of 0.04) which covers a large part of the monsoon period. The increase of Tmax was the highest in January and November (respectively 0.08 and 0.07).

These results are in line with findings of IPCC (Cruz *et al.*2007) which states that surface air temperature has increased, which is more pronounced during winter. Shrestha *et al.* (1999) found the largest increase in winter and the lowest increase in pre-monsoon. For the period 1977-1994 he found an increasing trend of 0.094 for the months October and November whereas while averaging out for all stations, this study showed an increasing trend of 0.07 for the months October and November. Baidya *et al.* (2008) did a comparable analysis for stations spread over whole Nepal.

Also here, except from two months in Godawari, all numbers implied an increase in monthly averaged minimum temperature. In contrast to the maximum temperature, the highest increase in minimum temperature was found in Khumaltar (0.06), while the lowest slope was found in Godawari (0.01). Khumaltar is a station located in the urban area of Kathmandu valley, while Godawari is situated in rural area. The urban heat island effect is especially pronounced in minimum temperature (Mitchell, 1961), thus the result obtained support the idea that an urban heat island has developed in Kathmandu valley.

Table 7: R^2 trend line through monthly averaged maximum (top) and minimum (bottom) temperature

Tmax	Khumaltar	TIA	Godawari	Panipokhari
Jan.	0.29	0.53	0.34	0.16
Feb.	0.00	0.44	0.23	0.02
Mar.	0.00	0.34	0.14	0.07
Apr.	0.06	0.23	0.13	0.11
May	0.07	0.17	0.11	0.17
Jun.	0.06	0.47	0.22	0.09
Jul.	0.17	0.57	0.73	0.22
Aug.	0.07	0.60	0.64	0.31
Sep.	0.20	0.76	0.41	0.57
Oct.	0.28	0.55	0.35	0.20
Nov.	0.32	0.64	0.39	0.25
Dec.	0.03	0.52	0.39	0.15
Tmin	Khumaltar	TIA	Godawari	Panipokhari
Jan.	0.03	0.12	0.00	0.12
Feb.	0.26	0.29	0.07	0.44
Mar.	0.45	0.28	0.00	0.09
Apr.	0.12	0.12	0.01	0.06
May	0.22	0.11	0.01	0.02
Jun.	0.08	0.14	0.05	0.08
Jul.	0.19	0.20	0.15	0.00
Aug.	0.38	0.28	0.23	0.02
Sep.	0.22	0.33	0.16	0.13
Oct.	0.37	0.17	0.02	0.25
Nov.	0.20	0.24	0.04	0.30
Dec.	0.30	0.35	0.02	0.49

The highest increase in minimum temperature was on average in February and December. The lowest increase in minimum temperature was not, like with maximum temperature, in June, July and August but had moved to earlier in the year: from April until July. This still confirms the IPCC findings (Cruz *et al.* 2007) that temperature increase is more pronounced during winter.

Baidya *et al.* (2008) found an increasing trend in minimum value of minimum temperature.

The R^2-values given in table 7 gave information about the variation in the monthly averaged temperatures throughout the years. Except for station Khumaltar, the averaged over 12 months R^2-value was higher for the maximum temperature than for the minimum temperature. This means that in three stations, the variation in minimum temperature over the years was larger than the variation in maximum temperature. Maximum temperature showed the highest variation (lowest R^2-value) in the months February to May (pre-monsoon) and minimum temperature showed the highest variation in January and the period April to June.

b. Mann-Kendall trend analysis per month

The Mann-Kendall trend test was applied per month over the complete available record for all four stations and for maximum as well as minimum temperature. An overview of the complete tables with test-results can be found in annex 2. For all significant trends, Sen's Slope Estimator was calculated, and is given in table 8. Compared to the slopes obtained with linear regression in the previous section, there are only small differences with Sen's Slope.

Many significant trends were found for the temperature data ($\alpha = 0.05$). For the maximum temperature in Godawari and TIA, a significant increasing trend was found for all twelve months. For minimum temperature, many significant trends were found: all increasing without any exception. For Tmax, a significant increasing trend was found for all four stations in the month January and the period July to November whereas a significant increasing trend was found at all four stations only in the month September for Tmin. The results showed clearly that both minimum and maximum temperature had increased over the last 38 to 43 years. There were more significant trends found for maximum temperature, and the increase was also slightly stronger than for minimum temperature. By setting the slope of the non significant months equal to zero, Tmax had an average increase of 0.05°C per year. The average slope of Tmin was 0.04°C per year. Both for maximum and minimum temperature, the increase was stronger during winter period and weaker in summer season (although for Tmax more significant trends are found in summer), as also was found in the previous section and by Cruz *et al.* (2007) and Shrestha *et al.* (1999).

The average slope per season (as defined by Thapa and Joshi, 2011) over all months with significant trend is given in table 9.

Table 8: Sen's Slope of significant trends through monthly averaged maximum (top) and minimum (bottom) temperature

	Khumaltar		TIA		Godawari		Panipokhari	
Months	Tmax	Tmin	Tmax	Tmin	Tmax	Tmin	Tmax	Tmin
January	0.05		0.09		0.08		0.06	
February		0.07	0.10	0.06	0.06			0.09
March		0.09	0.08	0.05	0.05			0.08
April		0.05	0.07		0.05		0.06	0.06
May		0.07	0.05	0.03	0.04		0.07	
June			0.06	0.02	0.04			
July	0.03	0.02	0.05	0.02	0.03	0.02	0.03	
August	0.03	0.06	0.06	0.02	0.04	0.03	0.04	
September	0.03	0.07	0.08	0.03	0.06	0.03	0.06	0.08
October	0.04	0.09	0.09	0.04	0.07		0.04	0.11
November	0.06	0.06	0.08	0.05	0.09		0.06	0.10
December		0.06	0.07	0.07	0.09		0.04	0.10

Joshi *et al.* (2011) analyzed seasonal temperatures over the whole of Nepal for the period 1978-2008, and found a yearly increase of 0.03°C for Tmax in summer and 0.05°C for Tmax in winter, which is respectively equal and slightly lower than the numbers given in table 9. For Tmin in summer they found an increase of 0.01°C, and a decrease in winter Tmin of 0.001°C. Both numbers are lower than given in table 9, and could indicate that Kathmandu valley is under the influence of an urban heat island.

Table 9: Average Sen's Slope per season

Season	Months	Tmax	Tmin
Winter	Dec-Feb	0.06	0.04
Spring	Mar-May	0.04	0.04
Summer	Jun-Aug	0.03	0.02
Fall	Sep-Nov	0.06	0.05

c. Block Bootstrap Mann-Kendall trend analysis

With the residuals for maximum and minimum temperature, the autocorrelation function showed how many time lags significantly influence the temperature on day n. Figure 5 shows the autocorrelation for the minimum and maximum temperature. Autocorrelation seemed stronger for maximum temperature as compared to minimum temperature. Tmax was significantly influenced by time lags of more than 40 days.

There is no means that the (Seasonal) Mann-Kendall can be applied to this data without correcting for autocorrelation. The alternative is the Block Bootstrap procedure. The length of the blocks should mimic the autocorrelation of the observed series (Khaliq *et al.* 2008). The default for the maximum number of autocorrelated lags is 10 * $\log^{10}(N)$, where N is the number of observations. For the temperature data (not taken into account the Not Available Data) this came down to 41 time lags for all four locations. All the 41 time lags were significantly autocorrelated for Khumaltar station (figure 5). Applying the autocorrelation function on the data of the other stations too, it learned that all locations have 41 significantly autocorrelated time lags for minimum as well as maximum temperature (for significance level $\alpha = 0.01$).

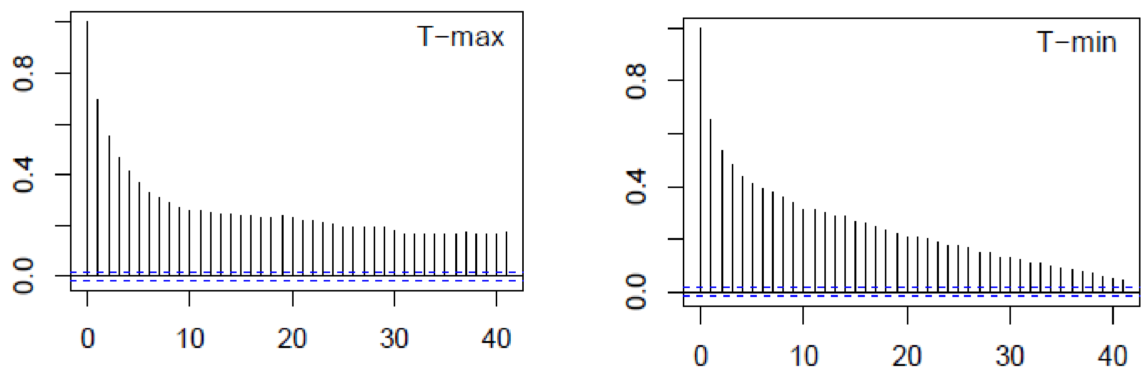


Figure 5: The autocorrelation for minimum and maximum temperature, for different time lags (in days).

A Block Bootstrap (BBS) procedure (2000 repetitions, block length of 41) was conducted for all four stations for maximum and minimum temperature. The BBS was applied to Mann-Kendalls Tau to account for the autocorrelation of the temperature data. An overview of the calculation results is given in table 10. The first two columns (MK's Tau and P-value) give the test statistics if the ordinary MK-test is conducted. The extremely low P-values and the positive Tau-values for all the data series implied that there was an increasing trend for minimum and maximum temperature at all stations. Anyhow, this conclusion could not be drawn because the data was strongly autocorrelated.

Table 10: Results of Mann-Kendall trend test (Tau and P-value) and BBS procedure (95%CI)

Station	T	MK's Tau	P-value	95% CI lower value	95% CI upper value
Khumaltar	Tmin	0.049	$<2.22*10^{-16}$	0.350	0.1625
	Tmax	0.097	<2.22*10	0.1364	0.2534
TIA	Tmin	0.065	<2.22*10	0.0653	0.1951
	Tmax	0.149	<2.22*10	0.2378	0.3559
Godawari	Tmin	0.024	$3.15*10^{-5}$	-0.0201	0.1151
	Tmax	0.097	$2.22*10^{-16}$	0.1300	0.2569
Panipokhari	Tmin	0.50	$<2.22*10^{-16}$	0.0323	0.1672
	Tmax	0.112	$2.22*10^{-16}$	0.1598	0.2866

The last two columns of table 18 give the upper and lower boundary of MK's Tau for a 95% Confidence Interval (CI, α = 0.05), obtained with a BBS procedure. For these numbers, autocorrelation was taken into account and all conclusions should be drawn from these two columns. The 95% CI was based on the assumption that MK's Tau was normally distributed after repeating the procedure 2000 times. The distribution of Tau after the BBS conducted for Tmax in Khumaltar is shown in figure 6. This figure shows that MK's Tau was clearly approaching a Gaussian distribution. There is a significant trend if Tau=0 does not lie within the 95% CI. If all values are above zero, the trend is increasing.

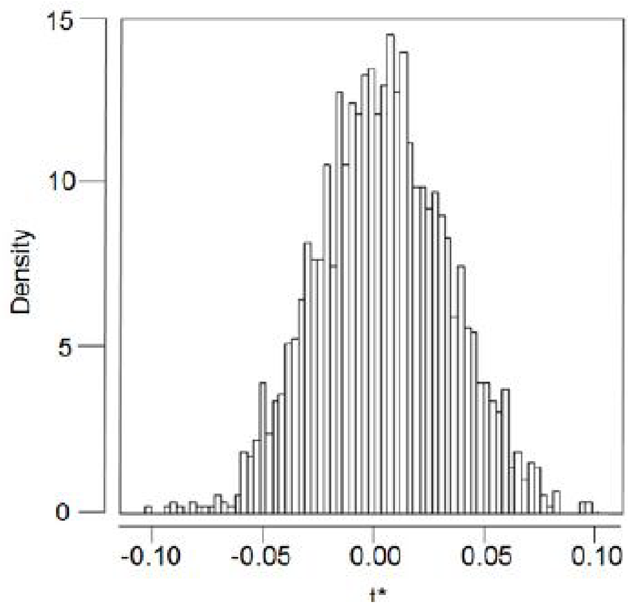


Figure 6: The frequency distribution of t* after 2000 repetitions for Tmax in Khumaltar.

This was the case for all stations, except for Tmin in Godawari. This example showed why the BBS procedure was necessary.Based on the ordinary Mann-Kendall test the conclusion would have been that Tmin in Godawari had increased significantly, while after the BBS procedure the test was not significant anymore. The ordinary MK-test was influenced by the autocorrelation of the data.

Thus it can be concluded, that there was a significant increase in minimum as well as maximum temperature for all stations, except Tmin in Godawari. This confirms the findings of the linear trend line through the data, where Tmin in Godawari also showed the lowest increase.

For all significant trends, Sen's Slope Estimator was calculated. The BBS-procedure was applied to daily temperature data, but because of computational limitations Sen's Slope Estimator was calculated based on monthly values; therefore the slope is giving the temperature increase per month. By multiplying this number with12, the slope on yearly basis is obtained and given in table 11. The temperature increase for Tmax is the strongest in TIA. The increase in Tmin is strongest in Khumaltar. Khumaltar, TIA and Panipokhari are three stations located within urban area while Godawari station has relatively rural setting. The lack of increase in minimum temperature in this station, while a clear increase in minimum temperature was found in the other stations, strengthens the idea that an urban heat island has developed in the urban core. Shrestha *et al.* (1999) thought it is unlikely that the warming trend in Kathmandu is only due to urbanization. They state that the high warming rates in Kathmandu also might be caused by its physiographical characteristics inside the valley.

Table 11: Sen's Slope on yearly basis per station

Station	Tmax	Tmin
Khumaltar	0.02	0.06
TIA	0.07	0.04
Godawari	0.05	0.00
Panipokhari	0.05	0.07

On average, a temperature increase of 0.04°C per year was found for minimum temperature, and an increase of 0.05°C per year for maximum temperature, which is equal to the numbers found in the monthly analysis. In half of the stations, the increase in minimum temperature was stronger whereas for the other half, the maximum temperature showed a more pronounced increase.

Shrestha *et al.* (1999) found an annual increase in temperature in the middle mountains of 0.075°C per year, and an average increase in temperature of 0.059°C per year for whole Nepal. Compared to these numbers, the found temperature increase is in the same range but on the lower hand. In general for South-Asia, a temperature increase from 0.01°C to 0.03°C per year is found (Cruz *et al.* 2007). The worldwide temperature increase is estimated between 0.010°C and 0.016°C per year (Bernstein *et al.* 2007). Compared to these numbers the found temperature increase is high, confirming the statement of Chaulagain (2006) that climate change is emerging faster in Nepal than the global average.

Summary

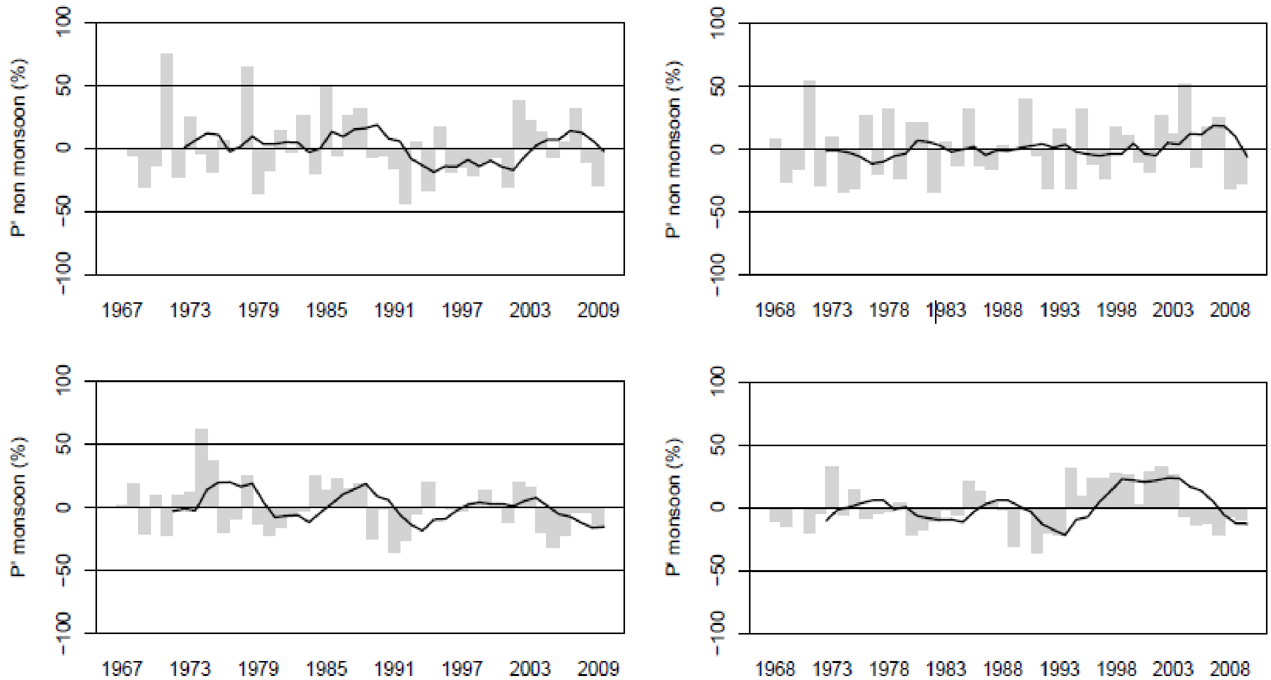
There was a decrease in number of days with temperature < 0°C in all four stations. This decrease was more pronounced in the stations settled in the urban area. There was an increase in all four stations in the number of hot days (> 30°C), again more pronounced in the urban stations. Both the maximumand minimum Tmax of the year had increased. The same counts for the maximum Tmin of the year and the minimum Tmin of the year, which might imply that the warmest day of the year had become warmer, and the coldest day of the year too. This signal was clearer for the Tmax-values.

Increase in temperature was the lowest in summer season and the strongest in fall and winter season for both Tmin and Tmax.

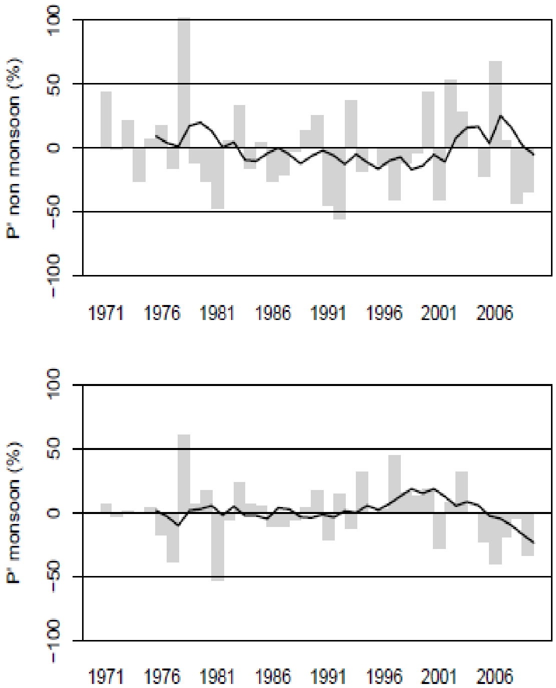
Based on Sen's Slope applied to the complete data series, Tmin showed an average increase of 0.04°C per year and Tmax showed on average an increase of 0.05°C per year; this increase is higher than the South-Asian and global average. For half of the stations, the increase in minimum temperature was stronger, while for the other half, the increase in maximum temperature was stronger. If the increase in maximum temperature was stronger than the increase in minimum temperature, it implies that daily variations in temperature have increased.

3.1.2 Rainfall

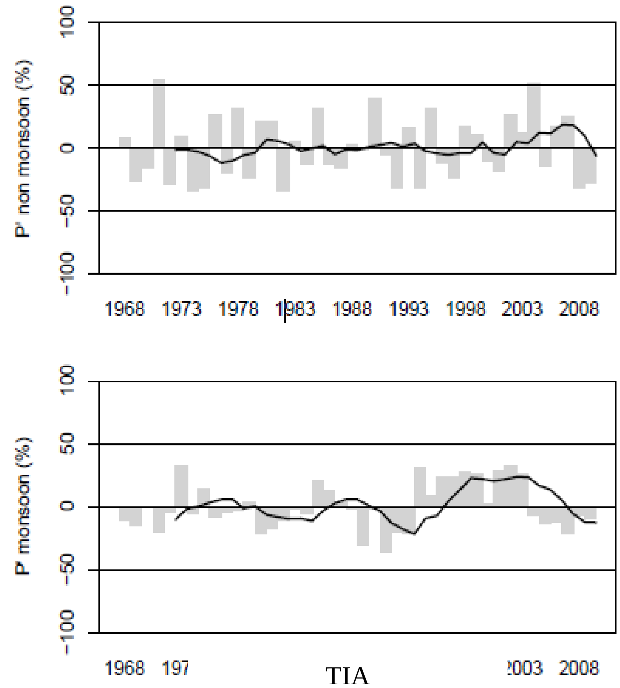
Deviation figures were drawn to get a first sight on the rainfall pattern in Kathmandu valley of the last years. The anomalies of rainfall over the 40 year average rainfall in different stations of Kathmandu valley are given in figure 7. The deviations are expressed as a percentage and the line gives the 5 year moving average. The first impression is that both in monsoon and non-monsoon period there is no clear pattern recognizable. Shrestha *et al.* (2000) assigned large temporary variation in rainfall in Nepal to the El-Nino-Southern Oscillation (ENSO). The five year moving average for the Godawari station is not drawn due to presence of the years without data or Data Not Available (DNA).



Khumaltar TIA

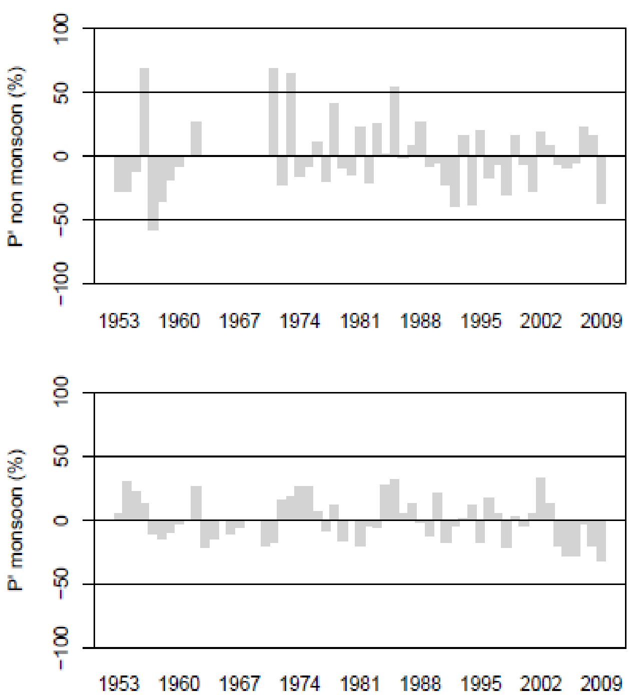


Sankhu

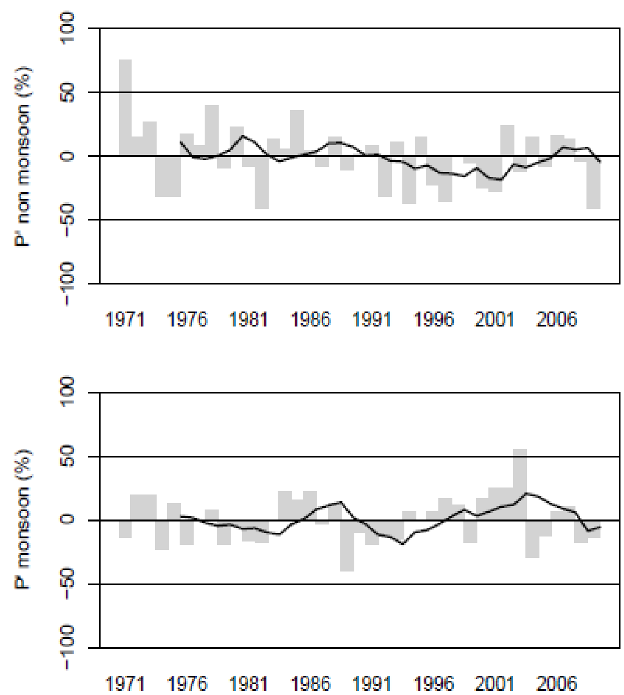


TIA

Changunarayan



Godawari



Panipokhari

Figure 7: Deviation from long term annual mean rainfall, expressed in percentage. The black line gives the 5 year moving average.

A brief overview of the average yearly rainfall sum in mm per station is given in table 12. Also the minimum and maximum measured rainfall sum and the year are mentioned. Kripalani *et al.* (1996) found a mean annual rainfall of 1404 mm with a maximum of 1794 mm in 1948 and a minimum of 842 mm in 1864, measured in Kathmandu based on data from 1851-1900 and from 1921-1975. These numbers found by Kripalani *et al.* (1996) are in the same range as the numbers given in table 12.

Table 12: Average yearly rainfall (mm) and minimum and maximum yearly rainfall (mm)

Station	Mean	Min	Year	Max	Year
Khumaltar	1212	827	1992	1698	1978
TIA	1437	1068	1991	1871	2002
Godawari	1834	1242	2009	2553	1985
Panipokhari	1510	1066	1989	2027	2003
Changunarayan	2003	965	1981	3425	1978
Sankhu	1696	1148	1978	2456	1983
Naikap	1404	778	2009	1811	2003

3.1.2.1 Indices

a. Number of rainy days in and outside monsoon period

For every station for every year, the number of days with rainfall was counted for monsoon and non-monsoon period. The slope of the trend line and the value of R^2 are given in table 13 and the moving average for the number of rainy days in Khumaltar is shown in figure 8.

Table 13: Slope of trend line through number of rainy days per year

Station	Non-Monsoon	R^2	Monsoon	R^2
Khumaltar	0.22	0.09	0.19	0.10
TIA	0.35	0.17	0.16	0.13
Godawari	0.12	0.01	0.12	0.01
Panipokhari	-0.68	0.33	-0.11	0.04
Changunarayan	-0.46	0.16	-0.31	0.18
Sankhu	-0.35	0.09	0.06	0.01
Naikap	-1.03	0.25	-2.03	0.52

From table 13, it can be seen that four out of seven stations have a decrease in number of rainy days in non-monsoon period. Although this is not really convincing (also with very low R^2 values) the pattern can be recognized that the negative direction (decrease in number of rainy days) seems to be a stronger signal than the positive directions. For monsoon period only three out of seven stations have a decrease in number of rainy days. Again it is recognizable that the negative numbers are in general stronger than the positive numbers. Naikap station seems to give the strongest decrease in number of rainy days, both in and outside monsoon period but only 13 years of data is available from Naikap station, which is too short to draw any conclusion concerning climate.

Cruz *et al*. (2007) found a decrease in number of rainy days in South-Asia. This finding is not completely supported by the results of this research. There seems to be a tendency towards a decrease, but the signal is weak.

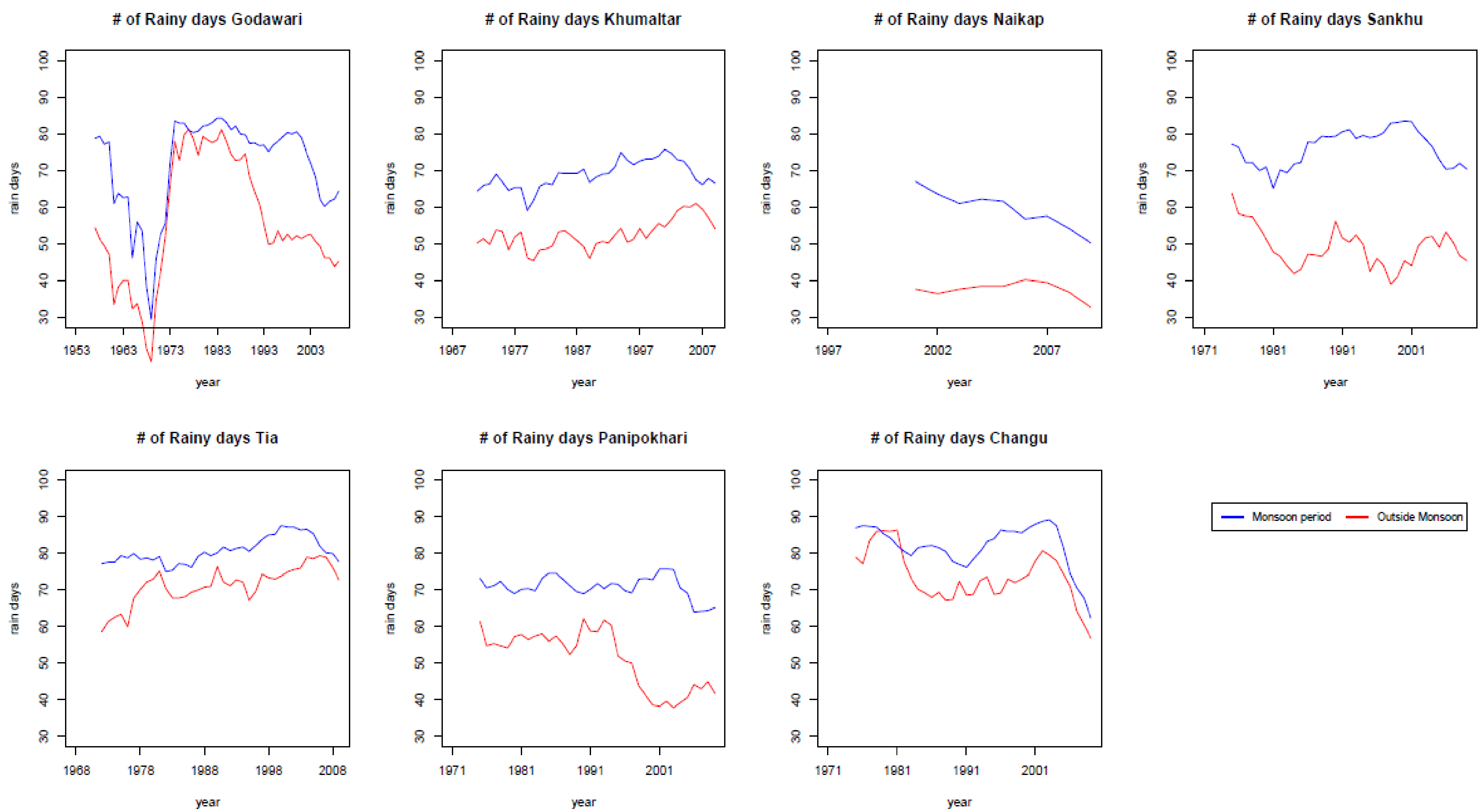


Figure 8: Five years moving average of number of rainy days

b. The daily intensity index for monsoon period

The Standard Daily Intensity Index (SDII) was calculated for every station for every year only for monsoon period. An overview of the slopes of the trend lines and value of SDII to give an idea of the magnitude of the SDII during monsoon (average mm rainfall/rainy day) are given in table 14.

Table 14: Slope of trend line through SDII for monsoon period

Station	SDII	$R2$
Khumaltar	-0.08	0.17
TIA	0.04	0.04
Godawari	-0.01	0.00
Panipokhari	0.04	0.02
Changunarayan	0.07	0.10
Sankhu	-0.06	0.03
Naikap	-0.13	0.04

Four stations show a decreasing trend whereas three stations an increasing trend. There is no clear pattern recognizable, so it is not possible to draw any conclusions concerning the SDII during monsoon period for Kathmandu valley. The low R^2-values indicate a large variation over the years. Though the chapter contributed by Cruz *et al.*, (2007) in IPCC report mentioned an increase in rainfall intensity in temperate and tropical Asia, Baidya *et al.*, (2008) did not find any significant trend for the SDII applied to rainfall data covering the whole of Nepal.Rainfall data was only available on a daily basis, measured one time a day, so it was not possible to analyze individual rainfall events from a couple of hours. Intense rain showers can precipitate a lot of rain in a short period, but the daily rainfall sum might not differ significantly from a full day of not intense rainfall. This analysis is based on daily numbers and not on individual rain showers; hence, it would be too blunt to conclude from these that rainfall had not intensified.

c. Number of extreme events

The number of rainy days that exceeded 50 mm, 100 mm, and 150 mm per day was counted for all seven stations within the monsoon period. The slope of the trend line can be found in table 15 for the number of days with more than 50 mm rainfall. Figure 9 shows the moving average for Khumaltar, to show the magnitude of the number of events. From the data of Godawari, it seemed that the number of extreme events had increased after the '70. Because the other data series were not long enough, this cannot be confirmed by any other station.

Because there was only limited number of days with more than 100 mm, no linear trend line was plotted through these data. Events with more than 150 mm rainfall on one day barely took place. Godawari had three events (1954, 1975 and 2002) and all other stations except Khumaltar measured one event in 2002 with more than 150 mm rainfall.

Table 15: Slope of trend line through number of extreme events per year

Station	>50mm	R^2
Khumaltar	-0.02	0.02
TIA	0.02	0.02
Godawari	0.02	0.01
Panipokhari	0.00	0.00
Changunarayan	0.03	0.03
Sankhu	0.08	0.05
Naikap	-0.05	0.01

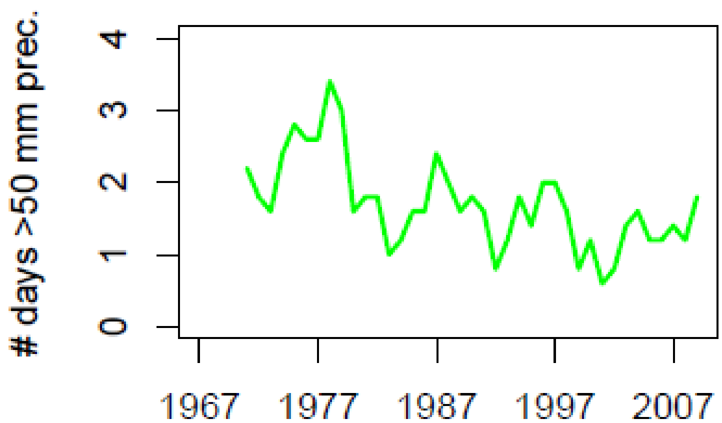


Figure 9: The five years moving average for number of days with >50mm rainfall in Khumaltar

Most of the stations find an increase in the number of days with rainfall more than 50mm in a day in monsoon period (averaged without taking into account Naikap, an increasing slope of 0.02). The low R^2 values show that there is large variation in the yearly number of > 50mm rainfall events. The trend in Panipokhari had a R^2 of 0, implying that the given slope (0.00) is from a straight line through the average value. The linear model could not explain the data.

Baidya *et al.* (2008) did a comparable study for data series throughout the whole country of Nepal and applied this to the whole year, not only monsoon period. An average increase of 0.001 was found for the number of days with more than 50 mm rainfall. The slopes found in table 6 imply a larger increase in events with more than 50 mm rainfall than found by Baidya *et al.* (2008), but this is only for monsoon period and only for Kathmandu valley. However, these numbers are based on daily rainfall sums only. This leaves out the possibility to identify heavy rainfall which for example started few hours before measurement time and lasted some hours after measurement time.

d. Number of dry spells in monsoon

The number of days without rainfall in monsoon period was counted for every year for every station. It was found that the slope of the trend line through the number of individual dry days in monsoon is the opposite of the slope of the trend line through the number of rainy days in monsoon. The length of the dry spells was also studied in this section. The number and length of dry spells per year for all the stations are given in annex 3. Figure 10 shows the number of dry spells per year and their length for Khumaltar station as an example.Each grey bar represents one year. The first graph shows the number of individual dry days in monsoon whereas the second graph shows the number of dry spells where it did not rain for two successive days and the most right graph shows the number of dry spells in monsoon where it did not rain continuously for three days. It is hard to find any pattern in this figure. Annex 3 shows the number of dry spells per station up to a length of ten days, and it seems that the length of dry spells had not clearly increased.

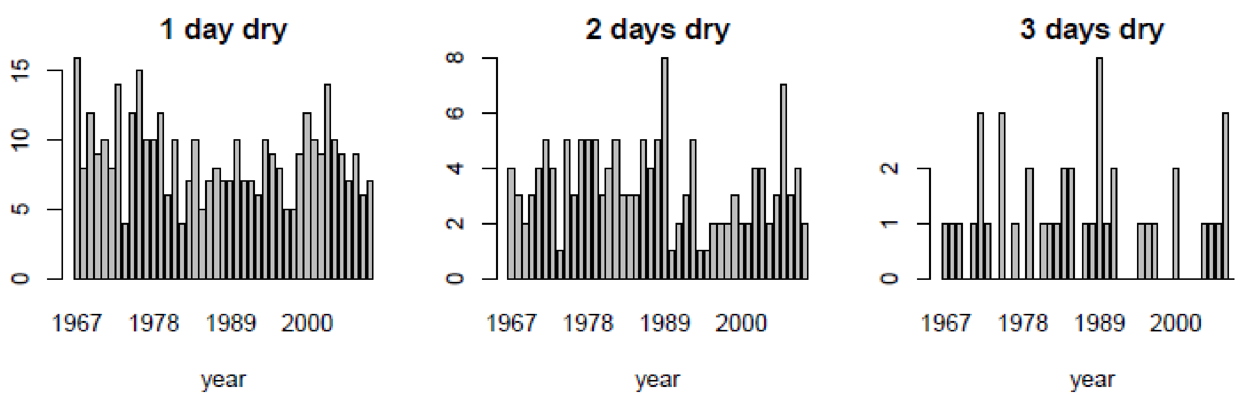


Figure 10: The number and length of dry spells in monsoon period in Khumaltar.

3.1.2.2 Trend analysis

The results from linear trend analysis and the Mann-Kendall statistical test are shown below:

a. Linear trend analysis per month

A linear trend line was plotted through the graphs with monthly rainfall sums. The slopes of this line can be found in table 16. There is no clear identifiable trend. Three stations have on average an increasing trend, and three stations have on average a decreasing trend (Naikap not taken into account). The signal for the increasing trend is somewhat stronger than the decreasing signal. By averaging the trends over all months and all stations (leaving out Naikap), an increasing trend of 0.06 is found, implying that rainfall on average had increased.

Table 16: Slope of trend line through monthly sum of rainfall

Month	Khumaltar	TIA	Godawari	Panipokhari	Changu	Sankhu	Naikap
January	0.02	-0.03	-0.15	-0.11	0.02	0.15	-0.15
February	0.12	0.12	0.27	0.07	-0.19	-2.01	-0.72
March	0.28	0.08	-0.07	-0.22	0.17	-0.31	1.28
April	0.04	0.40	0.46	0.11	-0.06	-0.29	-3.18
May	1.00	0.88	1.32	0.55	1.12	1.30	-5.60
June	-1.30	-0.46	0.55	0.60	2.77	-3.59	-8.97
July	-2.03	0.12	1.23	1.45	0.93	-0.61	-21.26
August	-0.08	1.64	0.63	2.15	-2.06	1.19	-4.28
September	-0.18	0.87	0.90	1.66	-0.84	-0.38	4.45
October	-0.51	-0.80	0.19	-0.55	-1.85	-1.16	-0.40
November	0.04	0.04	0.14	-0.14	-1.02	-0.11	-0.55
December	-0.10	-0.00	0.28	-0.10	-0.10	-0.12	-3.33

Rainfall decreased mainly in the months October to March which is the period for winter rainfall implying decrease in winter rainfall. Increase in rainfall took place from April to September, except for June. June is the month with the onset of monsoon. This average decrease in June can imply that the onset of monsoon had shifted to later in the season.

Changunarayan had a strong increase in rainfall in June, probably; monsoon had shifted to earlier in the season in this site. In May, all stations except Naikap had an increase in rainfall. The R^2 value for all months for all stations is given in table 17. On average (ignoring Naikap) the highest R^2 values, so the lowest variation, is found in the pre-monsoon and monsoon months May, June, July and August.

Table 17: R^2 trendline through monthly sum of rainfall

Month	Khumaltar	TIA	Godawari	Panipokhari	Changu.	Sankhu	Naikap
Jan.	0.00	0.00	0.01	0.01	0.00	0.01	0.00
Feb.	0.01	0.01	0.04	0.00	0.01	0.00	0.03
Mar.	0.03	0.00	0.00	0.01	0.01	0.02	0.04
Apr.	0.00	0.01	0.04	0.00	0.00	0.01	0.08
May	0.08	0.04	0.12	0.01	0.07	0.04	0.12
Jun.	0.03	0.00	0.00	0.00	0.12	0.08	0.19
Jul.	0.07	0.00	0.01	0.02	0.01	0.00	0.36
Aug.	0.00	0.06	0.00	0.06	0.04	0.01	0.04
Sep.	0.00	0.02	0.01	0.03	0.01	0.00	0.04
Oct.	0.01	0.04	0.00	0.01	0.05	0.05	0.00
Nov.	0.00	0.00	0.02	0.01	0.06	0.01	0.35
Dec.	0.00	0.00	0.03	0.00	0.01	0.01	0.22

b. Mann-Kendall trend analysis per month

A Mann-Kendall trend test was conducted for every month over the complete available period per station. The null hypothesis H_0 was that there was no trend, the two-sided alternative hypothesis H_a was that there was an increasing or decreasing trend.

Table 18 gives an overview of all the Tau and P-values for every month for every station. In total only four significant trends were found: an increasing trend in May in Godawari (Sen's Slope: increase in rainfall of 1.54 mm in May every year), a decreasing trend in Sankhu in February (Sen's Slope: -0.36, implying a decrease in February rainfall of 0.36 mm/year) and two decreasing trends in July and November in Naikap. Taking into account here that for Naikap station only 13 years of data is available and that it is not valuable to draw any conclusion concerning climate from this short time series. For November in Naikap, only rainfall in the first two years of the data series is measured, for all the other years November was completely dry.
As overall conclusion, it can be drawn that there is no clear and significant pattern recognizable that proofs that rainfall distribution over time had changed (considering the six stations with a long enough time series). This means that the possible impacts of a change in rainfall timing, as was drawn in the previous subsection, are very uncertain. This conclusion only holds on a monthly level, it might be that rainfall distribution within the months had shifted.

Table 18: Kendalls' Tau and two sided P-value per month for Khumaltar

Month	Khumaltar		TIA		Godawari		Panipokhari		Changu.		Sankhu		Naikap	
	Tau	P-value	Tau	P-value	Tau	P-value	Tau	P-value	Tau	P-value	Tau	P-value	Tau	-value
Jan.	-0.071	0.514	-0.132	0.224	-0.049	0.607	-0.203	0.081	-0.058	0.624	-0.052	0.653	-0.055	0.850
Feb.	0.009	0.942	-0.053	0.633	0.156	0.097	-0.049	0.671	-0.238	0.036	-0.177	0.122	-0.228	0.320
Mar.	0.116	0.281	-0.001	1.000	-0.020	0.831	-0.052	0.653	-0.027	0.818	-0.010	0.942	0.231	0.300
Apr.	0.067	0.537	0.119	0.274	0.178	0.052	-0.035	0.762	-0.206	0.066	0.020	0.865	-0.154	0.502
May	0.194	0.069	0.134	0.217	0.295	0.001	0.095	0.404	0.144	0.200	0.123	0.276	-0.194	0.392
Jun.	-0.112	0.295	-0.037	0.737	0.035	0.705	-0.016	0.894	-0.155	0.168	0.209	0.062	-0.256	0.246
Jul.	-0.172	0.107	0.000	1.000	-0.040	0.664	0.004	0.981	-0.028	0.809	0.042	0.717	-0.436	0.044
Aug.	0.016	0.892	0.154	0.153	-0.030	0.746	0.166	0.140	0.104	0.358	-0.139	0.217	-0.154	0.502
Sep.	-0.052	0.630	0.076	0.488	0.047	0.615	0.112	0.321	-0.046	0.690	-0.096	0.397	0.154	0.502
Oct.	-0.007	0.958	-0.163	0.132	0.057	0.535	-0.071	0.537	-0.127	0.260	-0.136	0.226	0.080	0.757
Nov.	0.012	0.928	-0.022	0.856	0.133	0.183	-0.139	0.256	-0.100	0.422	-0.219	0.051	-0.496	0.049
Dec.	-0.033	0.776	0.026	0.829	0.188	0.058	-0.053	0.660	-0.100	0.422	-0.118	0.326	-0.374	0.133

c. Seasonal Mann-Kendall trend analysis

The Seasonal Mann-Kendall (SMK) test was applied to monthly sums of the rainfall data for the complete available period. First an autocorrelation check was carried out. The autocorrelation function was applied to the data of Khumaltar. The correlation for different time lags is shown in figure 11 below where the blue lines are the boundary for significant autocorrelation ($\alpha = 0.01$).

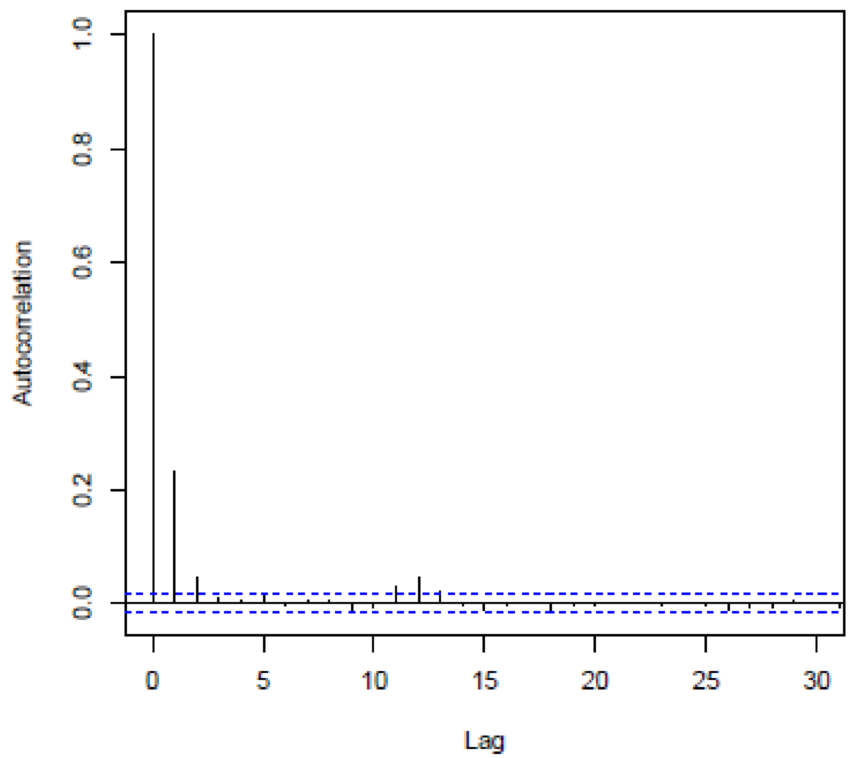


Figure 11: Autocorrelation between lags in days of rainfall residuals for Khumaltar station.

Obviously time lag 0, so day n, depends completely on day n. The rainfall number of day n depends much less on the rainfall of the day before, day n-1, although there is still a significant relation. Rainfall on day n also still depends on rainfall of day n-2. Further time lags do not lead to any significant result anymore. Further research in the autocorrelation function learns that the data is especially autocorrelated during monsoon period, while outside monsoon period there is hardly any autocorrelation. But this autocorrelation is on a daily basis; the Seasonal Mann-Kendall test is conducted with monthly values and seems therefore free of correlation.

SMK-test showed that none of the data series found a significant trend. An overview of the SMK testresults are shown in table 19. Because all the P-values were above the significance level ($\alpha = 0.05$), the H_0 hypothesis cannot be rejected: there was no significant trend. These findings confirm the conclusion of Shrestha *et al.* (2000) that there is no significant long term trend in rainfall.

Table 19: Kendall Tau and significance of Seasonal Mann- Kendall

Station	Kendalls Tau	P-value (2 sided)
Khumaltar	0.00	0.996
TIA	0.01	0.703
Godawari	0.01	0.801
Panipokhari	0.02	0.514
Changunarayan	-0.02	0.633
Sankhu	-0.02	0.594
Naikap	-0.05	0.324

Summary
There is no clear increase visible in the number and length of dry spells, the number of rainy days and the daily intensity index. There was much spatial variation. An increase of events with > 50mm of rainfall was found for most stations. There were no significant (based on Seasonal and ordinary Mann-Kendall test) increasing or decreasing trends in total rainfall.

3.1.3 Evapotranspiration

PAN-evaporation data (ETpot) was available for a short time period (10 years of data for Khumaltar and for TIA 16 years) and further had large and consistent data gaps. The data series of both do not meet WMO (1966) criterion for a robust climate analysis. For the analysis, Penman-Monteith (PM) evapotranspiration for a reference crop (ETref) was calculated, and the difference between PAN-evaporation and the Penman-Monteith evapotranspiration methods was studied. A linear trend line was drawn through the PAN-evaporation and the Penman-Monteith evapotranspiration to find out if there was an increase or decrease visible in the last years and some indices were calculated.

The overlapping period for PAN-evaporation and PM-evapotranspiration was 2002-2009 for Khumaltar and 1999-2009 for TIA. Most of the differences (PM evapotranspiration– PAN evaporation) were between -6 and +6 mm per day, and this difference went up to a maximum of 16.4 mm/day in Khumaltar. These are relatively large differences, if it is considered that average daily PAN-evaporation during monsoon was 4.3 mm (see Table 20). Noticeable is that there was clear seasonality visible in the differences, see figure 12 for Khumaltar (the differences for TIA follow the same pattern). During summer season, PM's ETref was higher, while during winter season the PAN ETpot had the highest value of both. Striking is what the differences are not normally distributed; the differences are larger when PAN-evaporation is higher than PM-evapotranspiration. For the days with the highest differences, it is always the PAN-evaporation having a much higher value than the PM-evapotranspiration.

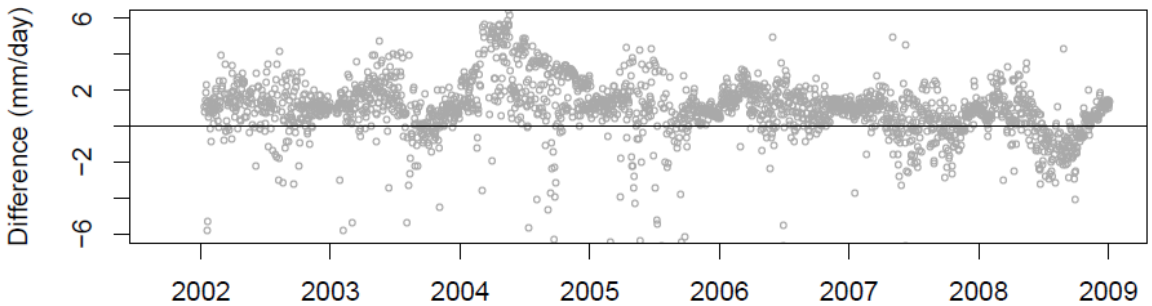


Figure 2: Difference between daily PM-evapotranspiration and PAN-evaporation.

The great differences between both methods that were found should raise awareness for the rest of this section that the data (whether ETpot or ETref) was uncertain and maybe unreliable. Table 24 gives the correlation between the two different methods. This correlation was higher for Khumaltar than for TIA.

3.1.3.1 Indices

With the available ETpot data and the obtained ETref data, two indices were calculated for evapo-transpiration; the number of days that evaporation exceeds rainfall and the evaporation sum and mean per season.

a. Number of days that evaporation exceeds rainfall in monsoon period

With the PAN-evaporation numbers of TIA and Khumaltar estimation could be made of the daily evaporation during monsoon period. Table 20 shows the average daily evaporation for both stations.

Table 20: Average evaporation in mm/day

Period	Khumaltar	TIA
15 June – 15 July	4.5	4.5
16 July – 15 August	4.9	4.4
16 August – 15 Sept	3.6	4.0
Average	4.2	4.3

As a threshold level, 4.3 mm evaporation per day is assumed. For all seven stations for all years the number of days that evaporation exceeded rainfall was counted during monsoon period. The slope of the trend line is given in table 21.

Table 31:Slope of trend line through number of days that evapotranspiration (ET) exceeded rainfall (P)

Station	ET > P	R^2
Khumaltar	0.096	0.03
TIA	0.004	0.00
Godawari	0.133	0.12
Panipokhari	0.023	0.00
Changunarayan	0.177	0.08
Sankhu	0.124	0.03
Naikap	1.214	0.43

The slopes in table 21 were positive for all seven stations, implying that the number of days that potential evapotranspiration exceeds rainfall had increased for all seven stations. The signal was sometimes very weak, for example for TIA where a slope of 0.004 (andR^2=0.00) almost is a horizontal line. It is still remarkable that all seven stations showed the same direction. Naikap had the strongest signal, probablybecause this station had only 13 year of data.

In this analysis, ETpot was used, potential evapotranspiration. In an agricultural field potential evapotranspiration will only occur if there are no water limitations. This analysis might thus give an overestimation of the actual evapotranspiration that is taking place in the field. However, if the number of days that evaporation exceeds rainfall had increased, several impacts are potential. Rain-fed agriculture might need additional irrigation, or irrigation should start earlier after monsoon due to soil moisture deficit (Shukla *et al.*, 2011). Increase incidences of drought stress which leads to yield decline (Allen *et al.*, 1998) and decreases the disease resistance of the crop (Chakraborty and Newton, 2011). If the trend as given in table 21 continues, the peri-urban areas in the valley face a serious threat in combination with the declining water availability in the areas due to the rampant water mining as a result of the strong population growth and urbanization.

b. Evaporation sum per season

For the seasons as defined by Thapa and Joshi (2011), ETref sums and mean were calculated. Disadvantage of the ETref data was that it was only available for a really short period. The average evapotranspiration per season was calculated to make the effect of data gaps smaller.

The slope of the trend line is given in table 22. As visible in table 22, it seems that evapotranspiration had only increased in summer season (June until August), and decreased in all the other seasons. This conclusion should be taken really carefully, because there was missing data and these numbers were only based on a short period of time. Still this signal is visible in both stations and for both the sum and the mean, which gives at least an indication.

Table 42: Slope of trend line through seasonal PM-evapotranspiration sums and means

Season	Khumaltar sum	Mean	TIA sum	Mean
Winter	-1.316	-0.024	3.129	-0.024
Spring	-5.682	-0.052	-4.967	-0.025
Summer	1.910	0.021	6.176	0.011
Fall	-0.368	-0.004	0.4547	-0.003

3.1.3.2 Trend analysis

A linear trend line was drawn through 41 and 40 year of ETpot data for respectively Khumaltar and TIA. These data contained large gaps. Also a linear trend line was drawn through Penman-Monteith ETref -calculations, for which 10 and 16 year of required wind data was available for respectively Khumaltar and TIA.

The slopes of both trend lines can be found in table 23. The low slope values show that neither increase nor a clear decrease in ETpot and ETref took place over the period given in the table.

Table 5: Slope of linear trend line through evapotranspiration for given period

Station	Period	ETpot	R2	Period	ETref	R2
Khumaltar	1968– 2008	3.55*10-4	0.01	1999-2008	-8.65*10-5	0.01
TIA	1969– 2008	-1.39*10-4	0.01	1993-2008	-2.74*10-5	0.00

Since evapotranspiration depends on temperature, and a significant increase in temperature was found, an increase in evapotranspiration would have been expected.In literature on climate, it is found more often that PAN-evaporation did not have the expected increase. This phenomenon is referred to as 'the Evaporation Paradox' (Roderick and Farquhar, 2002), and has been found in among others India, Venezuela, China, Italy, Australia, Japan, Thailand, New Zealand and Canada (Cong and Yang, 2008). Research in India by Chattopadhyay and Hulme (1997) showed not only that PAN-evaporation had decreased over the years, but that the same holds for reference evapotranspiration ETref. With regression analysis Chattopadhyay and Hulme (1997) showed that the increase in relative humidity had the strongest correlation with the decrease in ETpot. Other explanations given for 'the Evaporation Paradox' are a decrease in wind speed due to monsoon change (Cohen *et al.* 2002) and decreasing sunlight due to increases in cloud cover (Peterson *et al.* 1995).

Table 24 gives the Pearson's correlation coefficient between different climatic variables. The correlation coefficientsdiffered strongly for the two different stations, and it was not possible to say which of the explanations, or a combination, explained the steadiness of the evapotranspiration in this case. It is still in debate what the effect of steadiness or decrease in ETpot and ETref is on actual evapotranspiration ETa (Cong and Yang, 2008). For agricultural crops, the ratio ETa/ETpot is important and determines to a large extent the crop growth.

Table 6: Pearson's correlation coefficient between different variables for Khumaltar and TIA

Khumaltar	PAN	PM	T_{air}	Wind	Humidity
PAN	1				
PM	0.358	1			
T_{air}	0.418	0.490	1		
Wind	0.228	0.558	0.152	1	
Humidity	-0.085	-0.410	0.073	-0.186	1
TIA	**PAN**	**PM**	**T_{air}**	**Wind**	**Humidity**
PAN	1				
PM	0.312	1			
T_{air}	0.243	0.725	1		
Wind	0.183	0.467	-0.051	1	
Humidity	-0.241	-0.749	-0.444	-0.399	1

Summary

Substantial differences were found between PAN-evaporation ETpot and Penman-Monteith evapotranspiration ETref. The quality of the data is not optimal to draw any robust conclusion. An increase was found for number of days that evaporation exceeds rainfall during monsoon for all stations. This has implication for water availability in agriculture, and might lead to yield decline, putting pressure on food security.

The seasonal analysis gave the impression that evapotranspiration had only increased in the summer season, and decreased in all the other seasons over the past few years. Linear trend analysis through both ETpot and ETref showed, against the expectation, no increase. This phenomenon is in literature known as 'The Evaporation Paradox'. It is unknown what the effect is on actual evapotranspiration.

For the evapotranspiration section, only data of poor quality (PAN-evaporation) or for a short time period (Penman-Monteith evapotranspiration) was available. The data series of both do by far not meet the criterion of the WMO (1966) that the length of the data should at least be around 40 years to do a robust climate analysis. In the overlapping period where data was available for both ETpot and ETref, the data showed non-negligible differences. The analysis of these data could only raise some suspicions, but it was impossible to draw any firm conclusions.

Warmer temperature increases both the water holding capacity of the atmosphereand the evaporative demand, i.e. potential evapotranspiration. Despite an increase inpotential evapotranspiration, the reduction in soil moisture storage decreases the rate ofactual evapotranspiration.

3.2 PERCEIVED CHANGES IN CLIMATE

The study areas were peri-urban areas of Kathmandu valley and were under rapid rural to urban transition. The study captured the perception of local people on change in climatic conditions based on those attributes of climate that play key role in agricultural system as it is either the primary or secondary occupation of most of the people resided across the sites.

3.2.1 Perceived Changes in Rainfall Pattern

The overall average trend for Nepal indicates that the annual average rainfall over Nepal is decreasing at the rate of 9.8 mm/decade (MoPE, 2004). The changes in the rainfall pattern perceived by the local people across the study sites were captured based on the perceived changes in the total amount of rainfall, number of rainy days, onset and cessation of monsoon and amount of winter rainfall as these direct the decisions made by the local farmers for selecting cropping pattern. The respondents were asked to base their perception of change on rainfall attributes over time period of past four decades- prior to 1980s, 1980s, 1990s and 2000s.

3.2.1.1 Total Amount of Rainfall

The perception of the local people on the total amount of rainfall was based on the observed changes in the amount of water retained in the farm lands, available flow of water in the rivers and irrigation canals, water yield at the springs sources, timely completion of transplanting of rice during monsoon and on extreme conditions or events that caused the greatest hardships in terms of water management or occurrence of disaster.

All respondents in Dadhikot, Matatirtha and male respondents in Lubhu perceived a continued decrease in the total amount of rainfall starting since 1990s which further declined in 2000s. However, they perceived 2010 onwards the situation has been better and some even considered that the climate was taking its original trend. In Dadhikot, they recalled that till 1990s, sufficient water could be retained in the farms during first week of *Baisakh* (mid April) which favored the rice transplantation to begin by *Jestha* (May/June). In Lubhu, majority of female respondents perceived a sudden and drastic decline in the total amount of rainfall. However some female respondents in Lubhu noticed cyclic nature of rainfall. They explained even prior to 1980s the rainfall was much lower with extremely dry years. The period of 1980s and prior to that was considered asgood rainfall decades but from 1990s, the total amount of rainfall started decreasing and 2000 onwards, it had reduced in large scale.

In Jhaukhel VDC, the female respondents perceived no change in the total amount of rainfall. Contrastingly the male respondents in the VDC perceived a consistent increase in the total amount of rainfall after 2000s with 2009 as exception. As per them, 1983 was good rainfall year while 1979 and 1982 were recalled as dry years. Majorities of respondents in Jhaukhel VDC agreed that there has been good rainfall for the last 8 to 10 consecutive years (2009 being an exception). This allowed them to complete rice sowing within June which traditionally used to be cultivated only during July. The magnitude of perceived changes in the total amount of rainfall across all the sites is given in table 20.

In general, the change in the rainfall pattern was perceived to be more stressful than the changes in the total annual rainfall. Very recently starting from mid 2000s, unusual changes in the pattern of rainfall were noticed making rainfall no more predictable. The respondents were also surprised with the incidences of intense rainfall in one part of area and remaining completely dry in other part.

Table 20: Perceived change in the total amount of rainfall over time

Site	Sex	2000s	1990s	1980s	Prior to 1980s
Lubhu	Male	-2	-1	0	0
	Female	-2	0	0	0
Matatirtha	Male	-2	-1	0	0
	Female	-2	-1	0	0
Jhaukhel	Male	2	0	0	-1
	Female	0	0	0	0
Dadhikot	Mix	-2	-1	0	0

The perceived changes are based on scale, as: Large increase (2), Small Increase (1), No change (0), Small decrease (-1), Large decrease (-2).

(Source: Field survey, 2011)

3.2.1.2 Number of Rainy Days

The practice of relating the rainfall events to traditional rituals celebrated annually was common in the study sites and those commonly linked with rainfall events were *Krishna janmaastami* celebrated during August/September (*Bhadra*), *Shiva Ratri* that falls in the month February/March (*Falgun*). Similarly *Nag Panchami jhari, Shaune jahri, Shora Shraddha Jhari, Nauratha Jhari, Maghe jhari* were associated with persistent rainfall. The term *Jhari* indicated persistent rainfall lasting for days.

Across the study sites, the traditionally established belief was that prior to 1980s, the date on which winter rain starts during December/January (*Poush*) and January/ February (*Magh*), used to be the same date to start rain on June/July (*Ashad*) and July/August (*Shrawan*) respectively. However the respondents across the sites, perceived this trend was disturbed from 1980s. Female respondents in Matatirtha and male in Lubhu considered a gradual decline in the total number of rainy days to have started in 1990s. The male respondents in Matatirtha VDC though perceived similar trend in 1990s, they felt there was larger decrease after 2000s. The perceived change in the number of rainy days in Dadhikot VDC and female respondents in Lubhu was same as those perceived by male respondents in Matatirtha. However the male respondents of Jhaukhel had a different view and perceived an increasing number of rainy days since 2000s providing much relief over the dry years prior to 1990s however the female respondents of the same site felt the small decline in the number of rainy days started in 1990s and continued to decline in the same rate in 2000s.

Though there was variation in the perceived magnitude of decline in the number of rainy days, in general the respondents perceived this trend gradually got disturbed since 1990s. The situation further got disturbed in 2000s since when there have been a further decline in the number of rainy days (except in Jhaukhel) making the rainfall erratic and unpredictable. The details of magnitude of perceived changes in number of rainy days is given in table 21.

Table 71: Perceived Changes in the Number of Rainy Days

Site	Sex	2000s	1990s	1980s	Prior to 1980s
Lubhu	Male	-1	-1	0	0
Lubhu	Female	-2	-1	0	0
Matatirtha	Male	-2	-1	0	0
Matatirtha	Female	-1	-1	0	0
Jhaukhel	Male	1	0	-1	-1
Jhaukhel	Female	-1	-1	0	0
Dadhikot	Mix	-2	-1	0	0

The perceived changes based on scale, as: Large increase (2), Small Increase (1), No change (0), Small decrease (-1), Large decrease (-2).

(Source: Field survey, 2011)

3.2.1.3 Changes in Monsoon Rainfall

June- September 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 rainfall, which enters the country from eastern part of Nepal (Rai *et al.* 2011).Normally, in Kathmandu, the onset of the monsoon occurs on the 12th June and retreats on the 21st September respectively (Department of Irrigation, Hydrology and Meteorology, 1977 as cited in Nayava, 1980).

The monsoon rainfall is very important from the agricultural point of view, because it is the main season for planting paddy.Changes in monsoon rainfall was related to the timely completion of paddy transplanting in the area, availability of water in irrigation canals and standing water in the paddy fields at the time of weeding and soil moisture retention at the time of harvesting of the crop. Similarly, onset and strength of monsoon was related to the puddling of the soil in the fields for starting rice transplantation whereas the cessation of monsoon was characterized with the occurrence of short intensive rainfall and usually monsoon rain used to stop prior to *Dashain* celebrated in the month of September- October.

Respondents in Jhaukhel perceived monsoon rainfall in Jhaukhel used to be very less till 1990s. Rice transplantation was mostly started only in the second week of July (*Shrawan*). Since the decade of 2000, they felt that the monsoon rainfall started to be generous. The ease in the rice cultivation was agreed upon by the female respondents however they perceived declining pre-monsoon rainfall in 2000s, affecting the germination of the rice seeds. They perceived the monsoon onset to be delayed by around15 days but once the monsoon got started, it has been more dependable since 1990s while no change in the off-set of monsoon was perceived.

Female respondents in Lubhu considered the decline in the amount of monsoon rainfall since mid 2000s whereas male respondents perceived small decline started since 1990s and felt more decline in monsoon rainfall since 2000s. Some respondents felt that the change in the rainfall pattern was more stressed because of the changes in the onset of monsoon and total rainfall. They felt persistency in the rainfall has been changed and the intense short duration rain that was considered a characteristic rainfall pattern occurring in September indicating offset of monsoon had started to occur even during June July.

The perception of female respondents in Matatirtha VDC was similar to that of female respondents in Lubhu while male respondents in Matatirtha felt the small decline started in 1990s and continued to decline at same rate in 2000s. Prior to 1980s, monsoon used to be persistent in Dadhikot which was elaborated through a local statement saying "*Shrawan ma aakash ma euta tara dekhiyo vane, ek lagh muri anna ghattcha*" indicating the cloudy and rainy monsoon nights and the relation of such weather to the crop yield. However, the gradual decline in the monsoon rain was noted by 1990s, and decline was profuse after mid 2000s.

In addition to the disturbance in monsoon period, the farmers also perceived the disturbances in monsoon rainfall pattern making rainfall intensive and erratic and decline in the number of pre-monsoon rainfall which was evident in terms of drying of paddy seedlings, delay in the sowing of maize and need of irrigation in the newly germinated crop seedlings to protect them from drying.The preparation of rice nurseries particularly in rain-fed farming practice depends on the pre-monsoon rainfall starting around a month ahead of transplanting and therefore the delay in monsoon can damage the seedling. The weak monsoon with longer dry spells in between can affect the puddling of soil needed for the transplanted paddy.

In general, the onset and cessation of monsoon was perceived to be unpredictable and therefore the respondents explained about the needs of alternative irrigation among which using electric motor pumps to lift water from the nearby rivers or ground water from dug wells or tube wells or springs for timely transplantation of rice was being the most common option.

3.2.1.4 Persistency in Rainfall and Dry Spells

Farmers recalled the occurrences of persistent rainfall (*Jhari*) lasting over days and nights prior to 1980s in such a way that they could not leave "*Ghum*" (folded mat made from bamboo strips and leaves and used by farmers as umbrella) for a long time and remembered the incidences of occurrence of Lice in *Ghum* which they locally called "*Ghum ma Likha Parthyo*". This was a regular event during monsoon and termed as "*sat din sat rat jhari*" (rainfall lasting for days and nights for seven consecutive days) which as per the respondents has remained only in their memory. *Shaune jahri* during July/August, *Shora Shraddha Jhari* during September, *Nauratha Jhari* during September/October, *Maghe jhari* during January/February were recalled as common incidences prior to 1980s.

Besides, they also remembered occurrence of long dry spells; among which 1952, 1954 were some they could recall. Prolonged dry seasons may carry a high risk of crop failure for rain-fed production (FAO, 2008). Across all sites, majorities of the respondents agreed there was progressive increase in the dry spells exceeding 7 days during monsoon since 1990s. Male respondents in Lubhu and female respondents in Matatirtha perceived the increasing dry spells as relatively recent phenomenon starting only after mid 2000s and felt it was increasing over years. An elderly farmer in Lubhu mentioned the farmers in Lubhu wished for a lighter and persistent rain so that the agricultural labor could be distributed sufficiently in the fields. With the changes in persistency in rainfall, they perceived the occurrence of intense rain for short duration which compelled the farmers to finish rice transplantation from the same shower as occurrence of long dry spells following the shower was getting common which would then result delayed rice transplantation. This caused acute increase in the demand of the labor for timely accomplishment of paddy transplantation making an apparent labor shortage during rice cropping season.

In Jhaukhel, the persistence in the monsoon rainfall was perceived to have improved and been better compared to the 1980s and 1990s. They considered dry spells as regular event but has been less stressful to them as compared to 1980s. In Dadhikot, farmers agreed on the less persistency of monsoon in 1990s but the situation improved in 2000s (table 22).

Table 22: Persistence in monsoon rainfall

Site	Sex	2000s	1990s	1980s	Prior to 1980s
Lubhu	Male	-2	0	0	0
Lubhu	Female	-1	0	0	1
Matatirtha	Male	-2	-1	0	0
Matatirtha	Female	-1	-1	1	2
Jhaukhel	Male	1	0	0	-1
Jhaukhel	Female	1	1	0	0
Dadhikot	Mix	1	-1	0	0

The perceived changes based on scale, as: Large increase (2), Small Increase (1), No change (0), Small decrease (-1), Large decrease (-2).

(Source: Field survey, 2011)

3.2.1.5 Amount of Winter Rainfall

Westerly wind is responsible for the winter rainfall in Nepal and has maximum strength in western Nepal which decreases as it progresses towards east (Ichiyanagi *et al.* 2007). Kathmandu valley lies in the central part of the country. In the study sites, the respondents held a common opinion of decreased amount of winter rainfall as compared to the period prior to 1980s. Winter rain recalled as *Maghe jhari* occurring during the month of January/ February used to be very common till 1980s. In addition to the change in the amount of winter rainfall, the participants in Dadhikot opined that winter rainfall till1980s used to be lighter but persistent thus recharging groundwater and maintaining soil moisture for cultivation of wheat, potato and vegetables.

In Lubhu, farmers perceived a sudden and drastic decline in the winter rainfall in 2000s. The decline in winter rain was perceived as a major cause of shifting towards low water demanding crops in the areas where supplementary water sources could be arranged while the land was left fallow in the areas with no alternative water source. In Matatirtha, male respondents perceived the small decline in winter rain 1990s onwards while the female respondents felt it to have started only in 2000s. In the up-hill side of this VDC, consistent winter rainfall used to be followed by snowfall prior to 2000s but in 2000s such incidence was noticed to be very rare. In Jhaukhel, people perceived only small decline in winter rainfall in 2000s.

The participants across the sites considered the decline in winter rainfall (table 23) as a major cause of drying up of natural sources of water.

Table 23: Perceived changes in the amount of winter rainfall

Site	Sex	2000s	1990s	1980s	Prior to 1980s
Lubhu	Male	-2	0	0	0
Lubhu	Female	-2	0	0	0
Matatirtha	Male	-1	-1	0	0
Matatirtha	Female	-1	0	0	0
Jhaukhel	Male	-1	0	0	0
Jhaukhel	Female	-1	0	0	0
Dadhikot	Mix	-2	-1	0	0

The perceived changes based on scale, as: Large increase (2), Small Increase (1), No change (0), Small decrease (-1), Large decrease (-2).

(Source: Field survey, 2011)

3.2.1.6 Occurrence of Extreme Events

The perceived changes in occurrence of extreme rainfall events were interpreted based on the changes observed in the incidences of water logging on plants and the incidences of rainfall hazards. The male respondents in Jhaukhel perceived no change in the occurrence of such extreme events whereas the female respondents in the same area perceived small increase in the occurrence of such extreme events in 2000s. While both the respondent groups did not perceive increase in the incidences of crop inundation duration, female respondents felt there was accelerated erosion of soil from crop fields. This however was also felt to have increased as a result of rampant sand mining in Jhaukhel.

People of Dadhikot perceived a decrease in the occurrence of extreme rainfall events. The incidences of damaging floods, landslides and soil erosion had never been problems to this site over the past 40 years. Respondents from Lubhu recalled the flood in Dovan River in the year 1981 and 1993 damaging the *Dovan Shringarishi Rajkulo*. They also perceived small decline in the occurrence of extreme rainfall events since the flood events in 1990s. Similarly people of Matatirtha perceived a decline in the occurrence of extreme rainfall events. They recalled the disastrous landslide in 2002 killing 16 people and washing away several houses. However, they felt that the area is not prone to water induced disasters and no incidences of disastrous flood and landslide was experienced in the recent years.

3.2.2 Perceived Changes in Temperature Pattern

The changes in temperature perceived by the people were based on the indicators related to the changes in temperature such as changes in the duration of summer and winter seasons, extreme hot and cold days and the changes in the occurrence of fog and frost.

3.2.2.1 Duration of Summer and Winter Season

The respondents related the seasonal cycle of summer and winter to the traditional rituals. *Shree Panchami* celebrated during the month of February/March was symbolized as the day for the onset of summer while winter was believed to start since *Naag Panchami* celebrated in the month of

July/August. There was an unequivocal opinion across all the sites concerning the increasing duration of summer season and decrease in the duration of winter season. While the male respondents in Jhaukhel experienced a gradual increase in summer duration since 1980s, female felt gradual increase over a period from 1990s. In Dadhikot respondents experienced a small increase prior to 2000 but large increase in the 2000s. Male respondents in Lubhu and Matairtha experienced the progressive increase in duration of summer after 1990s and considered the increasing rate was lower in 1990s but higher in 2000s. Female respondents in both Lubhu and Matatirtha felt that the increase in the duration of summer month started only 2000s onwards. They perceived that if the summer season duration continued to expand in the perceived rate, winter season would be vanished in next few decades. The scale of perceived changes in summer duration is provided in table 24.

Table 24: Perceived changes in summer duration

Site	Sex	2000s	1990s	1980s	Prior to 1980s
Lubhu	Male	2	1	0	0
Lubhu	Female	1	0	0	0
Matatirtha	Male	2	1	0	0
Matatirtha	Female	1	0	0	0
Jhaukhel	Male	1	1	1	0
Jhaukhel	Female	1	1	0	0
Dadhikot	Mix	2	1	1	0

The perceived changes based on scale, as: Large increase (2), Small Increase (1), No change (0), Small decrease (-1), Large decrease (-2).

(Source: Field survey, 2011)

People of Dadhikot experienced small decrease in duration of winter season in 1980s and 1990s while in 2000s, they perceived large decrease. Male respondents of Jhaukhel, considered gradual decrease in duration of winter season since 1980s and female perceived small decrease in 1990s and large decrease in 2000s. Similarly, female respondents in Matairtha and both male and female in Lubhu considered small decrease in winter duration started from 2000s whereas male in Matatirtha opined the small decrease in winter duration started in 1990s.

Majorities of the respondents agreed upon the increasing duration of summer and decreasing duration of winter (table 25). Furthermore, they felt the spring seasons that used to be distinct starting around *Falgu Poornima* (full moon day in the month of March) and autumn seasons bringing festive weather during *Dashain* and *Tihar* (festivals celebrated during the month of October-November) were no more distinct. In spring, they felt that the days were much hotter giving feeling of summer. Similarly they felt autumn started very late and though the morning were colder the days were as hot as in summer. Prior to 1980s, people felt that winter used to begin by the second week of October(*Kartik*) and the peak winter season months used to extend from November second week to mid February (*Mangsir* to *Magh*). In 2000s, they felt winter began much later and ended earlier. Even during the months considered as peak winter, they noticed that though the days were cold during the morning, temperature gained higher peak by the afternoon giving no more feeling of winter.

Elaborating the change in temperature pattern, the participants across the sites shared their experienced of unexpectedly warmer winter afternoons on days with chilling mornings. Such incidences were recalled to have created discomfort due to the warm clothes worn based on the chills in the morning. Some of the participants explained the warmth of sun during winter which used to be appealing has no more remained such.

Table 25: Perceived change in winter duration

Site	Sex	2000s	1990s	1980s	Prior to 1980s
Lubhu	Male	-1	0	0	0
Lubhu	Female	-1	0	0	0
Matatirtha	Male	-1	-1	0	0
Matatirtha	Female	-1	0	0	0
Jhaukhel	Male	-1	-1	-1	0
Jhaukhel	Female	-2	-1	0	0
Dadhikot	Mix	-2	-1	-1	0

The perceived changes based on scale, as: Large increase (2), Small Increase (1), No change (0), Small decrease (-1), Large decrease (-2).

(Source: Field survey 2011)

The perceived increase in temperature was also linked with the increase in the occurrence of mosquitoes. Prior to 1990s, mosquitoes used to start appearing only in May and lasted for shorter period. Mosquitoes then used to be annoyance around the animal shed with surge immediately after rain but much lesser in indoors and thus there was no practice of using mosquito nets. They recalled the decline in the number of mosquitoes by *Qyanti Purni* celebrated during August and used to disappear by *Dashain* in October. However, this gradually changed 1990s onwards. By 2000s, the mosquitoes were observed till February and disappeared very late or even could be seen year round. In Matatirtha, the gradual increase in mosquitoes was experienced only from 2000s which could be due to the cooler climate of the site compared to the other study sites.

People also perceived that despite the temporal increasing trend of temperature within the village, the rise was not as extensive as they felt during their travels to city cores. The expression indicated towards experiences of the urban heat island. The respondents accrued the major causes of rising trend in temperature to deforestation, increased population, and rapid urbanization. The respondents from Dadhikot and Jhaukhel were puzzled despite the drastic decline in polluting industries around their villages after the government decision of displacing the polluting industries out of Kathmandu valley, the temperature in their village still was in increasing trend and perceived this could be the impacts of global climate change.

3.2.2.2 Frequency of Extreme Hot and Cold Days

The increase in the use of fan to avoid the extreme hot days started in 2000s in Lubhu and Dadhikot whereas in Jhaukhel respondents recalled the use of fans by 1990s and became more common in 2000s. Though the use of fan could be impact of socio-economic change, the change in its frequency of use also was found to be closely related to the changing experiences of extreme hot days and nights.

People of Lubhu perceived the increase of the extreme hot days and small decrease in extreme cold days started only in 2000s. They also felt a small increase in the frequency of extreme hot nights and perceived the more number of extreme cold nights as compared to the earlier decades.

In Matatirtha, the respondents felt the hotness during summer days and nights was increasing since mid 2000s. Despite this, they still felt the days and nights were not extremely hot which was also indicated through use of fan not being a common case for them. Similarly they felt the number of coldest days in 2000s were less as compared to the earlier decades. The male respondents in the area did not feel any change in the cold nights but the female respondents felt a decline in their number. They felt the small decline in the numbers of extreme cold days and extreme cold nights and increase in the numbers of extreme hot days and extreme hot nights started in 1990s. While the decline in the number of extreme hot days continued at the same rate as in 1990s, they felt a large decline in the number of extreme cold days and extreme cold nights in 2000s. The respondents in Dadhikot felt the extreme summer temperature in and around Kathmandu valley were being comparable to that of Terai, the warmest ecological region of Nepal.

The female respondents of Jhaukhel felt that the increase in hot days had started earlier in 1990s whereas male perceived it only from 2000s. Both groups of respondents felt numbers of extreme hot nights started to increase from 1990s and agreed to a decrease in extreme cold days and extreme cold nights after 2000s. They considered the increase in brick kilns in Jhaukhel and consequent increase in air pollution after 2000s was a major cause of anomalies in the temperature patterns.

In general, the respondents in the peri-urban areas of Kathmandu felt that extreme hot days incidences were getting more frequent whereas the extreme cold winter were gradually declining (table 26). The respondents remembered the practice of setting up fire called as *Maghe Mudo* during the month of February used to be common till 1980s. However, this practice had almost disappeared across all the sites. They felt the switch from the traditional mudstone built houses to the concrete houses and rapid development of infrastructures and flow of vehicles within the sites as the causes that have been responsible for the perceived changes in the temperature. The change in clothing habit was also identified as a cause for the change in the perceived feeling of reduction in the extreme cold winters.

Table 26: Perceived changes in the number of extreme hot and cold days

Site	Sex	Number of Extreme Hot Days				Number of Extreme Cold Days			
		2000s	1990s	1980s	Prior to 1980s	2000s	1990s	1980s	Prior to 1980s
Lubhu	Male	1	0	0	0	-1	0	0	0
Lubhu	Female	2	0	0	0	-1	0	0	0
Matatirtha	Male	1	0	0	0	-1	0	0	0
Matatirtha	Female	1	0	0	0	-1	0	0	0
Jhaukhel	Male	1	0	0	0	-1	0	0	0
Jhaukhel	Female	1	1	0	0	-1	0	0	0
Dadhikot	Mix	1	1	0	0	-1	-1	0	0

The perceived changes based on scale, as: Large increase (2), Small Increase (1), No change (0), Small decrease (-1), Large decrease (-2).

(Source: Field survey, 2011)

3.2.2.3 Occurrence of Frosts and Fog

The respondents across all four sites perceived a decline in the number of frost days (table 27). During discussions in Lubhu, people felt this decrease became apparent in 2000s. Perceptions of male respondents in Matatirtha and Jhaukhel felt the small decline in frost days started in 1990s which became more intense in 2000s. Female respondents in Matatirtha felt only small decline in the number of frost days starting only in 2000s whereas female respondents in Jhaukhel and all respondents in Dadhikot perceived the decline in frost have started back in 1990s.

Since mid 2000s, there has been a drastic decline in the practice of covering the potato plants by straw as a protection against frost in Dadhikot. Majority of respondents across all the sites admitted the decrease in the frost damage to winter crops as a result of decline in the frost days. However, people explained the increased occurrence of pest due to decreasing winter kills resulting in decreasing the crop yield and compelling them to increase in use of pesticides, mostly in vegetables. Female respondents from Lubhu shared theirobservation of the decline in the occurrence of frost during winter through their perception of the decline in the taste of the green leafy vegetables that they believed was added by frost during winter.

People of Jhaukhel and Dadhikot recalled the occurrence of *Thanto*, icy film formed on the water surface was more common prior to 1980s. This gradually decline during 1990s and stopped occurring in 2000s. They considered that the general trend of occurrence of frost was from the November second week to February second week and then *Kalo Tusaro*, invisible black frost used to occur by third week of February. This was believed to be responsible for morning chills though the afternoon temperature was much higher by this time of the year. The *Kalo Tusaro* used to extend till first week of March but after mid 2000s, they experienced decrease in usual frost while the period of *Kalo tusaro* was extending up to March last week.

Table 27: Perceived change in days with frost during winter

Site	Sex	2000s	1990s	1980s	Prior to 1980s
Lubhu	Male	-2	0	0	0
Lubhu	Female	-2	0	0	0
Matatirtha	Male	-2	-1	0	0
Matatirtha	Female	-1	0	0	0
Jhaukhel	Male	-2	-1	0	0
Jhaukhel	Female	-1	-1	0	0
Dadhikot	Mix	-1	-1	0	0

The perceived changes based on scale, as: Large increase (2), Small Increase (1), No change (0), Small decrease (-1), Large decrease (-2).

(Source: Field survey, 2011)

Similarly, people recalled the occurrence of fog started by second week of September linking the occurrence of light fog in the days prior to Dashain and used to extend till February. They felt the occurrence of fog started much later around second week of October in 2000s and was much lighter by the mid of February. In addition, they also felt the decline in the fog density and decline in foggy duration within a day. The female respondents believed days in the second week of December to second week of Januaryused to be very foggy and the sun used to be visible only after 11 a.m. Owing to this weather pattern, a local statement "*Poush Fas Fus*" was generated indicating passing away of the days of Poush (December/January) by the time fog got faded.

Though the perception on time of declining in occurrence of frost was varied, the study found a general agreement on drastic decline in the number of frost and fog days.

3.2.2.4 Perceived Changes in Wind

The respondents in Dadhikot felt no major change in the regular wind pattern. They felt a small increase in the days with dry intense wind during summer in 2000s whereas in Matatirtha, male respondents felt a decline in both the dry intense wind in summer and intense chill winds in winter during 2000s. However, female respondents in Matatirtha felt only a small decline in the chills winds during winter of 2000s. Contrastingly, male respondents of Lubhu perceived a large decline in the days with intense wind during summer and a small decline in intense chill winds during winter. They considered that the windstorm bringing hail that used to be common phenomenon during the months of March-April when the Newar residents at Lubhu celebrated *Malalaxmi Jatra* and *Karunamaya Bhujya* has remained only an occasional phenomenon in the recent years. They also remembered the incidences of "*Pani Bataash*" occurring prior to *Dashain* during September used to damage rice. But female respondents in Lubhu felt only a small decline in both the summer and winter winds. They also felt that there was reduction in this abnormal wind causing damage to crops and infrastructures. The respondents of Jhaukhel felt the dry and intense wind that used to blow during summer was more frequent in 2000s. Male respondents felt this increase in dry intense wind started in 1980s while female considered it had started only in 2000s. Female respondents also felt a small increase in intense chills blowing in winter. They felt that there was increase in the damage to the crops due to increasing abnormalities in wind pattern. This was a reason for them to switch to shorter rice varieties *Khumal-4*and *Khumal-8* and hybrid maize which were shorter and could sustain the wind more.

3.3 IMPLICATIONS OF CHANGES IN CLIMATIC INDICATORS

The primary information on perceived impacts of climate change in agriculture, water resources and other natural resources and in livelihood of local people were studied through the focused group discussions, semi-structured interviews and informal discussion with local people. Along with these, secondary data were also reviewed to identify the possible impacts of climate change and also substantiate the perception of local people.

The increase in frequency of extreme rainfall events can increase the vulnerability of the water supply system by increasing the maintenance and replacement costs, blockage in water supply tunnels and power failures (DFID, 2004). It is also likely to cause inundation which can affect plant growth by impeding proper root respiration as a result of reduction in oxygen levels in the soil (Ayoade, 2008).

Shrestha *et al*. (2000) found a lack of long term increasing trend in rainfall over Nepal whereas Baidya *et al*. (2008) found a strong increase in annual rainfall in wet days (> 1mm). The study also did not find a clear change in the rainfall trend. However the results indicated towards increased rainfallespecially during pre-monsoon followed by a delayed onset of monsoon and increase towards the end of monsoon (indicated by increasing rainfall in April and May and decrease in June) and a decline in winter rainfall. It is difficult to define impacts for the peri-urban areas in Kathmandu valley based on the results. However strongly possible result for agriculture might be that paddy rice can only be planted later in the monsoon season. Increase in rainfall in pre-monsoon might lead to the possibility to grow different crops. It also might lead to a decrease in irrigation, but the winter-season might need an increase in irrigation as a consequence of decreasing rainfall in those months. This all comes down to a shift in time in water use.

Similarly, an increase in rainy days could enhance pests and pathogens and the risk of vector-borne diseases (Chakraborty and Newton, 2011; Ziska *et al.* 2011). Literatures show the relation of daily rainfall threshold to destabilize a hill slope (Larsen and Simon, 1993; Gabet *et al.* 2004). An increase in extreme events, in defined as > 50mmrainfall per day for this study, can have serious consequences for the peri-urban areas in Kathmandu valley. The peri-urban areas of Kathmandu include hill slopes and are vulnerable to land slide and soil erosion. Urbanization enhances the impacts of increasing extreme events: Sand mining activities make the soil even more vulnerable for landslides and erosion. This finding on the changing rainfall events in Kathmandu can be an important caveat to the ongoing unplanned land pooling and rampant sand mining activities in the peri-urban areas of Kathmandu.

3.3.1 Changes in Agricultural Cropping System

Climate change will affect agriculture through effects on crops; soils; insects, weeds, and diseases; and livestock (IPCC, 1996). Nepalese agriculture is mainly rain-fed and agriculture productions in both rain-fed as well as irrigated areas are being badly affected due to droughts, flooding, erratic rainfall, and other extreme weather events (WECS, 2011). Other changes in agriculture, such as loss of local land races of both crops and domestic animals, changes in cropping sequences, scarcity of water due to drying up of wells, and increasing incidences of disease and pest have also been noticed (Regmi *et al.* 2009). Climate change is not always the main reason behind these changes but may have acted in many cases as a catalyst (Manandhar *et al.* 2010).

Beginning in the mid-1960s, early maturing semi dwarf materials imported from Mexico via India enabled Nepali farmers to switch from their traditional rice-fallow rotation to an intensive production system in which rice and wheat were double-cropped within the same year (Morris *et al.* 1992). Similarly across the study sites, rice-wheat rotation was the most important cropping pattern in the *Khet*(irrigated land) and maize and beans in circulation with mustard as winter crop was common in *bari* (unirrigated terrace land). Other crops cultivated were potato, pulses, garlic, onion, millet, radish and wide range of vegetables.

Peri-urban farmershave been shifting from traditional crops towards cash crops such as mushroom, vegetables and flowers starting around mid 2000s. However, rice has remained the dominating monsoon crop grown in most of *Khet*. The high yielding rice variety Taichung locally called *Taichin* was introduced in early 1970s and the traditional varieties namely *Thapchini, Marsi* and *Tauli* were gradually replaced. Despite the need of additional inputs of water and fertilizers, the farmers were increasingly attracted towards the new varieties due to much higher yield compared to traditional varieties of rice. After 1980s, *Taichin* became the dominating rice variety. National Agricultureresearch Council (NARC) has developed 11varieties of early rice and 38 varieties of mainseason rice depending upon the local climate (NARC, 2005).It was in mid 2000s, the farmers across the study sites started to cultivate new varieties like *Khumal-4, Khumal-8* and*Pokherili*in addition to *Taichin*. However,*Taichin*is still the most preferred rice variety across all the sites.

Maize is the second most important cereal crop in Nepal. It is a traditional crop cultivated as food, feed and fodder on slopping *bari* land (rain-fed upland) during the summer (April-August) with pre-monsoon rains and harvested before the end of the monsoon rains (Paudyal *et al.* 2001). For higher maize yields, crop water requirement is 500-600mm depending upon the climate and duration of the crop. There should be adequate water during the crop establishment period (Navaya and Gurung, 2010). Water deficit during the grain filling period results in reduced grain weight. However, during the maturity and harvesting period, rainfall has negative impact on maintaining grain quality. Cold stress occurs when temperature is below 10°C and development of plant growth ceases. Similarly, heat stress occurs when temperature is higher than 35°C (ibid).

Maize was cultivated in May in the upland unirrigated farms (*bari*). The cultivation of maize in combination with sundry varieties of pulses was a general practice, soybean being the most common pulse. Prior to 1970s, only the local varieties of Maize were cultivated. The hybrid varieties (*murali*) started to be cultivated in addition to the local maize varieties in 1970s. Due to shorter height, hybrid maize was able to withstand the spring wind but these were less resistant to drought. Farmers also perceived that this hybrid variety produced less corn flour.

Till 1990s, the farmers planted pulses on the bunds at the edges of rice fields. The farmers felt a major reduction in the practice of cultivating pulses as a result of continuous decline in yield since 1990s. Varieties of pulses were planted in the *bari* in mixed cropping system with maize. However, with the continuous decline in yield, this practice has been reduced in 2000s and further more reduced to no more cultivation due to almost negligible yield for some pulses such as*masyang, gahat*. Though the farmers had no idea about the cause of this drastic decline but considered the increasing pollution could be a possible cause.

Across the study site, the major crops cycle of Rice in the *Khet* (irrigated land) and Maize-bean combination in *Bari* (unirrigated land) has not undergone major change though few farmer have also opted commercial vegetable farming replacing the traditional cereal cropping during monsoon.

Similarly, wheat was the major winter crop cultivated in *khet*. The high yielding wheat varieties (*rato, rato chausathhi, baunna*) were introduced in 1970s and area under cultivation of these varieties expanded replacing the original wheat varieties by 1980s. Wheat was produced in the mid-hills mostly under partly irrigated conditions in terraces and was less input-demanding with the exception of the Kathmandu Valley, where fertilizer use was relatively high (Morris *et al*. 1992). Prior to 1980s, there was practice of irrigating wheat however with declining irrigation facility by mid to late 2000s, the practice of irrigating wheat has been possible only for the farmers along the river banks.

Mustard was the most common winter crop cultivated in the uplands (*bari*). Similarly other crops cultivated during winter included millet, barley,pea, *musur, bakulla* (varieties of pulse). Potato was cultivated by the farmers with dependable irrigation service.

Farmers were attracted towards crop diversification since 1990s. Consequently area under wheat cultivation started to decline and preference towards pulses such as pea plants and vegetables as the alternative cropping came up. In 2000s, farmers were increasingly abandoning wheat cultivation. The increasing switch from cereal to the alternative cash crops was influenced by the increasing market opportunities at urban areas. Additionally, the hardship involved with cereal based cropping particularly wheat harvest was stated as another prime reason. Similarly farmers considered increasing labor cost, declining wheat production with declining winter rain and low market values of wheat so produced were responsible for growing disinterest towards wheat cultivation. A common response of the peri-urban farmers towards this was increasing shift towards the alternative crops.

Unlike monsoon and winter cropping, spring cropping was relatively new cropping practice and spread with the increasing income opportunity of urban oriented vegetable farming. Prior to 2000s spring season was generally a period of leaving the land fallow. After this period a wide range of vegetables were started to be cultivated across all the study sites. Traditionally, vegetable cropping used to be a part of intercropping in which farmers planted several kinds of vegetables together with major cereal crops in the same field.

The preference towards vegetable farming started to appear in 1990s and became more common after mid 2000s. The vegetable farming was practiced both on a smaller scale for household use as well as on a larger scale for commercial purpose.

3.3.2 Shifting in Rice Planting and Harvesting Time

Prior to 1980s, generally rice used to be planted before *Guru purnima,* a ritual celebrated in the first week of July. However over the decades, rice plantation in the study areas was found to be increasingly dependent on the onset of monsoon. The study has documented the change in the planting time of rice over a period of past 40 years. These changes in cropping dates inferred the perceived change in onset of monsoon.

In Lubhu rice transplantation till 1980s used to begin in June second week and used to continue for a period of month across fields in different terrace. However, in 1978 and 1982 they had planted rice much later up to August second week which had caused problem in ripening of rice. The state sponsored irrigation canal called *Singha Rishi Dovan Rajkulo* was damaged by flood in 1981 and again the flood in 1993 deteriorated the canal and reduced its command area. After 1990s, period of rice transplantation delayed to later in Julythough in some years they could start it within June. In 2000s, the farmers felt the rainfall was being erratic and there was no distinct trend in beginning of rice transplantation. While some farmers used to take advantage of new technology to lift water from rivers immediately transplanting the seedlings planted after the pre-monsoon rainfall, those away from alternative water source had to wait for rainfall. In attempts to protect the transplanted paddy seedlings from prolonged dry spells, the rice transplantation used to get delayed up to August.

In Dadhikot, till 1980s, rice transplantation was generally started in June first week and completed within June.In 1990s the rice transplantation got gradually delayed and a month starting from June third week became the peak period of rice transplantation. Prior to 1990s, even during the peak of dry season in April/May, water flow in the state sponsored irrigation canal called *Mahadev Khola Rajkulo* used to be sufficient for timely completion of rice plantation up to the tailrace. However, 1990s onwards, the water yield in the irrigation canal was declining making the agriculture increasingly climate sensitive. By 2000s, the rice transplantation started in June third week along the field adjacent to the irrigation canals and rivers. In the lower belts of the village, the irrigation facility was poor and rice transplantation was completely dependent on rainfall. In those parts of the village, rice transplantation delayed up to August second week.

Similarly in Matatirtha, prior to 1980s rice transplantation used to get started by June first week and completed by second week of June.*Ashad* 15th, during end of June was the particular day celebrated for the accomplishment of rice transplantation but the transplantation gradually started getting delayed 1980s onwards. During 1980s and 1990s, rice transplantation used to begin by June second week and extended to July while in some extremely dry year it could be conducted only in August first week. In 2000s, the transplanting of paddy extended till August second week.

In case of Jhaukhel, till 1990s rice transplantation was started in June second week and extended up to August. Unlike other VDCs, in 2000s rice transplantation in Jhaukhel has been much earlier and completed within second week of July. They attributed it to the better monsoon in 2000s as compared to the earlier decades.

Though a significant delay was mentioned in the date of rice transplantation, there was no major change in the harvesting period. This period primarily ranged from October to November. However the delay in the transplantation date had serious implication on the quality and quantity of the rice grain produced.

3.3.3 Change in crop production

Nepal was self sufficient in food grain production until 1990. Due to drought condition in 2005/06, production fell short by 21553 metric tonnes and by 179910 metric tonnes in 2006/07 due to drought and natural calamities (WECS, 2011). A study by Rai *et al.* (2011) at NARC, Tarahara using CERES, Rice v 4.0 models showed that there was a decreasing trend in grain yield of rice per degree rise in seasonal mean temperature. The rising maximum temperature had a negative impact on the rice yield and increase in minimum temperature can also lead to yield decline due to early maturity of the crop as shown in table 28 (Rai *et al.* 2011 and Lal, 2011). If the increase in minimum temperature is less strong than the increase in maximum temperature, the daily variability of temperature increases. This can decline crop yields (Wheeler *et al.* 2000). The study by Rai *et al.*(2011) also found a negative yield response to diurnal temperature range (DTR); the difference between daily maximum and minimum temperature), and indicated that temperature increase is more harmful during day than at night.

Changes in temperature per season have impact on the crops grown in that particular season. During summer and the beginning of fall (monsoon), paddy is the main cultivated crop. Rice yield is optimal at 25°C (Luo, 2011). Currently the long term average monsoon temperature ranges between 21.6°C in Godawari and 23.9°C in TIA. This might imply that an increase in mean temperature could thus positively affect rice yield which was also stated by Malla (2008), although one should realize that rice growth has different development stages demanding their own particular optimal conditions (Lal, 2011).

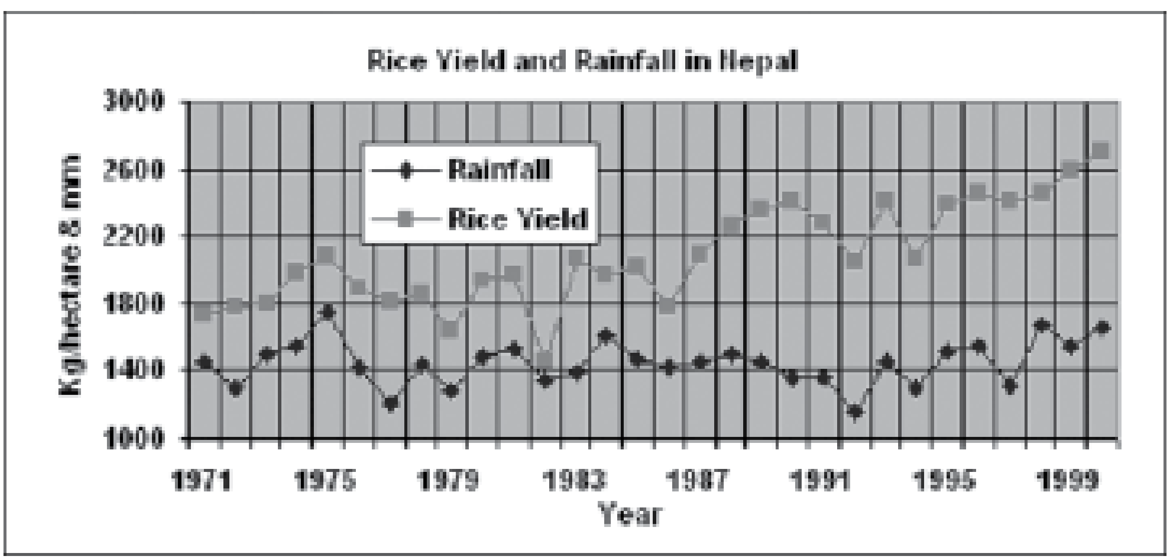


Figure 13: Rice Yield and Rainfall in Nepal (Source: Nayava, 2008)

While observing the rice yield from 1971 to 2000, Navaya (2008) found a positive corelation between the rainfall and rice yield in Nepal with exception in 1999. This increment of yield during

1999/2000 was due to use ofhigh yielding seeds, which occupied 71% of thecultivated area during 1999/2000 (MoAC, 2000).Intensity of the summer monsoon rains in Nepal and the date of the onset ofthe monsoon are both important factors in the country's economy, because it is the main season for thecountry's major crop (Nayava, 1974).Comparing with the context across the study sites, the rainfall data analysis indicate increasing tendency in pre-monsoon and post monsoon but a delayed onset of monsoon. Thus the delayed onset of monsoon is likely result in the delayed paddy transplantation which implies that the seedlings remaining in the seed beds will need extra protection or might be seriously damaged and the production will be poor.

The optimal temperature for wheat growth depends on the development stage, between 20.3°C and 22.0°C (Luo, 2011). Long term average winter temperatures in Kathmandu valley vary between 11.2°C (Godawari) and 12.7°C (TIA). So, also for wheat production, an increase in temperature might mean an increase in yield which was also again mentioned by Malla (2008), although also here every development stage has its own preferred conditions and a strong increase in minimum temperature causes early maturity and thus decrease in yield (Lal, 2011).

Table 28: Effects of plus temperature in maximum, minimum and mean existing temperature

Temperature (°C)	Yield at Max. Temp. (Ton/ha)	Yield at Min. Temp. (Ton/ha)	Yield at Mean Temp. (Ton/ha)
+1	3.67	3.56	3.42
+2	3.55	3.34	3.13
+3	3.35	3.27	3.12
+4	3.22	3.26	2.68
+5	3.2	-	1.88

(Source: Rai *et al.* 2011)

Across the study sites, farmers distinguished three stages on the basis of crop productivity. Prior to 1970s traditional varieties of cereal were planted. The traditional varieties had much lower yield. Based on focus group discussions, the yield averaged across the sites were 331.8kg/ha of rice, 191.7kg/ha of wheat and 207.7kg/ha of maize. Table 29 shows the changes in yield of major crops across the study sites from period prior to 1970s to 2000s.

With increasing cultivation of high yielding rice varieties Taichung (*Taichin* as called locally) post 1970s started the application of chemical fertilizers and the cereal production scaled up. After this period, the traditional varieties were gradually replaced by *Taichin* rice variety preferred due to much higher yield. This period was recalled by the farmers as the most productive period and was explained by the local statement "*mana ropera muri falne*". Lubhu has a historical fame associated with good rice yield and supported by the higher production of the traditional rice varieties in Lubhu compared to the other three VDCs. The farmers in Jhaukhel perceived during the stated period the onset of monsoon was much later causing delay in paddy transplantation and thus the yield was much lower compared to Dadhikot, another study site in the same district.

In Jhaukhel, the case was different. Farmers recalled that traditionally maize used to be the major crop,based on the area under cultivation while rice cultivation was limited by water availability. After mid 2000s, with rainfall being sufficient, the area under rice cultivation increased. The average yield of rice in the four different periods in Jhaukhel was in increasing trend from 294.9kg/ha to

491.5kg/ha to 589.9kg/ha and 688.2kg/ha. Though the absolute production of rice per unit area was increased, the farmers were having increased the cost of production thereby reducing the net gain for the farming communities.

Similarly in the other three VDCs, the farmers perceived the cost incurred for the production had increased. This was explained as a major reason behind the growing careless attitude towards agriculture.

Table 29: Production in kilogram per unit hectare

Sites	Crops	2000s	1990s	1970s to 1980s	Prior to 1970s
Dadhikot	Rice	442.4	737.3	737.3	344.1
	Maize	319.5	383.4	383.4	255.6
	Wheat	191.7	319.5	447.3	255.6
Jhaukhel	Rice	688.2	589.9	491.5	294.9
	Maize	511.2	511.2	255.6	255.6
	Wheat	191.7	127.8	127.8	127.8
Lubhu	Rice	589.9	786.5	786.5	393.2
	Maize	319.5	511.2	511.2	191.7
	Wheat	95.9	511.2	511.2	255.6
Matatirtha	Rice	442.4	589.9	589.9	294.9
	Maize	127.8	255.6	255.6	127.8
	Wheat	191.7	319.5	255.6	127.8

(Source: Field Survey, 2012)

The study by Nayavaand Gurung (2010) on maize yield and production with relation to pre-monsoon rainfall (March-May) showed maize yield and production was impacted by rainfall and recommended that maize planting needed to be adjusted according to the change in rainfall pattern in the recent decades. In the study sites the farmers perceived an increase in the yield from period prior to 1970s to 1990s but a declining trend in maize production 2000s onwards. They perceived this decline as a compounded effect of poor rainfall during pre-monsoon, delayed onset of monsoon and shift in the peak monsoon rainfall during August/September affecting the harvestable maize and increasing pest incidences along with degrading soil quality due to extensive use of chemical fertilizers.

Tall local varieties of wheat yielded on average 1.2 t/ha (Morris *et al.* 1992). The study on the wheat yield during 1970/71 to 2007/2008 showed, the yield was almost constant in the first decade, in the later part the yield increased to more than 2 mt per hectare (Nayava *et al.* 2009). However across the study sites, the wheat production as obtained from the discussions with farmers was much lower and more seriously showed a declining trend in production. Prior to 1970s, it was on average 191.7kg/ha and in 1970s to 1980s after the introduction of high yielding shorter varieties, it increased to 335.5kg/ha. In 1990s the decline started for wheat yield as well and the average yield across the site was 319.5kg/ha. In 2000s the wheat yield reduced drastically to 167.7kg/ha (figure 14).Study by Nayava *et al.*(2009)points that rainfall distribution in February and March had avery good impact on yieldand most of the up and down in the cultivation of wheat areawas a result of October rainfall as it helped asresidual moisture during planting time. Thus the relation pointed by the farmers across the study areas between the declining wheat cultivation area and the wheat yield to the declining winter rainfall seems relevant.

Rosenzweig and Parry (1994) found that wheat, maize, rice and soybean yields increased for changes in +2°C and ±20% rainfall and for a doubling of CO_2 while yields of all four crops were reduced at +4°C warming. Across the study sites though the farmers perceived an increasing temperature trend, its contribution on crop yield was perceived rather negative and the apparent increase in the yield was attributed to increased use of chemical fertilizers. Besides the major crops, alternative crops introduced at different times also showed declining trend in 2000s. The farmers considered several reasons behind the decrease in production. The elderly groups in the area had a fervent belief that after mid 1980s the nature has been unkind and hold human activities responsible for the disturbances. The farmers believed that the rain water had an additional capacity to improve the yield which was not possible through artificial irrigation expressed through quotation "*Aakash bata parne pani aamrit huncha*". Though the alternative irrigation practices emerged, the farmers considered the manual irrigation was not effective as compared to rainfall and felt the production quantity and quality was lower as compared to those in case of timely rainfall.

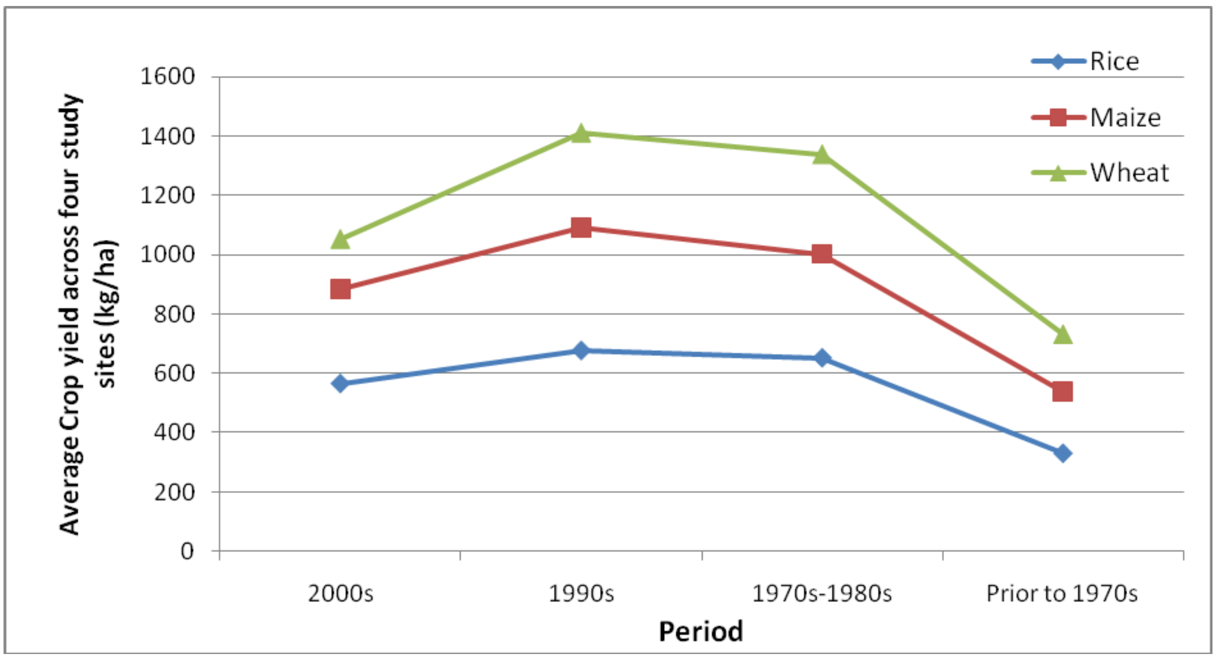


Figure 14: Change in average crop yield per hectare

(Source: Field survey, 2012)

Study by Rai *et al.* (2011) found that the decrease in rice yield was not only the cause of climate change but also the effects of improper management and recommended adaptation measures must be taken to increase or to keep constant yield of rice (crops) by the farmers. Understanding the impacts of climate change in agriculture across the study site was also highly complicated. It was found that along with the introduction of new crop varieties in 1970s, increased the crop yield and during the same time began the use of chemical fertilizers. However with the lack of knowledge on the ecological footprint of the chemicals, farmers applied the chemical fertilizers more than the recommended volumes. Farmers across the sites perceived this unbalanced use of fertilizer as the cause of soil degradation. While climate was agreed as one of the main determinants of crop yield, the unwise use of chemical fertilizers causing the degradation of soil was considered a major cause of declining productivity in the peri-urban areas. With increasing urbanization, the labor input for crop production was declining. Farmers considered decline in crop closely related to this changing behavior as well.

EEA (2003) considered deep ploughing as an unsustainable agricultural practice and responsible for loss of organic matter, soil biodiversity and consequent deterioration of soil fertility. Contrastingly, famers across the study sites believed the mechanization in ploughing system with the introduction of tractors for ploughing was limiting nutrient availability to the plant root and therefore was responsible for the declining crop yield. An additional effect of urbanization that was considered responsible was increase in the interception of the solar radiation in the field adjacent to the rapidly rising buildings.

The increasing practice of leasing out agricultural land for extraction of top soil for brick factories was a common case in Jhaukhel. Though lesser in number, such cases were also found in Dadhikot and Lubhu. The removal of topsoil is always a loss to agricultural productivity as topsoil is the part of the soil horizon with higher level of organic matter and nutrients and generally better structure (USDA, 1993). The other cause of crop decline across the study sites as perceived by the respondents was increasing incidences of pests and crop diseases.

3.3.4 Changes in pests and weeds in the crops

The majority of stations showed warming in the maximum temperature. An increase in maximum temperature has several possible impacts. It can enhance invasive weeds to enter the area (Dukes and Mooney, 2000) and also it increases the risk of vector borne and rodent borne diseases (Patz *et al*. 2000). A decrease in the number of days with < 0°C also can cause an increase in insects and pests because of less winter kill (Ziska *et al*. 2011), and this can be a serious threat for the peri-urban areas in Kathmandu.

Across the study sites the local land races planted prior to 1970s were drought and pest resistant. The new crop varieties introduced in 1970s provided better yield however were more input based and less tolerant to external environment. The use of chemical fertilizers for the new varieties disturbed the natural pest predator cycle and increased the occurrence of pests. The incidences of damaging insects, pests and weeds started in 1990s while 2000s onwards there were surge of pests. With rapid rising trend in temperature in 2000s in addition to the increase in the population of existing pest, the new pests had also emerged.

The most direct effect of seasonal frost is by killing exposed organisms, particularly microorganisms in the topsoil that break down organic matter and mineralize its nutrients (Scholes *et al*. 1994 as cited in Masters and Wiebe, 2000). With declining frost days, the respondents across the sites felt, the mild winter favored thriving of pests and diseases as a result of extensive decline in killing of the pests by winter chills, though the damage by frost reduced. Increase in temperature may lead to reduced soil organic carbon level, soil micronutrients and enhanced microbial decomposition in the soil (Malla, 2003). Climate change will also modify host pathogen interaction to determine the outcome of many diseases. Consequently, the greatest impact of climate change will be on the management strategies that utilize host resistance (Chakraborty *et al*. 2008). Farmers across the study areas were not clear about the exact causes of escalating pest attacks however they recalled that the winter rain and the winter chill used to play an important role in controlling the pests and attributed the accrued pests to the disturbances in the climatic phenomena particularly increasing temperature and declining rainfall. Similarly, delay in the onset of monsoon, erratic rainfall and increasing dry spells were considered other major causes of the pest surge.

The following sections elaborate the changes in the insects, pests and weeds observed by the farmers.

3.3.4.1 Monsoon crops

Manandhar (2007) recorded *mothe* (*Cyperus difformis*), *sama* (*Echinochloa colona*), *Thulo mothe* (*Cyperus iria*), *Gandhe jhar* (*Ageratum conyzoides*), *Chimke jhar* (*Spilanthes iabadicensis*)and *Echinochloa crusgallias* as the major weeds in transplanted rice field of Kirtipur.

In Dadhikot, till 1980s the common weed in Rice was *Teliya*. In 1990s, the weeds reduced with the increasing applications of chemicals and rather new disease called Sheath blight (*Rhizoctonia solani*) locally called *Daduwa* appeared as a major problem in rice. Wilting of the rice plants due to this disease has been responsible for the decline in rice yield in Dadhikot.

In Jhaukhel, prior to 1980s, the common disease in rice was*Rate* and the common weeds were *Ketu, Busingha, Chimke* (*Spilanthes iabadicensis*), *Dubo* (*Cynodon dactylon*), *Gandhe* (*Ageratum conyzoides*) while *ghun* and grain moth (*putali*)was the problematic during storage. The farmers perceived a decrease in the incidences of pest occurrence in 1980s which they thought could be result of starting of the chemical fertilizers application. But in 1990s new pests started emerging. *Daduwa* which appeared in 1990s increased in 2000s. In mid 2000s, a new weed locally called "*Maobadi Jhar*" (a weed with nodes and spreading massively on the surface of water) appeared in rice fields and increased in the successive years. They also noticed tall unidentified weeds with appearance resembling to rice plant was increasing in rice field starting from around mid 2000s.

In Lubhu, the occurrence of weeds increased in 2000s which has increased the need of weeding practice more.While *Sama*(*Echinochloa colona*), *Ketu, Kasauti, Phuke, Dubo* (*Cynodon dactylon*) were indigenous weeds, new weeds like *Maobadi Jhar, Navo, Madila, Tantane, Pire* (*Polygonum barbatum*), *Mothe* (*Cyperus difformis*), *Baspate, Pani ghans* appeared in rice field and progressively increased in 2000s. Similarly in this VDC, the disease called S*ete* (the tip of the leaves turning white as a result of inundation for longer period), *Rate* was increasing in rice plants however the use of pesticides in rice was not common. Snails and slugs were increasing in vegetables and soybean where as in Matatirtha, prior to 1980s, *Pahenle*, a disease turning the rice plants yellowish as a result of water scarcity was less frequent while in 2000s this has been more frequent. Similarly, severe incidences of water scarcity turning the plants reddish were observed (locally called *Rate*). The leaf roller insect attacking the leaves of rice plants was observed since 1990s while *Sete* were newer incidences startedto occur2000s onwardsonly. Common weeds in rice fields were *Bancho, Pire* (*Polygonum barbatum*), *Sama* (*Echinochloa colona*), *Mothe* (*Cyperus difformis*)and mosses.

Farmers considered increasing dry spells favored the growth of weeds and sufficient accumulation of surface water in rice fields could prevent germination and growth of many weeds.

In Maize, stem borer (*Chilo partellus*) locally called *Gobaro* was characterized as voracious leaf eating insect. In Dadhikot this pest was observed only after 2000 but was increasingly being problematic. Till 1990s sparrow used to be major problem for the maize farmers in Jhaukhel. 2000s onwards maize had been affected by stem borers (*gobaro*), parrot, monkey and a disease called head smut (*Kalo poke*) caused by smut (*Sphacelotheca reilian*).

Weeds common in Maize field in Jhaukhel were *Gandhe jhar* (*Ageratum conyzoides*) and *Dubo* (*Cynodon dactylon*). In Lubhu, though *Ganaune, Sitlange* were weeds observed in Maize even in the earlier decades, there was a growth in the density of these weeds in 2000s while *Chari amilo* had drastically reduced after 2000. In Matatirtha, Maize was affected by aphid (*Rhopilosiphum spp*), ants and white grubs (*Phyllophaga spp. and Cyclocephala spp.*) locally called *Khumre*. White grubs attacks on the roots of maize plants though started in 1990s, it became more problematic in 2000s.

3.3.4.2 Winter Crops

National Agricultural Research Centre in 2010 has recognized leaf blight (*Daduwa*), rust (*Sindure*), loose smut (*kalo poke*) as some of the prevalent diseases in wheat. These diseases were reported to be more frequent in 2000s. The potato damages by leaf blight, white grub, red ant (*rato kamila*) had been more frequent in 2000s. Aphids were commonly reported as a common cause of crop failure affecting a wide range of crops including mustards, different vegetables, maize, *bakulla* and other pulses.

The farmers across the sites remarked the occurrence of green aphids started in 1990s while black aphids appeared only in 2000s and considered the latter to be more destructive. In addition to insect pests, diseases caused by microbes were increasing massively in such a way that the application of pesticides had been inevitable among the farmers. Though the occurrences of the insect pests were lower during winter season as compared to the summer season, it was observed that the pest population was gradually increasing with winter being milder. In Dadhikot and Jhaukhel, the farmers mentioned the increasing needs of vitamins as inputs to the vegetables during winter. Farmers across the study areas commonly perceived the increasing weeds as a result of declining winter chills and the decline in winter rain. In the earlier decades the common practice was to use the weeds as cattle food but with the declining practice of livestock rearing, managing the weeds has been an additional burden for the farmers.

The agricultural intensification process render most crops more susceptible to pest attack and intensive use of pesticides in itself considerably affects the land and its biotic environment (Brader, 1987). While the farmers noted the linkage of increasing climatic variability on the severe incidences of pests, they also considered unbalanced application of chemical fertilizers and pesticides as a major cause of soil degradation and disturbance in the pest predator cycle thereby making the pest attacks more severe.

3.3.5 Change in crop phenology

Extreme temperatures can significantly reduce yield (Porter and Gawith, 1999) and especially during flowering time, crops are sensitive to extreme temperatures (Wheeler *et al.* 2000).

The farmers had not noticed major change in the growth and maturation dates of the major crops however they had noticed some peculiar incidences varying from the regular plant phenology. In the earlier decades when rice was transplanted after second week of July, they used to face problem in ripening. In 2000s they noticed despite delay in the transplantation of rice, the rice plants matured by the same time as in years of timely transplantation. In case of mustard some farmers in Jhaukhel noticed faster germination after sowing of the mustard seeds which further showed sudden growth in the height of newly germinated plants within few days. They perceived the linkages of this sudden growthwith the climatic variability, particularly warmer temperature.However the farmers noticed this had rather negative impacts on the crop growth making it less disease resistant and more prone to weather vagaries that follow during the crop growing period.

3.3.6 Decrease in Soil Mositure Content

Food and Agricultural Organization in 2008 stated the increase of instability in rain-fed agricultural production as the variability in rainfall increased. Soil moisture deficits, crop damage and crop disease are all driven by rainfall and associated humidity.The rain-fed crops in monsoon-season are especially vulnerable to dry spells. In a wet soil, water is easily taken up by the plants. In dry soils, water has a low potential energy and is strongly bound by capillary and absorptive forces to the soil matrix, making it harder for the plant to extract the water (Allen *et al.* 1998). This can finally lead to decline the yield. Drought-stress of the crop also affects the disease resistance of the crop, giving pests and pathogens more chance to succeed (Chakraborty and Newton, 2011). Our study on people perceptions' also shows the changes in soil moisture over time. Prior to 1990s, soil moisture used to be maintained for the whole year except during some exceptional years in Dadhikot. Farmers started noticing declining in soil moisture since 1990s and further more decline in 2000s. They related the progressive decline in soil moisture with the increase of pest in agricultural crops, the most common being occurrence of aphids in mustard plants, pulses and other vegetables as well. Similarly, people of Jhaukhel remembered the days back to 1980s and shared the higher occurrence of residual soil moisture during the rice harvest time which started declining by 1990s and further declined in 2000s as a result of erratic monsoon period. However, they felt the total rainfall has been more benign in the years after mid 2000s. This is same case for Matatirtha and Lubhu as well but people of Lubhu considered it as an inherent climatic characteristic of the area. They recalled occurrence of cracking of the land surface due to long dry spells occurred in the earlier periods; drought in 1989 was one of such dry years.

However, the degradation of the earlier water infrastructures such as water storage ponds and irrigation canals which people used for timely irrigation hasresulted the current increase in dependency of agriculture on rainfall and which over the years has been moreclimate sensitive. Taking into account the findings from the analysis of evaporation data, there has been an increase in the number of days that evaporation exceeded rainfall during monsoon period. With no intervention exploring the alternative water sources for agriculture, the findings speculates the increase in soil moisture deficiency, the impacts of which will be on the crop production ultimately affecting the farming communities.

3.3.7 Impacts on natural resources

Scientific evidences indicate changes in temperature and increased extreme events such as flooding and drought. These will significantly affectthe natural systems with diverse effects on a range ofecosystemservices diminishing the capacity to serve the human society which is likely to have far-reaching social andeconomic consequences(MEA, 2005; Olesen, 2006;Seppälä*et al.* 2009;Daccache*et al.* 2010). Water and its availability and quality will be the main pressures on, and issues for, societies and the environment under climate change (IPCC, 2007). Increase in the intra-annual variation in rainfalltogether with shrinkage of glaciers and snow cover can have profound impact on water the security in mountain regions (Schröter *et al.* 2005). Reduced velocities due to lower flows resulting in higher water residence times in rivers and lakeswill have negative effects on water quality (Whitehead *et al.*2009). Elevated water temperatures intensify biochemical processes favoring occurrence of algal blooms andreduce oxygen levels (Anderson *et al.* 2008; Whitehead *et al.*2009). Climate change impacts are observed in several sectors of Nepal among which water resources is one of the hardest hit sectors (WECS, 2011).

Study by Shakya and Sharma (2006) has emphasized that climate change will affect different aspects of local hydrology such as timing of water availability and quantity as well as quality. Considering the practice of lifting up of water from the river sources for fulfilling the irrigation water needs across the peri-urban areas that has been a major coping strategy to overcome the water stress, the likely impacts on local hydrology make the areas more prone to water insecurities. Furthermore with the increasing urbanization the water sources, mostly the rivers across these areas are degrading rapidly due to the effluent discharges from multiple polluting sources. The decline in water quantity leading to the declinein water quality willexpose both the wastewater irrigators and consumers of such products to a wide range of water borne diseases.

3.3.7.1 Impactson water sources

Prior to 1980s, nine ponds existed in the Lubhu. Most of them had disappeared by 2000s and those remaining had also reduced in size as a result of increasing urbanization and encroachment. As per the respondentsof Nepal Chaur area at Lubhu, this area held two springs. As a result of the changing rainfall patterns and rampant harvesting of trees around the spring sources for the construction of new houses and construction of road, the yield in the springs consistently declined. One of the spring completely disappeared by 2000s while the yield of other spring (*Karange ko pandhero*) has been declining progressively.As a result ofdeclining of water in spring sources and decrease in river flow with increasing rainfall variability, the existing community based drinking water supply systems and also irrigation systems have been adversely affected.

Till early 1970s, the water yield of the springs and flow of the streams used to operate seven traditional water mills in different parts of the Matatirtha. Though the introduction of grinding mills operated by electricity was also related to the displacement of water mills, the respondentsrememberedthedecrease in the stream flow since 1990s and further more declinedin 2000s. As per the respondents, though there has been no noticeable decrease in the yield of the major springs in wet season, they observed much decrease in the yield during dry season. They also mentioned decline in the existence duration of *Asare Mul*(temporary springs appeared during and after rainy season). The springs that never dried were observed to have dried in the year 2009. In addition to the diversion of yields from major springs for household water supply systems after 2000s, they considered widespread commercial extraction of ground water from spring sources, boring and dug wells as major causes of apparent decline in water flow. Till 1980s, two swampy areas called *Bhutya pokhari* and *Bhause pokhari*existed in the village, which used to be more prominent during rainy season. However during the study period these had already vanished and due to their minimum linkage with the local water requirements, these were in the memory of only few respondents. However it cannot be neglected these could certainly have ecological contribution which have been lost along with them.

Similarly among the six ponds existed in Dadhikot, only *Dhale Pokahri* and *Chitrapur Pokhari* contained water currently while the remaining four had been either encroached and reduced in size or completely dried and used for urban service. Beside this, since 1990s the local people also observed the continuous decreasing in river water flow and declining in spring discharge which has been prominent from the case of a community based water supply system called Uttisghari Community Water Supply and SanitationScheme. This service initiated in the year 2000. During that time, water reservoir of capacity 200,000 litres used to be filled within approximately 10 hours. As result of regular decline in the spring discharge this duration required in filling the reservoir escalated and during the study it was reported to take around 18 hours to fill the same reservoir. The respondents were puzzled about the decline in the spring sources even in the areas where vegetation was properly maintained through community forestry.

Mahadev River used to provide year round irrigation in ward no.1 and Khasang khusung River in ward no. 7 and 8 of Jhaukhel. The respondents noticed that there was a decline in the quantity of water flowing in these streams from 1990s. The agricultural land on the both sides the rivers had year round irrigation facility till 1990s.Local people noticed decrease in command area with the decline in the stream flow and found more prominent decrease in dry seasons which they perceived due to decline in winter rain and delay in onset of monsoon.

The declining water flow in the rivers and springs has to show adverse affects on the irrigation systems. Traditionally, the tail end farms in the VDC used to be irrigated only after the head end farms were fully irrigated. Having enough water flow in the river, this customary practice was considered reliable and got established as a kind of irrigation culture in the village. However, with the declining flow in the rivers, competition for limited water in canal started increasing, resulting in the appearance of water related conflicts. Also, the farmers have been facing additional burden by guarding irrigation canal at night time to irrigate their land.

A decrease in the monsoon rainfall and an increase in evapo-transpiration due to climate change may have caused the reduction in the flow in the monsoon season (UNEP, 2001). Respondents considered urbanization, human interference and decline in rainfall particularly, decline in winter rain affecting the spring recharge as the causes of decline in the springs, ponds and rivers flows. Community managed drinking water supply systems have evolved across all the study sites contributing to improve water access. However with the declining natural sources of water, people have anticipatedwater stress to grow in the future. There has been a growing realization of the needs of exploring new water sources and better ways to manage the existing water sources to maintain long term water security. Similarly, with the rainfall being no more dependable, farmers have accepted of the increasing need of irrigation services, gradually motivating the farmers to reunite for the revival of the traditional irrigation canals.

3.3.7.2 Impacts on wild flora

Climate change is expected to affectecosystems and biodiversity, though it isdifficult to attribute changes that havealready occurred to climate change alone. Shifting rainfall regimes particularly are expected to affect the long-term trends in forage production, plant community composition, and wildfire impacts (Ackerly, 2012).

Unlike the distinct changes observed in water resources across the study sites, observations made regarding the degradation of natural resources, such as changes in wild vegetables and medicinal herbs from forest were less distinct. In Lubhu, people felt that there was small decrease in availability of forage and fodder. It was considered mainly because of changing land use and change in climate. People of Jhaukhel mentioned the drastic decline in earthworms and the wild yellowish fruit "*Aainselu*" which they considered was a mainly impact of increasing pollution due to brick factories and increasing use of chemical fertilizers.

3.3.8 Changes in occurrence of natural hazards

Extreme rainfall events can instigate water induced disasters. Literatures show the relation of daily rainfall threshold to destabilize a hill slope (Larsen and Simon 1993; Matthias and Weatherly, 2003) and a relationship between monsoon rainfall and the triggering of landslides in Himalayas (Gabet *et al.* 2004).

Across the sites, people did not mention any major incidences of natural hazards except a disastrous landslide in Matatirtha and flood events in Lubhu. However, they were not considered as a regular threat.

3.3.9 Impacts on human health

The increase in number of hot days can have serious impacts for the people of Kathmandu valley. Human health is also impacted by an increase in temperature extremes. Patz *et al.* (2000) describes the increase in morbidity and mortality, related to extreme heat events. People in urban areas are more vulnerable to heat-related mortality, because of the urban heat island effect causing warmer night temperatures. They think that the absence of nighttime relief of the heat might be a factor in heat-related deaths. Peri-urban areas are exposed to the increasing temperature extremes, and are also likely to be more urbanized in the coming years, making the risks coming withan increasing temperature even a bigger threat.

Similarly, the air quality will also be threatened due to urbanization and industrialization. This can be further strengthened by the effect of increasing temperature. Increases in temperature can negatively influence the air quality due to the production of ozone (Patz *et al.* 2000). On top of that, Patz *et al.* (2000) state that especially urban areas are vulnerable to increasing air pollution. Increasing urbanization in the peri-urban areas can thus further threat air quality the ultimate impactsof which will be on human health.

The other major sector which cannot be neglected is the exposure of the peri-urban residents to a wide range of water borne diseases that can follow the declining availability of water quantity and degrading water quality with pressure on the water sources from the multiple stresses including both urbanization and climatic variability.

4. SUMMARY

The study captured both the climatic trend based on the analysis of the long term records of climatic parameters as well as based on the perception of the local people which are based on their long term experiences. The general perception on the decreasing rainfall across the site has been a progressive declining trend starting from 1980 which increased further in 1990s and 2000s. However as per the analysis of the long term rainfall trend, no clear rainfall trend and dry spells was visible. It has to be noted that the respondents considered dry spells to be a regular phenomena and incidences of extreme dry events to have occurred in the earlier decades as well.

Breaking into the seasonal analysis, rainfall records for Kathmandu valley showed that the variation was least in pre-monsoon and monsoon season while the variation was highest in winter rainfall. Looking into the variation in the monthly rainfall pattern it was found that increase in the rainfall took place from April to September except in June while decreased from October to March. Comparing with the local perception, in Lubhu, Matatirtha and Dadhikot, a common perception has been a decline and delay in the onset of monsoon thereby adding water stress for paddy transplantation, which has been indicated by the average decrease in rainfall in June. Unlike other study sites, the increasing rainfall trend, improvement in timing and amount of monsoon rainfall as observed by Jhaukhel respondents was primarily based on the ease in the rice transplanting which was found consistentwith the analysis of rainfall data showing an increase in rainfall in June in Changunarayan station, the station closest to Jhaukhel. The decline in the rainfall in some months while increase in the rainfall in some other months but no change in the total amount of rainfall indicate there has been change in the rainfall pattern. This point towards the chance that the total rainfall available that occur within a year occur in more intense forms which has been very close to the rainfall uncertainty perceived by the local people.

Delayed onset of Monsoon was found to have greater implications in terms of disturbances in the traditionally practiced annual cropping cycle and thus on the crop yield. Despite increasing rainfall in April and May the farmers commonly perceived the additional water stress for the protection of the nurseries which could be due to the observed decline in the rainfall in June, the month of monsoon onset thereby affecting the paddy seedlings. The decline in rainfall in the months from October to Marchexplains decline in winter rainfall common observation noted by the local people across the study sites. Winter rain breaking the long dry spells after monsoon rain has significant role in natural recharge of the water sources for the following dry season prior to the onset of summer monsoon. Therefore the decline in this associated with the decline in the yield of the natural sources of water seems a realistic observation and analysis made by the local people. However there could definitely be the additional from a diverse changes simultaneously occurring in the fields.

Though the irrigation services expand during monsoon, the winter crops in the valley are primarily cultivated in rain-fed condition. Considering the vital role of rain for winter cropping, the association made by local people between winter rain and the changing cropping practices and productionsseem insightful.As most of the irrigation systems are underperforming, without interventions in irrigation service, the rainfall uncertainty is likely to have more serious implications in future stressing not only peri-urban water security but simultaneously the peri-urban food security.

The perceived increase in the temperature was a common perception among the peri-urban communities. This was very consistent to the findings from the analysis of long term temperature records in both maximum and minimum temperature. The increase in the daily maximum temperature and minimum temperature were highest during winter months. This very much resembles to the findings from the perceived temperature change where the respondents held a strong view considering the winter being increasingly warmer.

Furthermore, the peri-urban residents noted the higher temperature across the urban centres were much warmer as compared to the temperature trend in their own peri-urban locality. Analysis of temperature records indicated urban heat island around Kathmandu, but more elaborate research is necessary to give scientific proof for a clear urban heat island in Kathmandu.

While the analysis of the monthly rainfall trends showed some shifts in the seasonal rainfall trend, the analysis of the total annual rainfall, extreme events, intensity of rainfall and dry spells did not show significant trends. The contrast in the overall perception on the decrease in the total annual rainfall across the study sites could possibly be due to the increasing water stress with the declining availability of reliable water sources for domestic or agricultural use. With rapid increase in water demands and rapid changes in water management practices, it would not be realistic to make any conclusionon the change in rainfall trend based on the changes in availability of water especially for the peri-urban study areas undergoing rapid changes due tourban expansion. However, the increase in temperature can definitely increase the demand for water, which has already started to be a major stress for the peri-urban communities.The decline, degradation and disappearance of the natural and traditional water sources coming up as the consequences of haphazardurban expansion across the study areashave been definitely exacerbated by the changes in climate.

Thus it can be concluded that the local ability to understand the climatic trend is very close to the trend depicted by the analysis done using scientific tools. The slight variations between two can be due to the limitation of the scientific basis based on the data variability at the same time influence of the diverse non-climatic factors in understanding and perceiving the exact climatic trends. The study can therefore be helpful to understand the ground realities of climate change, spectra of impacts associated with climate change and the coping and adaptive practices of the local people.

5. Way Forward

Water resources and agriculture have been the two sectors where the prominent impacts of the changing climatic attributes have been noted by the local people and farming communities have been the most vulnerable groups. However, converging to the impacts of climate change on water resources requires detail analysis of both opportunities and risks on the local water resource endowments and water management practices added by non-climatic factors.

Similarly despite the widespread local perception that the declining crop yield was primarily the impact of changing rainfall pattern in combination with pest attacks due to increasing temperature, certainly the more intensive studies assessing the interactions of weather and climate on agriculture are needed.

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ANNEXES

Annex-1

Deviations in minimum and maximum temperature

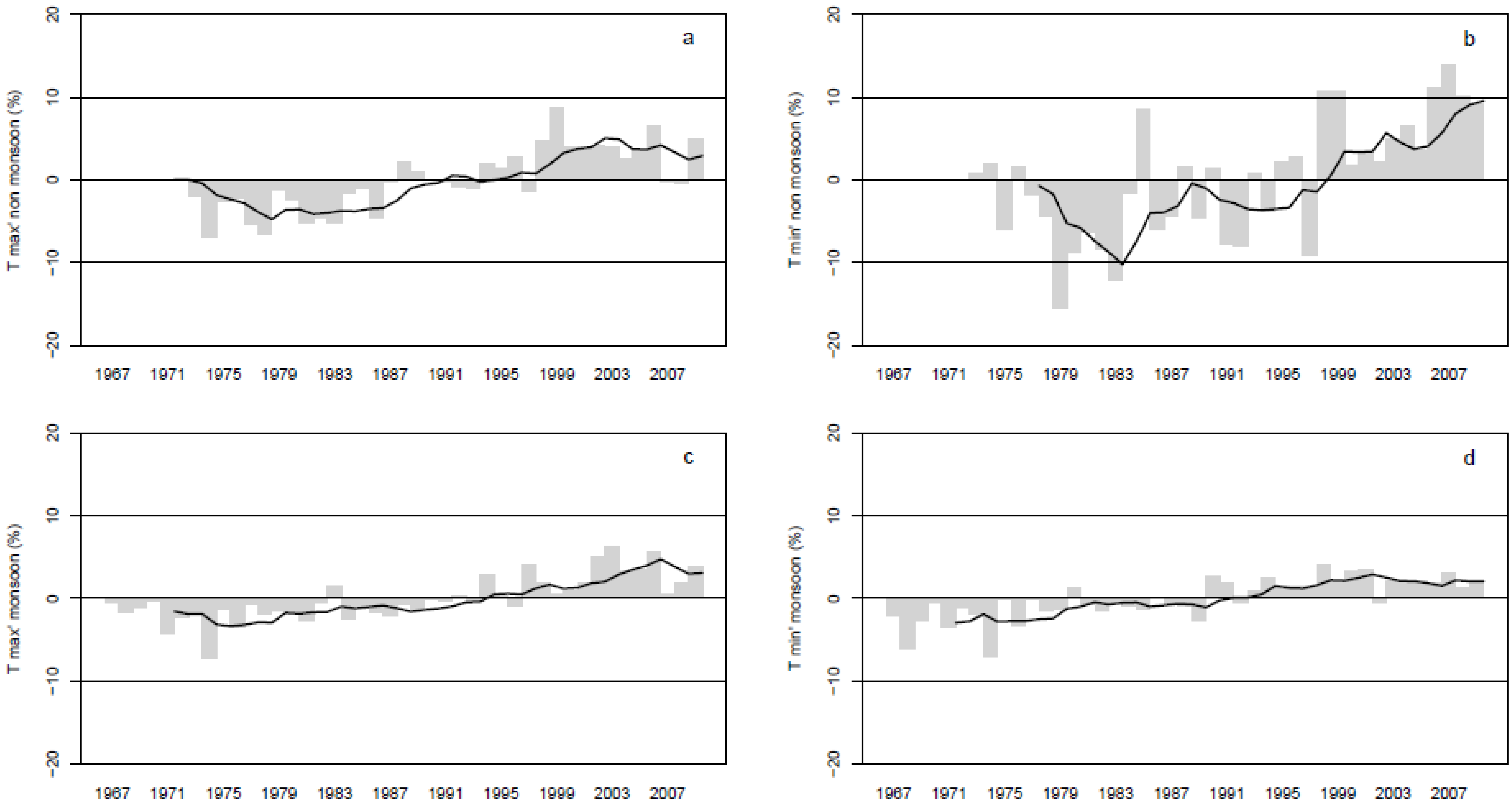

Figure 1: Deviation from long term annual mean max. (a and c) and mean min. (b and d) temperature in non-monsoon (a and b) and monsoon (c and d) period in Khumaltar, expressed in percentage. The line gives the 5 year moving average.

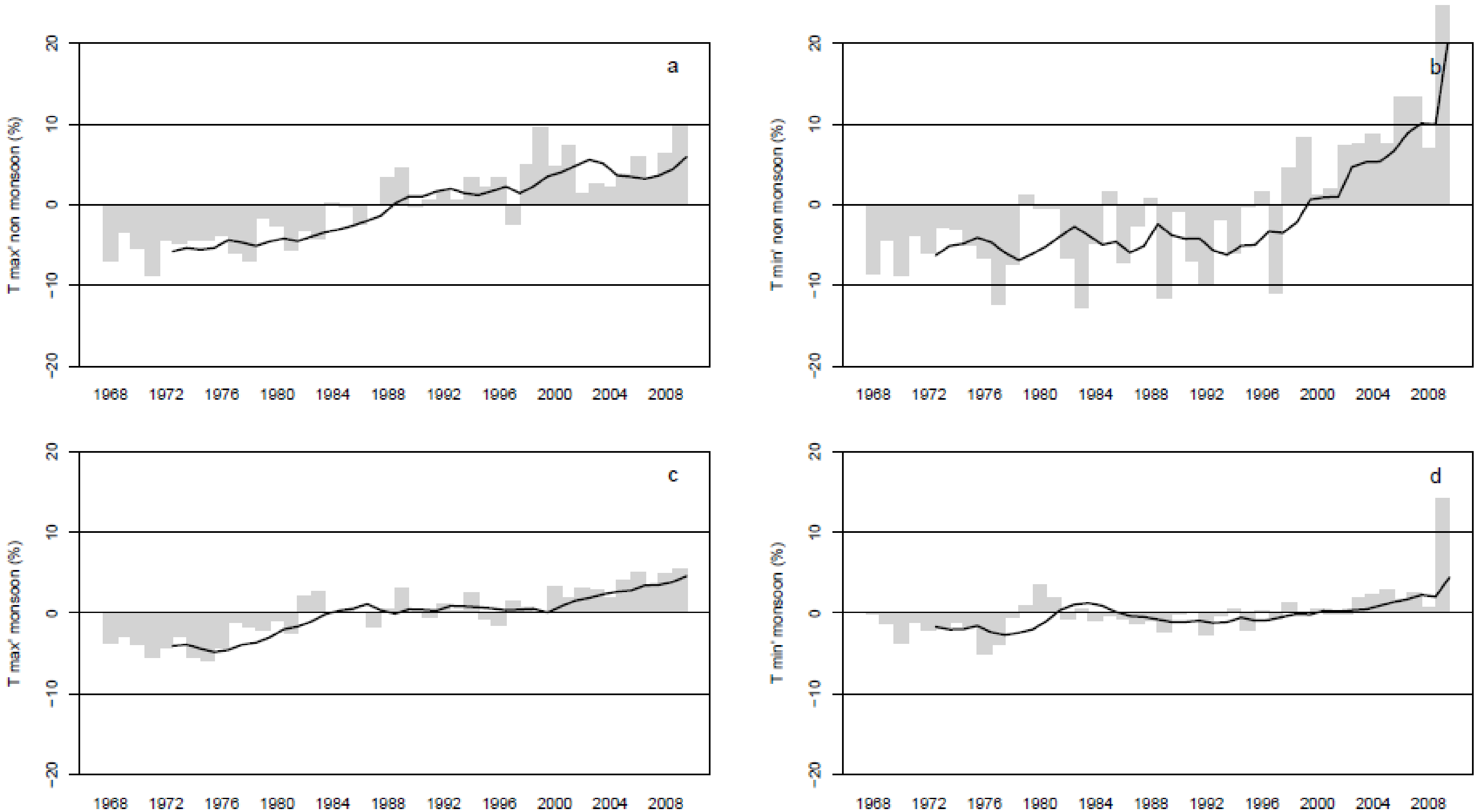

Figure 2: Deviation from long term annual mean max. (a and c) and mean min. (b and d) temperature in non-monsoon (a and b) and monsoon (c and d) period in TIA, expressed in percentage. The line gives the 5 year moving average.

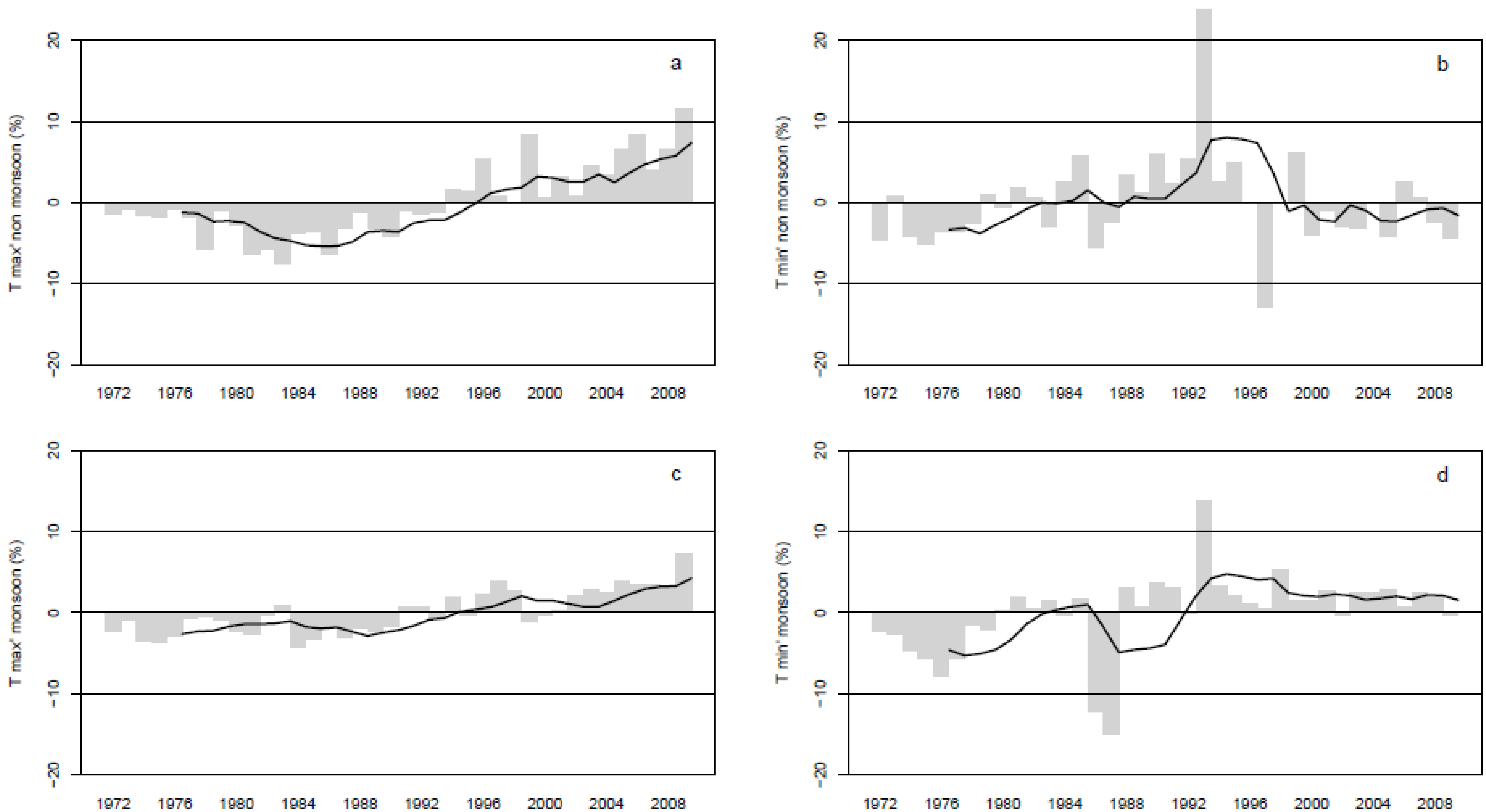

Figure 3: Deviation from long term annual mean max. (a and c) and mean min. (b and d) temperature in non-monsoon (a and b) and monsoon (c and d) period in Godawari, expressed in percentage. The line gives the 5 year moving average.

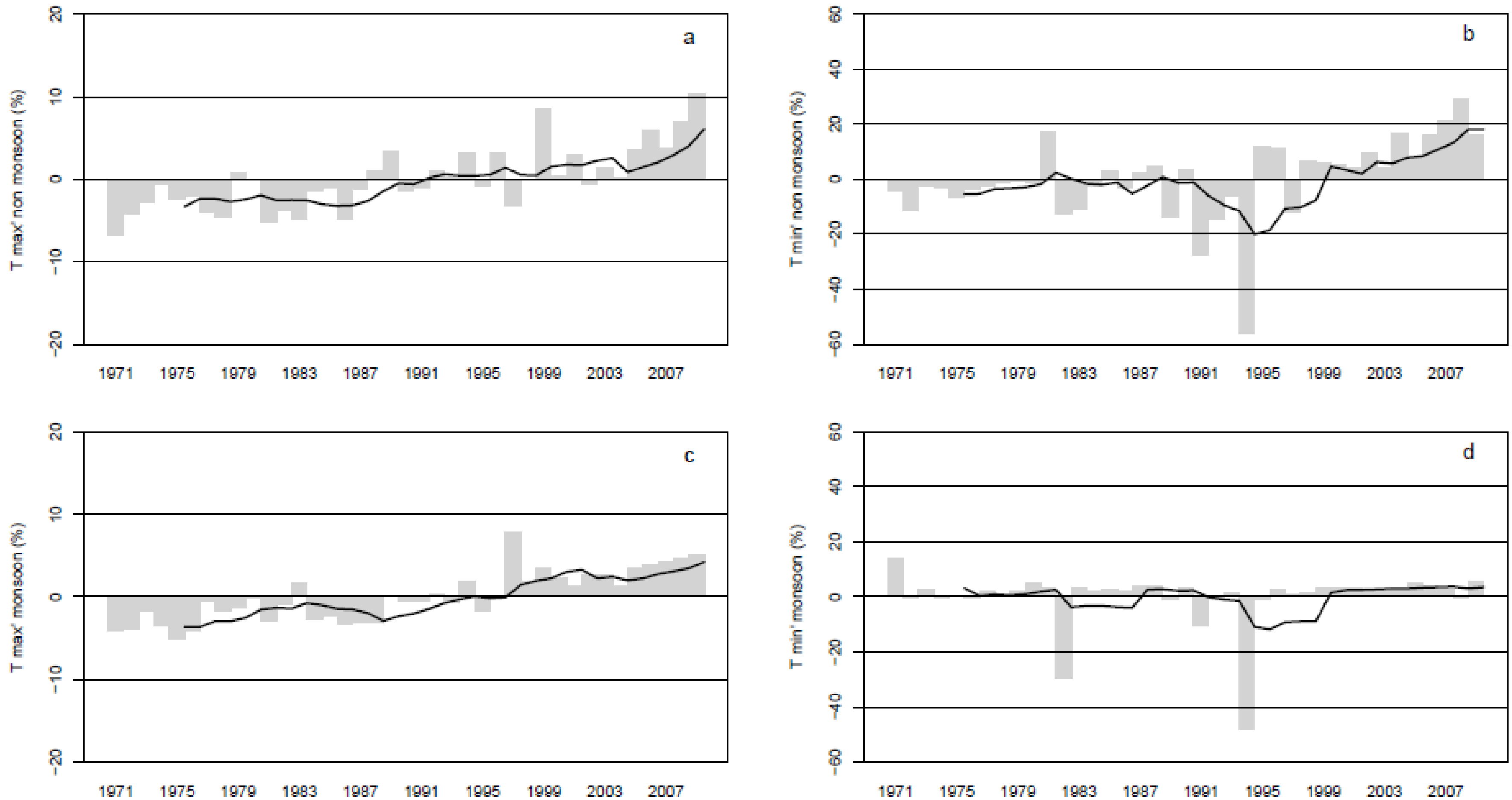

Figure 4: Deviation from long term annual mean max. (a and c) and mean min. (b and d) temperature in non-monsoon (a and b) and monsoon (c and d) period in Panipokhari, expressed in percentage. The line gives the 5 year moving average.

Annex-2
Mann-Kendall trend analysis per month

The Mann-Kendall trend test is significant if P-value is below 0.05 (assumed $\alpha = 0.05$).

Table 1: Kendalls' Tau and two-sided P-value of monthly Mann-Kendall for Khumaltar

	T_{max}		T_{min}	
Month	Tau	P-value	Tau	P-value
Jan.	0.408	0.000	0.172	0.117
Feb.	-0.087	0.433	0.356	0.001
Mar.	-0.040	0.720	0.534	0.000
Apr.	0.142	0.199	0.266	0.016
May	0.150	0.163	0.342	0.002
Jun.	0.184	0.090	0.161	0.137
Jul.	0.298	0.007	0.293	0.008
Aug.	0.375	0.001	0.618	0.000
Sep.	0.328	0.003	0.359	0.001
Oct.	0.412	0.000	0.426	0.000
Nov.	0.413	0.000	0.334	0.002
Dec.	0.036	0.745	0.409	0.000

Table 2: Kendalls' Tau and two-sided P-value of monthly Mann-Kendall for TIA

	T_{max}		T_{min}	
Month	Tau	P-value	Tau	P-value
Jan.	0.579	0.000	0.169	0.119
Feb.	0.507	0.000	0.402	0.000
Mar.	0.403	0.000	0.333	0.002
Apr.	0.335	0.019	0.140	0.197
May	0.284	0.008	0.237	0.029
Jun.	0.503	0.000	0.236	0.029
Jul.	0.542	0.000	0.354	0.001
Aug.	0.598	0.000	0.373	0.001
Sep.	0.696	0.000	0.406	0.000
Oct.	0.560	0.000	0.259	0.017
Nov.	0.596	0.000	0.319	0.003
Dec.	0.526	0.000	0.443	0.000

Table 3: Kendalls' Tau and two-sided P-value of monthly Mann-Kendall for Godawari

	T_{max}		T_{min}	
Month	Tau	P-value	Tau	P-value
Jan.	0.400	0.000	0.023	0.850
Feb.	0.262	0.021	0.157	0.170
Mar.	0.286	0.012	0.046	0.697
Apr.	0.278	0.015	-0.102	0.372
May	0.245	0.032	0.039	0.744
Jun.	0.364	0.001	0.164	0.152
Jul.	0.329	0.004	0.343	0.003
Aug.	0.419	0.000	0.479	0.000
Sep.	0.521	0.000	0.321	0.005
Oct.	0.516	0.000	0.043	0.715
Nov.	0.479	0.000	-0.127	0.269
Dec.	0.530	0.000	0.057	0.624

Table 4: Kendalls' Tau and two-sided P-value of monthly Mann-Kendall for Panipokhari

	T_{max}		T_{min}	
Month	Tau	P-value	Tau	P-value
Jan.	0.338	0.003	0.219	0.054
Feb.	-0.020	0.865	0.495	0.000
Mar.	0.219	0.055	0.301	0.008
Apr.	0.255	0.024	0.243	0.032
May	0.289	0.011	0.091	0.424
Jun.	0.195	0.085	0.211	0.062
Jul.	0.314	0.006	0.034	0.778
Aug.	0.387	0.001	0.200	0.085
Sep.	0.563	0.000	0.387	0.001
Oct.	0.267	0.018	0.348	0.002
Nov.	0.329	0.004	0.388	0.001
Dec.	0.266	0.019	0.506	0.000

Annex-3
Dry Spells

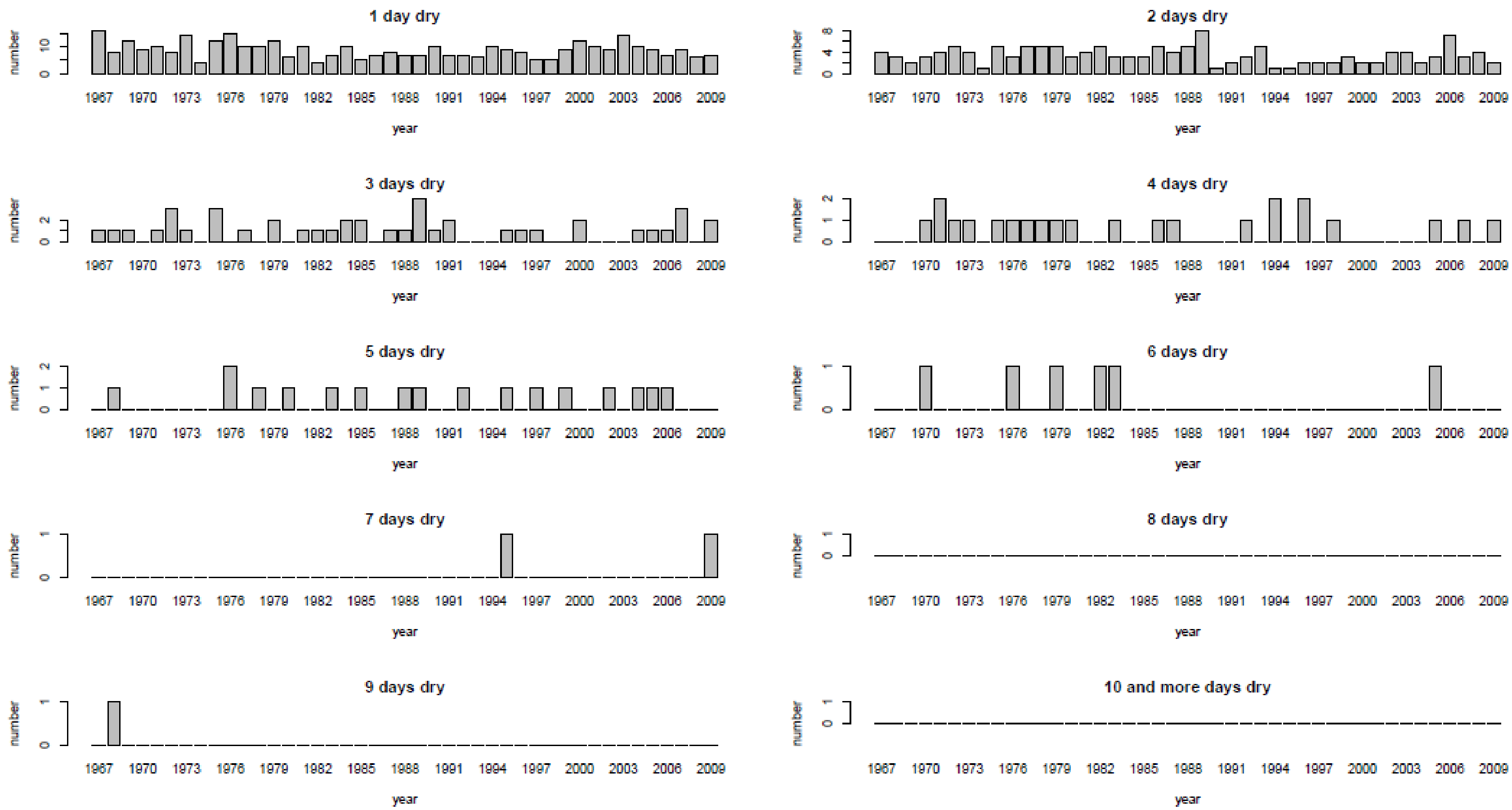

Figure 1: Number and length of dry spells in Khumaltar.

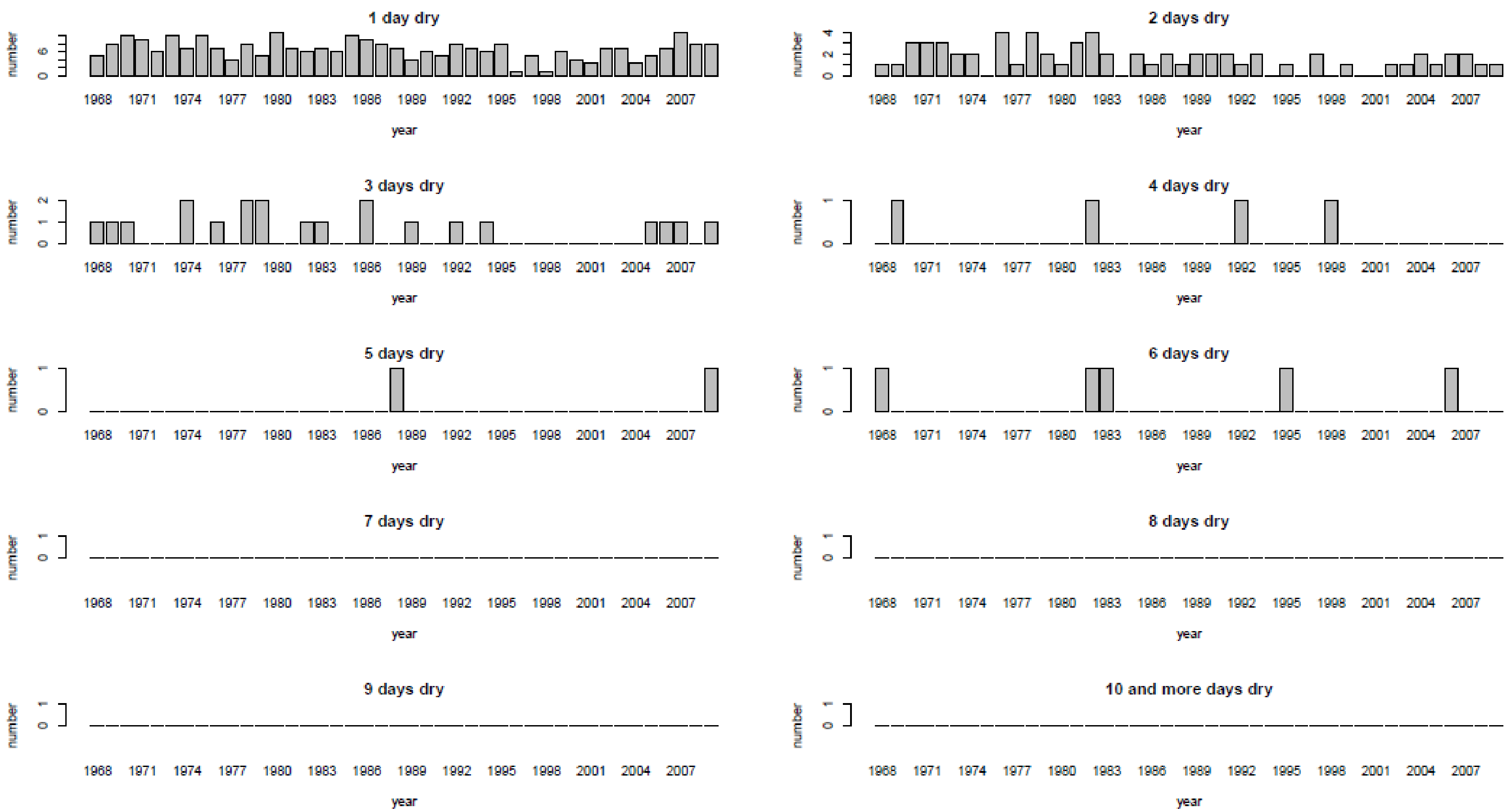

Figure 2: Number and length of dry spells in TIA.

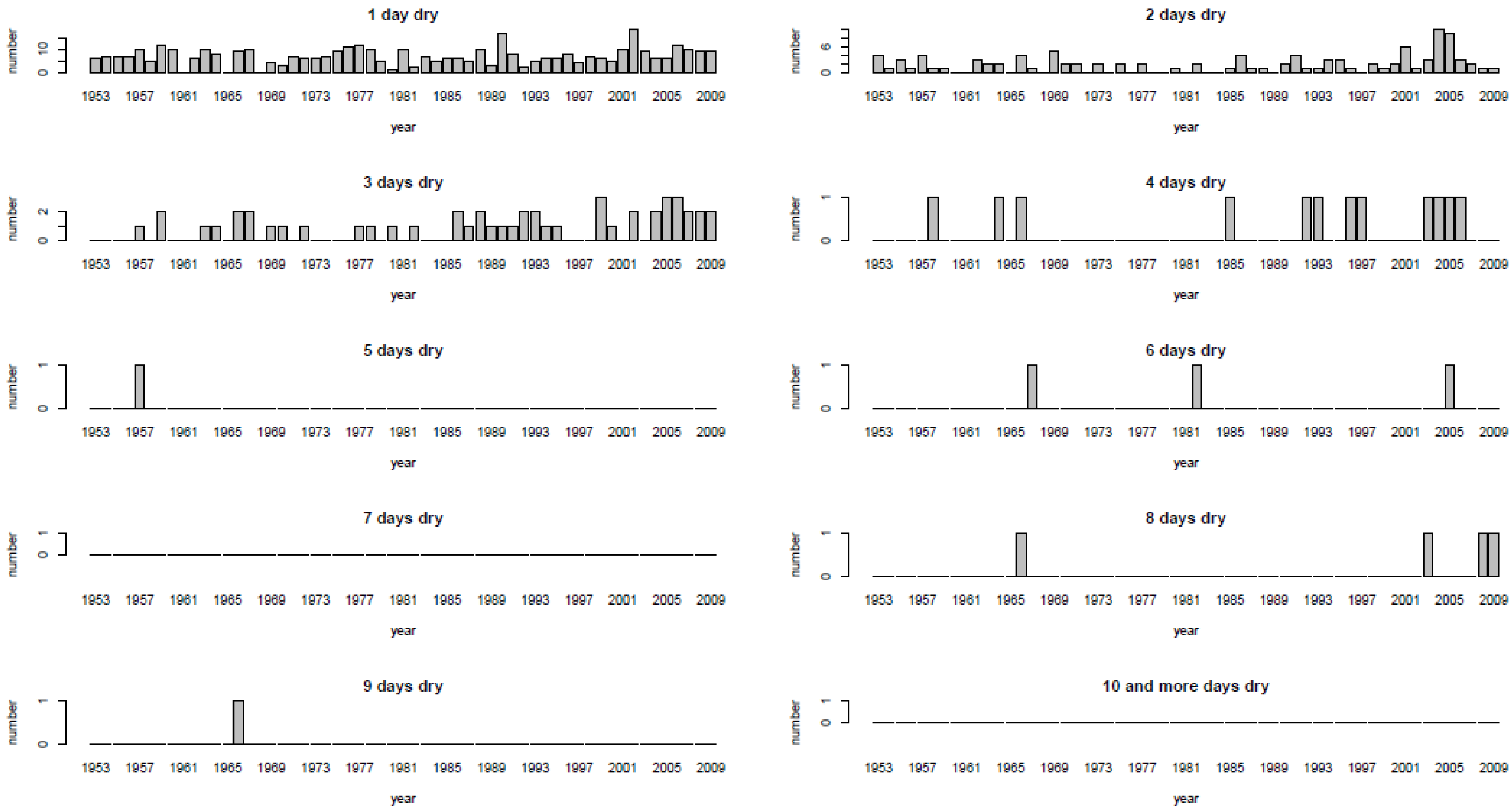

Figure 3: Number and length of dry spells in Godawari.

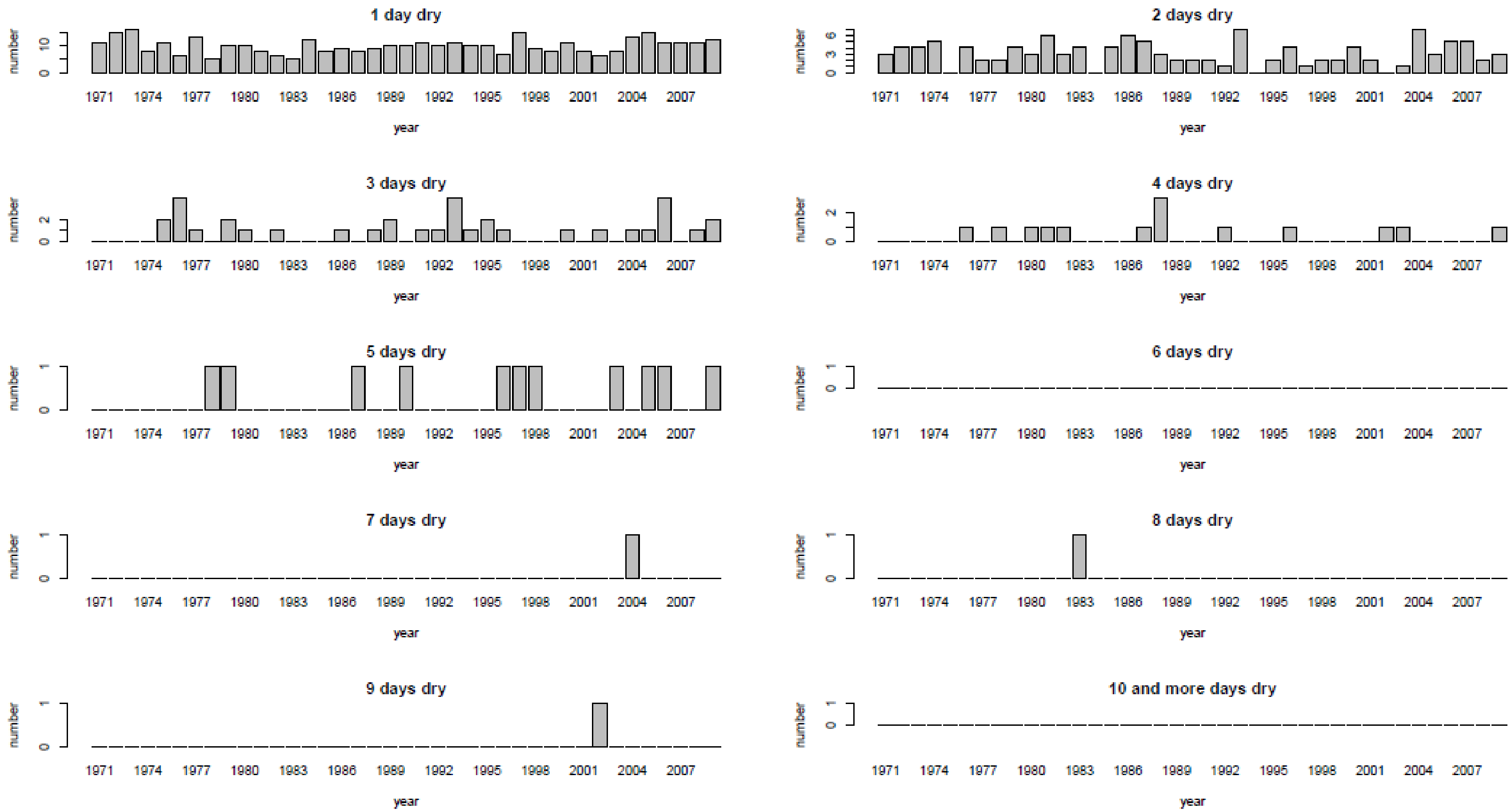

Figure 4: Number and length of dry spells in Panipokhari.

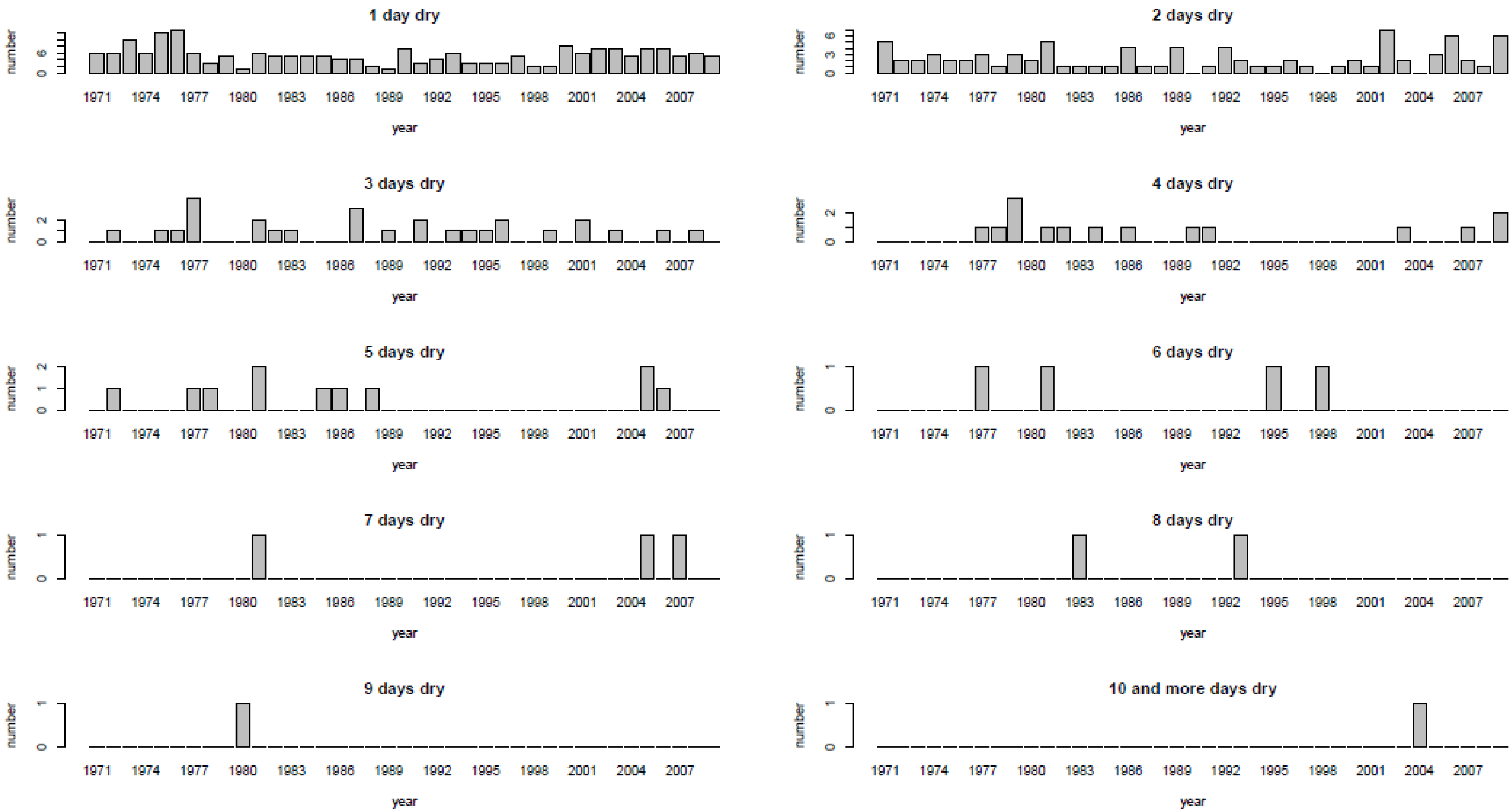

Figure 5: Number and length of dry spells in Sankhu.

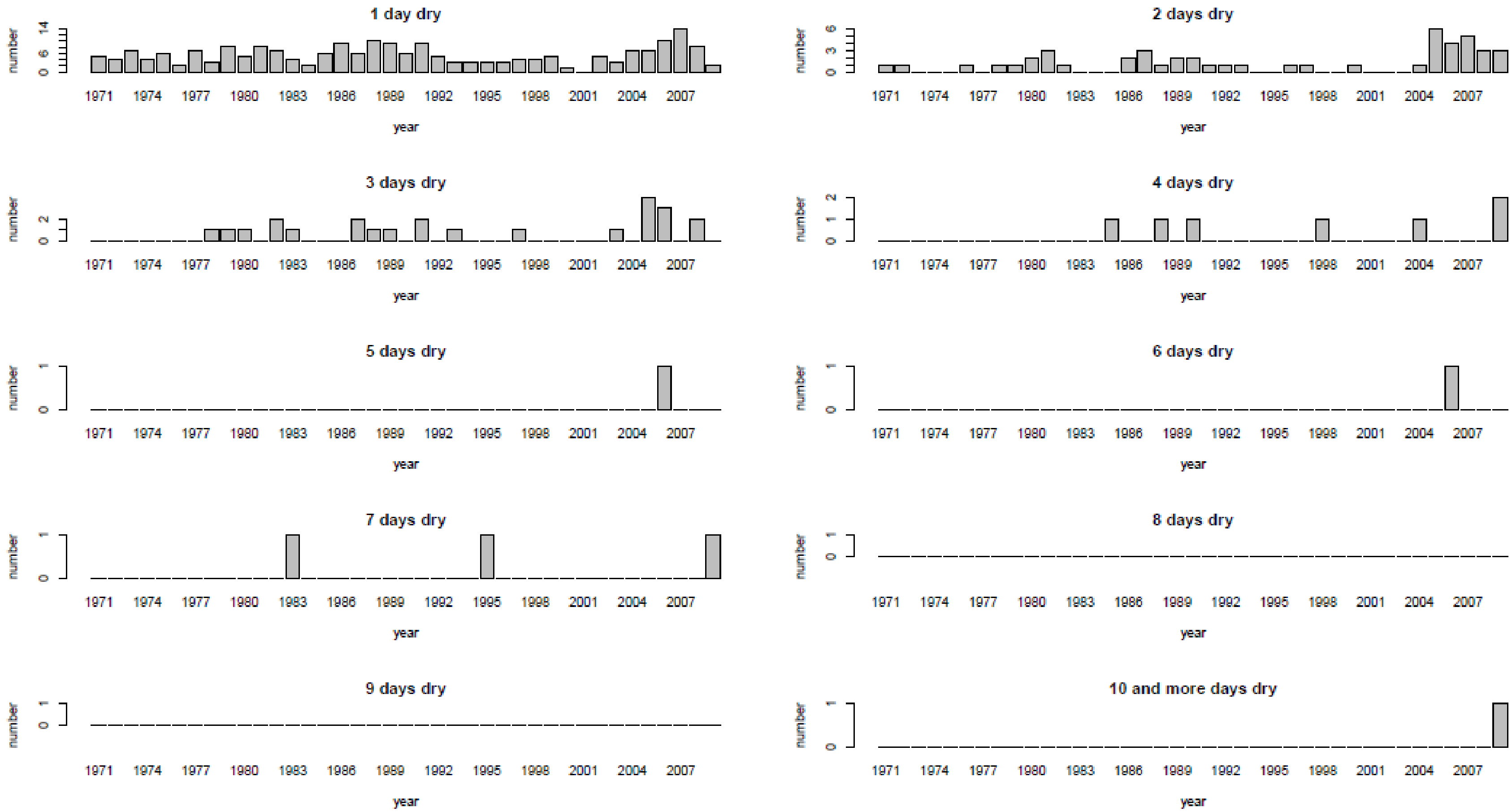

Figure 6: Number and length of dry spells in Changunarayan.

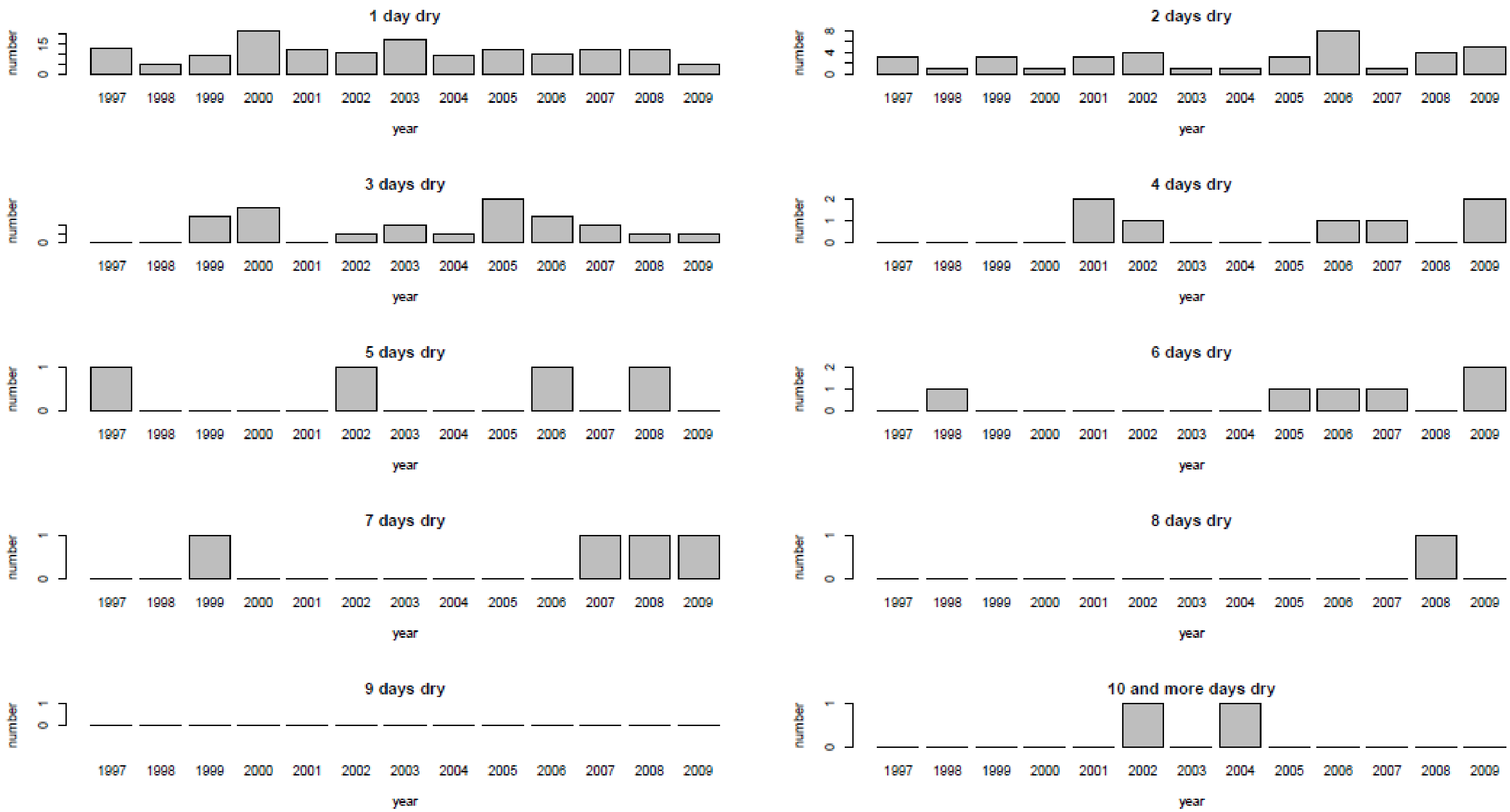

Figure 7: Number and length of dry spells in Naikap.