Climate Change and the impact on Agriculture in Kathmandu valley (Nepal)

Internship Report

Lieke Melsen - March 2012

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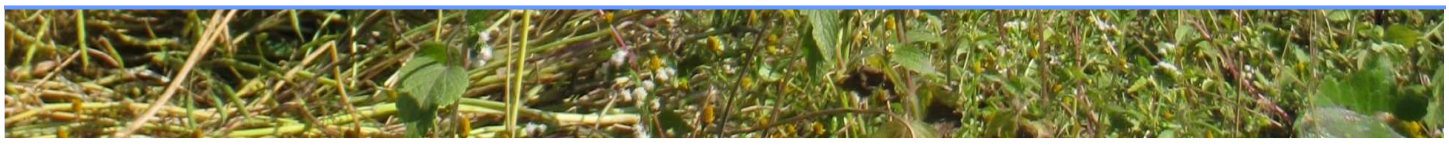
Internship as part of the research project
"Water Security in Peri-urban South-Asia"



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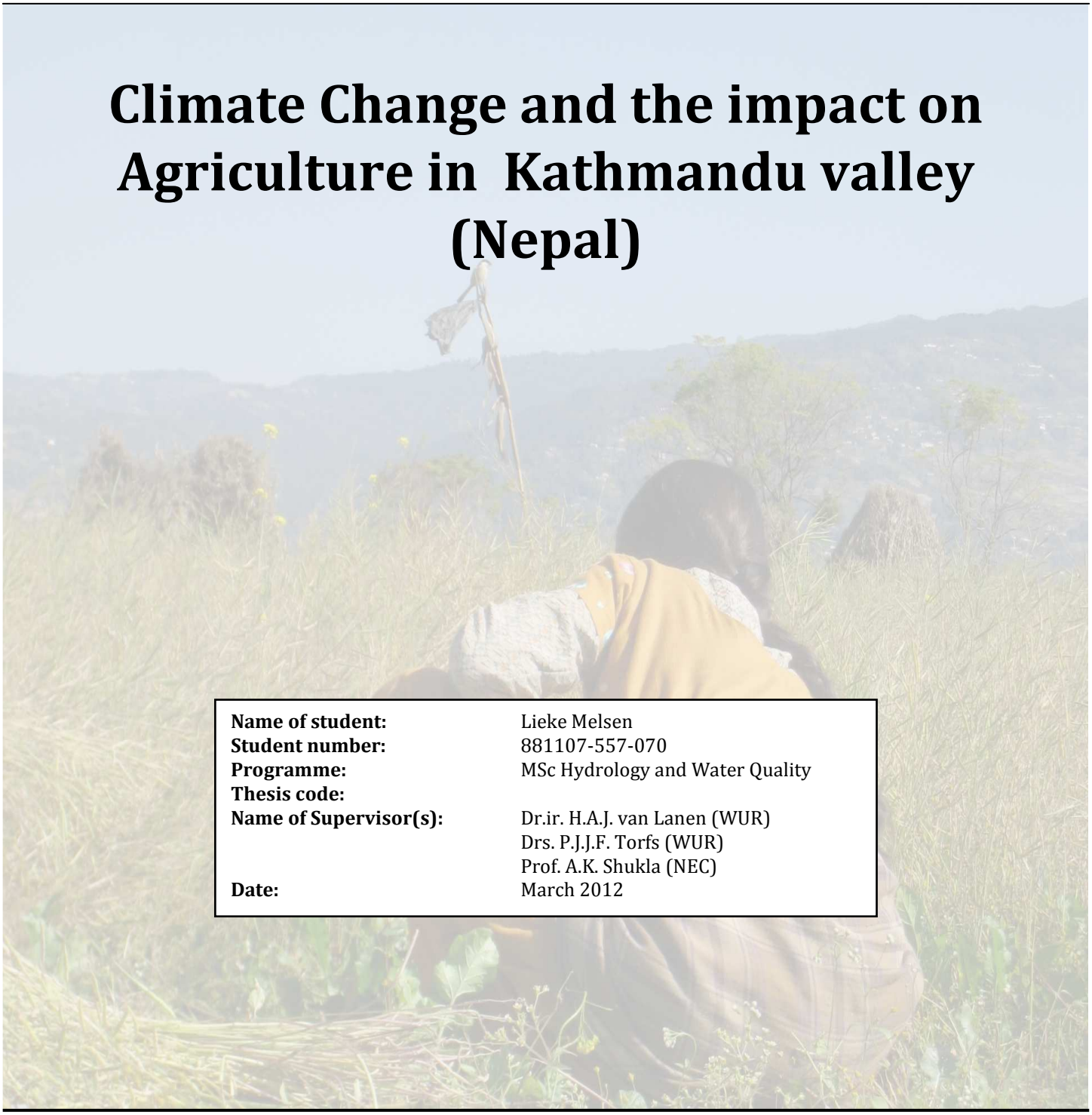

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Abstract

The purpose of this research was to determine the past climate change in Kathmandu valley over the last few decades, and link this to human perception and the impact on agriculture in the peri-urban areas of Kathmandu, Nepal. The study consisted of two major parts: a hydro-meteorological analysis of climatic data, and a study on human perception and adaptive strategies. Next to that, a literature study was carried out to describe possible impacts. For the climate analysis, statistical tests, like the Mann-Kendall test, were conducted. To study human perception on climate change Focus Group Discussions were organized in two peri-urban villages around Kathmandu.
No significant changes in precipitation were found, only the number of extreme rainfall events (>50 mm/day) had increased in most stations. For temperature a significant increase was found, on average a yearly increase of $0.05°C$ for daily maximum temperature and $0.04°C$ for daily minimum temperature. The number of days below $0°C$ had decreased and, on the contrary, the number of hot days ($> 30°C$) increased. For evaporation, no increase or decrease was found. For all the climatic variables there was high spatial variation.
From the Human Perception study it became clear that the perception that the inhabitants of the peri-urban areas have of climate change is to a large extent in agreement with the results from the data analysis. The farmers perceived a less reliable onset of monsoon and accordingly adapted their planting strategy. An increase in insects/pests was perceived and new weed species were observed, what can be the result of the increased temperature. In the perception of the farmers, urbanization is the most determining factor in agricultural development, but climate change is an important side player.

Key Words: *Climate Change, Human Perception, Kathmandu, Impacts, Agriculture*

Preface

Meanwhile already almost four months ago I stepped on the plane from Amsterdam to Kathmandu (via Delhi) for my internship as part of my master 'Hydrology and Water Quality', without any expectation or idea what was waiting there for me. And now, after four months, I can only conclude that I had a good time, which obviously went by before I realized it.

It is hard to explain the feeling you have as a Dutch girl, born and raised five meters below sea level, now having a daily view on the highest mountains of the world. Everyday again I was amazed when the white peaks became visible above the buildings from Kathmandu. The place where I stayed was only five minutes walking from Patan Durbar Square, probably one of the most beautiful squares in the world. And although working sometimes was made tough by load-sheds and bandh's (strikes), I could always find a relaxing moment in just walking around and wonder the rich and deep culture, full of traditions that people were always willing to share and explain.

This internship gave me a good opportunity to see a part of daily Nepali life. It took a while, but I can travel by bus in Kathmandu now independently! Next to that, I got the opportunity to see MSc-thesis presentations from fellow students, and do some interesting fieldwork in the surrounding villages of Kathmandu. Together with my colleague Anushiya we visited an ISET-meeting about Global Climate Change for Younger Professionals, where some interesting statements were made, and I joined the excursion to the drinking water treatment plant in Dhulikel, together with the villagers of Lubhu as part of a development project.

I like to thank Henny van Lanen for the recommendation, Paul Torfs for his help with statistics and programming R, and Hari Krishna Shrestha for helping me with arranging the internship. Of course, I want to thank Professor Shukla for the time he made for me in his busy schedule. I want to thank Rajesh as research coordinator, for arranging the beautiful brand new desk for me, and thanks to Anushiya for all the help, whenever I needed it and the nice conversations we had when there was load-shed (and also when there was no load-shed!). Thanks to all the people who joined the fieldwork and made it a success; 'big' Mahesj, 'small' Mahesj, Rajeshwori, Jagam. And last but not5 least thanks to Monica, who helped me with everything, from field work to shopping for a sari. And I shouldn't forget to thank the canteen-boy, for the tasty roti, chowmein, veg momo and pakoda, and for serving the best milk tea of Nepal.

Hopefully my work can contribute to the research project, and hopefully I will be back in Nepal one day!

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Photo at cover:
Woman working in the field in Jhaukhel, made on 27 November 2011

Summary

Climate change and urbanization are two phenomena contributing to global change, that have received special attention the last decades. In Asia, temperature is expecting to increase up to $5°C$in 2080, and more and more people are expected to live in cities. In many cases, urbanization can further strengthen the effect of climate change and vice versa. This makes especially the peri-urban areas, the areas in the periphery of the urban core, vulnerable for water- and food security challenges in the coming years.

Kathmandu, the capital of Nepal, has an average growth rate of over 4% per year. Due to this urbanization, the water demand has increased significantly. The official organization responsible for water supply (KUKL) is not able to fulfill the demand, causing rampant water mining in the peri-urban areas from private vendors and water service providers. This uncontrolled water extraction in the periphery of the city leads to (ground)water mining and water shortage in the peri-urban areas. Another effect from the rapid urbanization is the settlement of industry, e.g. sand mining and brick kilns, in the outer areas of Kathmandu, increasing the water demand even further and enhancing pollution and soil degradation. Climate change can further put the water availability and environmental change at risk. All these factors have impact on the agricultural production in the peri-urban areas, and therefore influence the food-security of the inhabitants. Agricultural practices and patterns will probably have to be adapted as a response to climate change. Therefore, the main question in this research is:

> *Are there significant changes in climate in Kathmandu valley, and what are the implications for agriculture?*

To identify the changes in climate in Kathmandu valley over the last decades, a statistical analysis for rainfall, temperature and evapotranspiration had been conducted with data from seven different stations. The analysis included linear regression methods and the (Seasonal) Mann-Kendall trend test, given value with Sen's slope estimator. To identify the perception on climate change of the inhabitants of the peri-urban areas, and the implications for agriculture, Focus Group Discussions (FGDs) were organized in two peri-urban villages: Dadhikot and Jhaukhel.

For rainfall, no clear increasing or decreasing trend was found for the number of rainy days. An increase in events with >50 mm precipitation per day was found for most stations. There are no significant (based on Seasonal and ordinary Mann-Kendall test) increasing or decreasing trends in long-term total precipitation.
For temperature, a clear decrease in number of days below $0°C$ was found for all stations. The number of hot days ($> 30°C$) had increased for all stations. Both the highest daily T_{min} and highest daily T_{max} and the lowest T_{min} and lowest T_{max} of the year had become warmer. Increase in temperature was lowest in summer season and the strongest in fall and winter season for both T_{min} and T_{max}. Based on Sen's slope, calculated for the significant trends, T_{min} and T_{max} showed on average an increase of respectively $0.04°C$ and$0.05°C$ per year.
No increase or clear decrease in PAN-evaporation and evapotranspiration was visible over the period where data was available from. An increase as a result of increasing temperature would have been expected, but 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'. It seems that evapotranspiration had only increased in summer season (June until August), and decreased in all the other seasons. This conclusion should be treated carefully, because there was missing data and only a short time period.

The change in climate in the last few decades as perceived by the inhabitants of the peri-urban area was in broad lines in agreement with the findings of the data analysis. Striking was that a clear decrease in precipitation was perceived, which was only visible as a weak non-significant trend in the data. A possible explanation can be that water shortage in general, caused by urbanization, gives the idea of less precipitation.
The people also perceived colder winters, while in the data analysis temperature increase was actually most pronounced in winter. The participants of the FGD explained this with the new way of building houses, which isolate less than the traditional houses.

As adaptive strategy to a less reliable onset of monsoon, farmers do the rice planting nowadays in patches according to the available water, in stead of planting the complete fields in a few days. The only change in crop pattern that had taken place in some farms around Kathmandu was the shift from wheat to vegetable cropping during winter and spring. This is mainly for economic reasons and not induced by climate change. During 'The Green Revolution', farmers have shifted from traditional crop varieties to High-Yielding Varieties (HYV) and hybrids. These varieties give higher yield, but are more vulnerable to climate variability and therefore an extra concern for future food-security. Insects and pests have strongly increased the last decades, and accordingly the use of pesticides. Also new weed species have been observed. Both might be the result of the rising temperatures. Productivity is showing a declining trend since the 1980s, despite the increased input of irrigation, fertilizer and plant protection.

It seems that the agricultural sector in the peri-urban areas perceived urbanization as the most dominant threat for agriculture, but the less reliable onset of the monsoon, the sensitivity of HYV and hybrid varieties to climate variability, the increase in insects/pests and new weeds probably as a result of climate change, and the further emphasized decrease in water availability probably due to climate change, certainly also play a role in agricultural productivity and food security.

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1 Introduction

Climate change and urbanization are two phenomena contributing to global change, that have received special attention the last decades. Since 2008 more than half of the world population lives in towns and cities. And this number is expected to increase the coming twenty years, especially in Africa and Asia (UNFPA, 2007). Climate change is expected to cause an increase in mean annual temperature up to $5°C$ in 2080 in Asia (Cruz et al., 2007). Rainfall intensifies, and gets less predictable.
The combination of urbanization and climate change leads to water security concerns, like the consequences for the livelihood and the wellbeing of the residents of urban areas. To raise awareness and to investigate water security in South-Asian urban areas the research project *"Water Security in Peri-urban South Asia: Adapting to Climate Change and Urbanization"* was initiated. The project started in July 2010 and aims to *"develop understanding on established and emerging water security concerns resulting from urbanization and climate change and thereby developing adaptive capacities of the residents in the peri-urban areas in four south Asian cities"* (Shukla et al., 2011). The cities participating in the research are Hyderabad and Grugaon in India, Khulna in Bangladesh and Kathmandu in Nepal. Nepal Engineering College (NEC) is responsible for the research in Kathmandu, Nepal.

Problem Description
Nepal has one of the highest rates of urban growth of Asia, with an average growth of 6.6% per year (compared to e.g. India with 2.9%, Pakistan 4.4%, and Bangladesh 5.3%)(Thapa and Murayama, 2010), but is still a country where agriculture is the main economic activity for 80% of the population (Regmi et al., 2002). 96% of the available water in Nepal is used for agriculture (Lal, 2011).

Since the beginning of the 1980s, Kathmandu has an average growth of more than 4% per year (Thapa et al., 2008). Figure 1 shows satellite pictures of how Baneswor area, now a quarter within Kathmandu city, converted from agricultural area to city core. The rapid urban growth

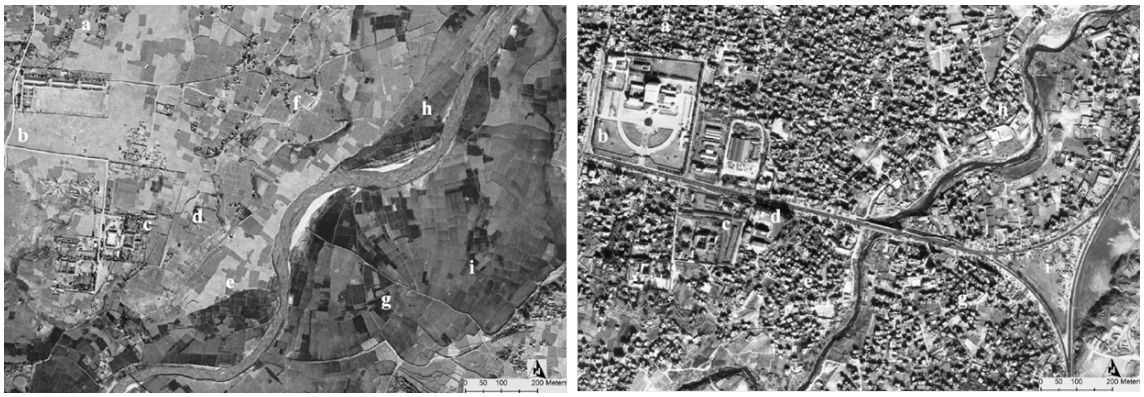

Figure 1: Satellite images of Baneswor area in the east of Kathmandu City in 1967 (left) and 2000 (right), adapted from Thapa and Murayama (2010).

of Kathmandu has significantly increased the water demand. Because the Kathmandu Upatyaka Khanepani Limited (KUKL), which is responsible for the water supply in the city, is not able to fulfill the demand, private vendors and water service providers pump up ground- and spring water from the peri-urban areas of Kathmandu and transport it to the city core. This rampant water mining in the periphery of the city leads to (ground)water mining and water shortage in the peri-urban areas. Pandey et al. (2010) found that the groundwater levels in Kathmandu valley have dropped 13 to 33 m in the period 1980-2000, and 1.4-7.5 m during 2000-2008.
Next to that, the rapid urbanization has established the settlement of industry in the outer areas of Kathmandu, increasing the water demand even further. Lack of water for irrigation, soil degradation, pollution, and the conversion of agricultural land into settlements and industry, had their impact on the agricultural production in the peri-urban areas, and therefore influences the food-security of the inhabitants. Another influence from urbanization on the peri-urban areas is

the shift in occupation. Where the main occupation always used to be agriculture, due to the opportunities given by the city more and more people find other jobs for their livelihood.
Another global threat, with consequences at the local level, is climate change. Chaulagain (2006) states that climate change in Nepal is even going faster than the global average. Increasing temperatures and changing precipitation patterns can worsen the water availability even more and affects crop production (Malla, 2008). Agriculture depends highly on the climatic conditions (Alam and Regmi, 2004), and it is likely that a changing climate affects growing season length, soil moisture regimes and heat stress to the plant (Chhetri et al., 2012). Agricultural practices and patterns will probably have to be adapted as a response to climate change. Ever since the 1990s, when population growth exceeded increase in agricultural productivity, Nepal became a net importer of food (Chhetri et al., 2012). To ensure food-security for an ever growing population, it demands a productive agricultural system.
The combined effect of climate change and urbanization on water- and food security in the peri-urban areas will be the main scope of this research, with focus on the Kathmandu valley. To gain insight in the awareness of climate change and adaptive strategies to climate change of inhabitants of the peri-urban areas of Kathmandu, hydro-meteorological records were compared with the inhabitants perception with regard to a changing climate and the subsequent consequences for water availability and food security. Next to that it was investigated if people have implemented adaptive strategies or changes in the agricultural production system as a consequence of climate change. Urbanization can strengthen the effects of climate change and vice versa. It will be a challenge to make a distinction between the effects mainly caused by urbanization and the effects mainly caused by climate change.
Comparable research has already been conducted especially in the African continent where also developing countries with agriculture as main economic activity can be found. For example, Sofoluwe et al. (2011) researched farmers' perception and adaptation to climate change in Nigeria, and Deressa et al. (2011) did the same for farmers in the Nile basin of Ethiopia. Also in this region, few studies on the perception of people on climate change have been conducted by, for example, Chaudhary and Bawa (2011) in the West Bengal in India and the Ilam district of Nepal and Manandhar et al. (2011) in the west of Nepal.

Figure 2 gives a schematization of the problem description. Both climate change and urbanization have direct and indirect impact on agriculture.

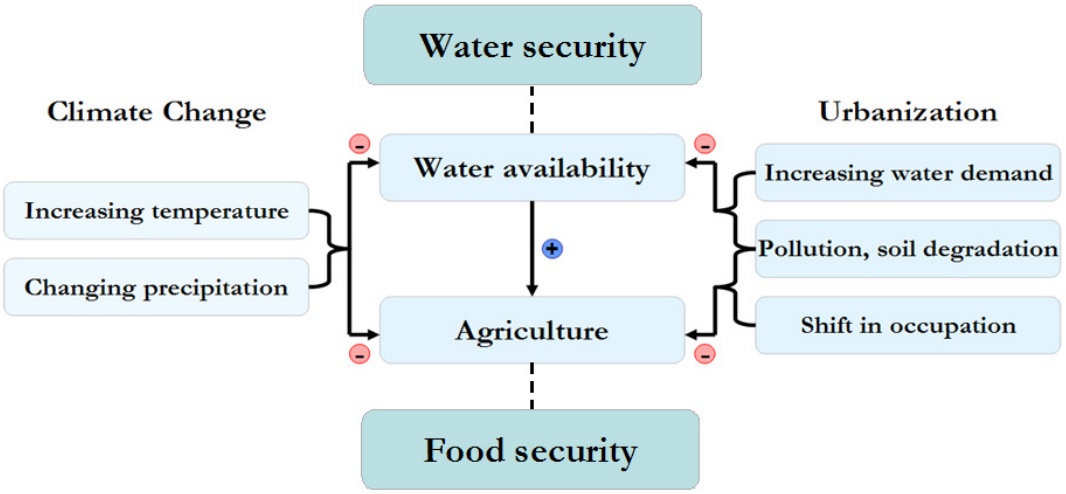

Figure 2: Scheme of factors influencing water availability and agriculture.

Objectives and Research questions
Goal of this internship is to describe trends in climate records from the Kathmandu valley and to link this to adaptive strategies in agricultural practice in the peri-urban areas of Kathmandu. The main question in this research is:

Are there significant changes in climate in Kathmandu valley, and what are the implications for agriculture?

This main question divides this research in two parts: a hydro-meteorological analysis part, and the part investigating the perceived climate change and the subsequent adaptations to climate change by the inhabitants of the peri-urban areas. This leads to the following research subquestions:

Hydro-meteorological analysis

- Is it possible to identify trends and patterns, e.g. dry spells, in precipitation in and outside the monsoon?
- Are there trends and/or patterns in minimum and maximum temperature detectable?
- Are there trend patterns detectable in evapotranspiration?

Human Perception

- How do inhabitants of the peri-urban areas perceive climate change?
- Which adaptations in cropping schemes and patterns have occurred over the last decades, and to what extent can these changes be attributed to climate change?

The research questions are subdivided in some more detailed specific objectives:

- To analyze climatic change in Kathmandu valley over the past few decades.
- To find the link between observed climate change and perceived climate change from inhabitants of the peri-urban area.
- To analyze consequences of climate change on agricultural practice in the peri-urban area.
- To document the adaptive strategies of the people to water uncertainty and food production systems.

The applied definitions for the key-terms used in the goal, research questions and objectives can be found in Appendix A.

Approach
This study is binary. The first part of the study is the hydro-meteorological analysis of climatic data from Kathmandu valley. The results were complemented with literature to describe potential impacts of climate change on peri-urban areas. The second part existed of research on the perception and adaptive strategies to climate change of inhabitants of the peri-urban areas of Kathmandu. Finally, both researches were linked.

A hydro-meteorological study of climatic data was conducted using linear regression and statistical tests (e.g. Mann-Kendal, (Stahl et al., 2010)) applied direct to the data and applied to several indices. The analysis mainly focused on the effect of climate change on food security, and therefore emphasize was put on monsoon-rainfall, which plays a large role in agriculture.
Analysis of the climatic data of Kathmandu valley was assumed to give insight in the past climate change in the valley over the past few decades. With a literature study it was anticipated to get insight in the potential impacts of the occurred change in climate on livelihood, agriculture, disaster events and human health. With this knowledge combined with a pre-survey, a questionnaire for the Focus Group Discussions (FGD) to identify human perception will be designed.

To gain insight in the perceived climate change and subsequent impacts by the inhabitants of the peri-urban areas, FGDs were organized in two villages in the peri-urban areas of Kathmandu. A FGD is a rapid, semi-structured data gathering method in which a purposively selected set of participants are gathered to discuss issues and concerns based on a list of key themes drawn up by the researcher (Kumar, 1987). Although results from a FGD cannot be generalized and only include a small sample of the population, the advantage of FGDs is that it is cost-effective, it helps to explore the depths and nuances of ones opinion, and with the discussions taking place it helps with obtaining more and richer information.
The results from the FGDs gave information about the local perception on climate change and

the impacts this had on the peri-urban areas. The comparison between perceived and observed climate change can be a measure for the vulnerability of the peri-urban areas to climate change.

Outline
In Chapter 2, the locations of the field sites, where the research had been conducted, will be discussed. For the hydro-meteorological analysis, data from seven different meteorological stations throughout the valley were used. For the human perception part, two peri-urban villages in Kathmandu valley were selected. In Chapter 3, Methods, the methodology of both analysis-parts is discussed, and a short description of the setup of the literature study. For the hydro-meteorological analysis the methodology includes the description of selected indices and trend analysis. For the human perception part, the design of the pre-suvey and FGDs are discussed. Chapter 4 describes the results of the research, and also includes an interpretation of the results. In this chapter, a comparison is made between the hydro-meteorological analysis and the human-perception study. Finally, in Chapter 5 conclusions are drawn about climate change in Kathmandu valley and the impact of climate change on agriculture in peri-urban Kathmandu valley.

Appendix B contains a conversion table from the Nepali calendar to the conventional calendar and some units often used in Nepal to express yield.

2 Data and Field Sites

This research was conducted in Kathmandu valley. This valley is located in the middle-mountain region of Nepal (see Figure 3), a relatively small-sized country clamped between China and India in South-Asia. Kathmandu valley gives home to Kathmandu, the capital city of Nepal. The average height of the city is 1350 meter above sea-level, and the climate in the valley is sub-tropical cool temperate (Thapa et al., 2008). The Bagmati river is the biggest river flowing through the valley. Kathmandu valley has an area 684 km^2, of which 14% is urban center (Thapa and Murayama, 2010). The valley is subdivided into smaller Village Development Committees (VDCs), the lowest organizational governmental layer. In 2009, Kathmandu valley counted 2.2 million inhabitants (Thapa and Murayama, 2010). Rutkowski et al. (2007) estimated that 59% of the valley is used for agriculture, of which 20% is formally irrigated, and the other 80% informal (e.g. with untreated wastewater). The average size of landholding is in the Bhaktapur area 0.16 ha. and in the Kirtipur area 0.11 ha. (Rutkowski et al., 2007). The farmer' households typically use family labor for weeding, harvesting and irrigation. Sometimes external laborers are hired to help with the paddy (rice) planting (Rutkowski et al., 2007). The dominant summer-crop in Kathmandu valley is paddy. In winter season wheat, mustard, potatoes and vegetables are cultivated.
In the 1970s, the development of chemical fertilizer enhanced what is known as 'The Green Revolution' in South-Asia (Khan and Shah, 2011). Also in Kathmandu valley the Green Revolution gave rise to crop yields, which increased tremendously by the use of chemical fertilizer. But currently, excessive use of chemical fertilizer, together with extensive use of pesticides leads to several problems like health risks, a disrupted pest-predator balance, and soil degradation, finally leading to decreasing yields again.

The first part of this research consisted of a hydro-meteorological analysis of climatic data of

Figure 3: The location of Kathmandu valley in Nepal, adapted from Thapa et al. (2008).

Kathmandu valley. The first section will give a description of the stations where climatic data for this research was used from. For seven different locations climatic data was gathered from the Department of Hydrology and Meteorology, Government of Nepal.
The second part of this research included group discussions with inhabitants of two selected peri-urban sites in Kathmandu valley. The second section of this chapter will give a description of the field sites where the FGDs were organized.

2.1 Field sites climatic data

There were seven sites in Kathmandu valley where meteorological data on a daily, weekly and monthly basis was available for analysis. An overview of these field sites can be found in Table 1. The maximum distance between the stations is less than 25 km, the difference in height is maximum 208 m (between Panipokhari and Changunarayan). Figure 4 shows where the different stations are located within the Kathmandu valley (Shukla et al., 2011). The stations TIA and Panipokhari are situated within Kathmandu City. Khumaltar lies in the urban area of Patan (Lalitput), which was converted from agricultural land to urban area later than the surroundings of Panipokhari and TIA. The stations Godawari and Sankhu are situated furthest away from the urban center. This information was assumed to help with gaining insight in the possible development of an urban heat

island (Mitchell, 1961).

Table 1: Meteorological stations in Kathmandu valley, adapted from Shukla et al. (2011)

Index	Station	Location (deg)		Altitude (m)
		Lat.	Long.	amsl[1]
1029	Khumaltar	27°40'	85°20'	1350
1030	TIA	27°42'	85°22'	1337
1022	Godawari	27°35'	85°24'	1400
1039	Panipokhari	27°44'	85°20'	1335
1059	Changunarayan	27°40'	85°25'	1543
1035	Sankhu	27°45'	85°29'	1449
1076	Naikap	27°41'	85°15'	1520

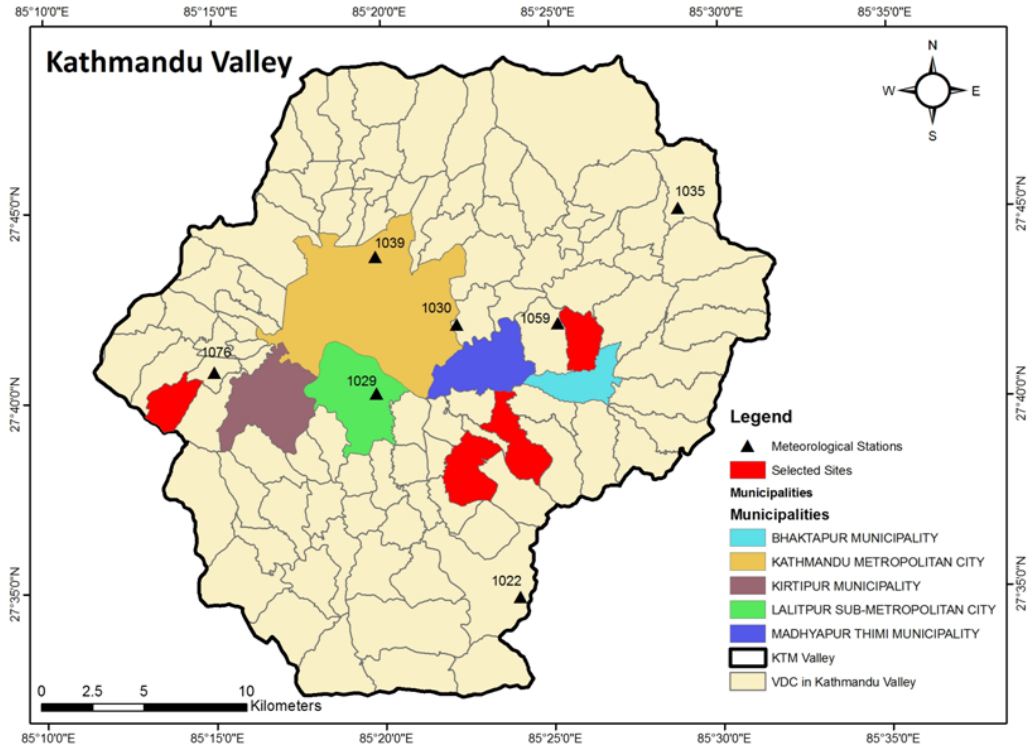

Figure 4: Location of the seven field sites in Kathmandu valley, from Shukla et al. (2011).

The available data for the different climatic variables and the measurement period are given in Table 2. If data was missing, the average of the closest sites was taken to give an estimation of the missing data. Sometimes there was not enough information available of the surrounding sites, the data was then named Not Available (NA).

Rainfall

The records vary in length. Godawari had a precipitation record of 57 years. Khumaltar 43 years, TIA 42 years, and Changunarayan, Sankhu and Panipokhari have a record length of 39 years. For location Naikap only 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 has been taken into consideration when analyzing the

[1] above mean sea level

Table 2: Available climate variables and covered period with daily measurements per station (Shukla et al., 2011)

Index	Station	Rainfall	Temperature	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				

results.
The available data for precipitation 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 overestimations.

Temperature
For the temperature data series, four stations had available data (see Table 2): Khumaltar for 43 years, TIA for 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 assumed to occur between 4.00 AM and 5.00 AM and thus measured in that hour, the maximum temperatures were assumed to occur in the early afternoon and were measured between 1.00 PM and and 3.00 PM.

Evaporation
PAN-evaporation data were measured only at two stations; Khumaltar and TIA. The Khumaltar data had a large data gap between 1986 and 2001, and for TIA a large data gap existed in the period 1983-1998. To calculate evapotranspiration with the Penman-Monteith equation (Allen et al., 1998), wind-data was required. Khumaltar station is an agro-meteorological station, measuring wind speed at 2 m height. At TIA, an aeronautical measurement station, wind speed was measured at 10 m height.

2.2 Field sites group discussions

Group discussions to give an idea of the perception of climate change in peri-urban areas were held at two peri-urban villages around Kathmandu: Dadhikot and Jhaukhel. In research parallel to this study, the same discussions were organized in Matatirtha and Lubhu. The location of the villages in relation to Kathmandu is given in Figure 5. Dadhikot and Jhaukhel are both situated in the eastern part of Kathmandu valley. More detailed information is given below, and is based on Shukla et al. (2010).

Dadhikot
Table 3 gives some general information of this VDC. Far the largest part of the households has agriculture as primary activity: 78%, followed by governmental jobs (11%) and business (5%). Although agriculture is the major source of income for a majority of the Dadhikot population, off-farm employment has increased. 25% of the households has women working outside the traditional agricultural sector. An important development stimulating this shift in occupation is the construction of a good road to the city and an improved communication network. The good road increased the possibilities of transportation of goods and services and therefore stimulated the economic and livelihood opportunities of the inhabitants.
The access to water is arranged differently for the different households. 12% of the households uses stone spouts as drinking water source, 2% dug wells, 1% sump wells and 1% uses other sources. Far the largest group of households (84%) is supplied with pipe water. The construction of the piped drinking water scheme for Dadhikot VDC started only after 1984. After 1995, the number

Figure 5: The four locations where field visits were held (adapted from google.maps).

Table 3: General information Dadhikot (adapted from Shukla et al., 2010)

AREA	6.27 km^2
POPULATION	7,244
MALE	3,623
FEMALE	3,621
HOUSEHOLDS	1,352

of drinking water schemes increased strongly, due to rapid population growth and urbanization. Currently, five different drinking water schemes are in operation, the largest serving 1400 households. Due to the easy accessibility and the good geographical position close to Kathmandu and Bhaktapur, Dadhikot is still a popular destination for new settlers. To meet the subsequent increasing water demand, a deep tube well has been constructed in 2008. In 2010, a water storage tank with a volume of 200 m^3 is constructed.

Beside drinking water, the people of Dadhikot are also struggling for irrigation water, with the upstream Gundu VDC (in Figure 5 northeast of Dadhikot). There is only one source for irrigation water, the canal 'Mahadev Khola Raj Kula'. During periods of water shortage, all the irrigation water is used by upstream farmers, making the downstream farmers more and more dependent on rain-fed farming. An alternative way to gain irrigation water is the use of waste water from the Hanunate river for irrigation, although during dry season the pollution level in the river increases, making the water less usable for irrigation. 62% of the farmers in the area have their own pump for lifting waste water from the river for irrigation (Sada, 2010).

The meteorological stations located closest to Dadhikot, and therefore considered most representative, are Godawari and Changunarayan.

Jhaukhel

General information of Jhaukhel is provided in Table 4. Agriculture is no longer the major activity in Jhaukhel (Shukla et al., 2011). A significant area of agricultural lands are leased for sand mining and brick industry, and were converted into building plots. The whole area has a good road network connecting the VDC of Jhaukhel to Kathmandu and Bhaktapur. There is electricity

supply and a telephone connection.

Table 4: General information Jhaukhel (adapted from Shukla et al., 2010)

AREA	5.41 km^2
POPULATION	8,705
MALE	4,354
FEMALE	4,351
HOUSEHOLDS	1,746

Drinking water is supplied by four different schemes. One of them is the Changunarayan-Duwakot-Jhaukhel Community Drinking Water Supply Scheme, which supplies drinking water to Changunarayan, Duwakot and Jhaukhel for 2.5 hours every morning. This scheme is initiated in 1982 and has been in use from 1993 onwards. The supply from the system is constrained, making people in the area dependent on dug wells and tube wells.
The only source of drinking water supply in Jhaukhel is groundwater, which is the main drinking water source during the dry season. A rich groundwater business has developed over the years, with several entrepreneurs investing in groundwater for commercial use. Seven water bottling industries are officially registered, but there are sixteen more unregistered illegal water extractors. Commercial water extraction from dug wells and deep boring at individual level is growing and has been emerging as a source of good income. Estimated is that 200 tankers per day are exported from the area. The extracted water is used to supply the core urban areas in Kathmandu and Bhaktapur.

Besides groundwater mining, excavation of sand is a growing industry in Jhaukhel. For this purpose, large areas of agricultural land are dug out. After mining the sand, the land usually is sold for housing plots. Currently there are 26 sites where sand mining takes place, of which only 13 have official license. The sand mining leads to soil erosion, landslides and damage to the surrounding agricultural lands and crops, but the owners of the sand mine have their ways to suppress the voice of the local farmers.
Similarly, brick industries have been flourishing in the VDC. Sada (2010) reported 12 brick factories extracting 33.5 million liters of groundwater per year for their production process. At this moment, there are 13 brick factories in operation. Next to the immense use of groundwater, the factories cause damage to the fertile topsoil. Altogether the sand mining and brick industries caused large changes in the landscape, and in combination with the rampant groundwater mining, water- and food security are seriously under pressure in this VDC.

The most representative meteorological station for Jhaukhel is Changunarayan.

3 Methods

In this chapter the methods for analysis of climatic data are discussed separately from the research on the perception of people on climate change. But before all this, a literature review was carried out.

3.1 Literature Review

The goal of this research was to identify the impact of climate change on agriculture, focused on the peri-urban areas of Kathmandu valley. To be able to give an interpretation to the observed changes in climate, a literature review was carried out to describe possible impacts of these changes in climate. This helped with formulating an hypothesis, and also helped with the design of the questionnaire for the Focus Group Discussions.
In the literature review, a distinction was made between impacts from changes in precipitation and impacts from changes in temperature, although sometimes these impacts were overlapping or sensitive for both changes. The impacts were subdivided into four categories: *Livelihood, Agriculture, Human Health* and *Hazards*.

3.2 Hydro-meteorological Analyses

With the hydro-meteorological data, see Table 2, an analysis was carried out to identify and quantify the changes in climate in Kathmandu valley over the past few decades.
For a first insight in the temporal evolution of precipitation and temperature in the valley in the last decades, deviation-plots were drawn. For every station the long-term annual average precipitation and temperature were calculated, and the yearly anomaly from that long-term annual average. A line giving the moving average was drawn to give insight in long-term patterns. For this moving average, the past five yearly observations were averaged out with an arithmetic mean for every year.
The indices and trend tests applied to the data will be discussed below one by one for Precipitation, Temperature and Evapotranspiration.

3.2.1 Precipitation

Below methods to identify changes in precipitation data are discussed. In the analysis in this report special attention was paid to the monsoon period, because this is the most important season for agricultural activity. The monsoon period is per definition from the 15th of June until the 15th of September in Nepal.

3.2.1.1 Anomaly plots

First two anomaly plots were drawn which show the development of precipitation over the last few decades. A division is made between monsoon season and non-monsoon season.
In these anomaly plots the 0-line represents the average yearly precipitation over the complete period with available data. Per year the deviation from this average is calculated in percentage and represented as a bar in a bar plot. Finally, a 5 years moving average line is fitted through the bar plot to get insight in the long term changes in precipitation. This 5 years moving average is the arithmetic mean of the past 5 observations.

3.2.1.2 Trend analysis on indices

Several indices were calculated to find a change in precipitation trend or pattern. These indices were calculated per station on a yearly basis, and with linear regression (described in the next paragraph) the slope of the trend line was calculated, giving an indication whether that particular index had increased or decreased over the years. Also the R^2-value was obtained, explained further in the next paragraph. Below a description of the indices is given.

Number of rainy days in and outside monsoon period
For every station for every year the number of days with rainfall was counted. This was done separately for the three months of the monsoon period and for the period outside the monsoon.

Days with only Traces rainfall (see Section 2.1) were counted as days with rainfall.

The daily intensity index for monsoon period
As described by Baidya et al. (2008) The Commission for Climatology (CCl) / World Climate Research Programme (WCRP) of World Meteorological Organization, project on Climate Variability and Predictability (CLIVAR) and Expert Team on Climate Change Detection, Monitoring and Indices (ETCCDMI) jointly recommended 27 climate change indices, which mainly focus on extreme events. One of these indices is the Simple Daily Intensity Index (SDII). For this index, the total amount of rainfall is divided by the number of rainy days over a certain period of time, where a rainy day is defined as more than 1 mm of precipitation. A higher SDII means a higher daily precipitation intensity. The SDII was calculated per year for the monsoon season (3 months).

Number of extreme events
To investigate if the number of extreme events had increased in time, the number of events were counted with > 50 mm, > 100 mm and > 150 mm precipitation per day during the monsoon period.

Number of dry spells in the monsoon
Dry spells are here defined as periods without rainfall ($Prec = 0$), and should not be confused with "drought", which in hydrological terms is *a sustained and regional extensive occurrence of below average natural water availability* (Tallaksen and van Lanen, 2004).
To study if the number and length of dry spells had increased, the length of dry spells were counted as the number of successive days without rain.

3.2.1.2 Trend analysis on the raw data

Two statistical methods were applied to discover trends in precipitation data: linear regression and the non-parametric Mann-Kendall trend test. The time series were treated univariate. Although data was available on a daily basis, many tests were conducted based on monthly data. Below a description is given of the trend tests and the way the trend tests were applied to the data.

Linear trend analysis per month
To investigate if the distribution of rainfall had shifted in time, the rainfall sum per month was analyzed. For every station, monthly precipitation sums were available. A trend line was fitted through these sums using linear regression; a linear trend line of the form $y = ax + b$ is fitted through the data with the least squares method, minimizing the sum of squares of the error (SS_{error}) between line and data point. The slope (a) of the trend line gave an implication if monthly precipitation had increased or decreased. This analysis was done for each month separately, e.g. trends in January precipitation was determined separately from trends in February precipitation.
For every linear trend line, the R^2 was obtained. R^2 is defined as follows:

$$R^2 = 1 - \frac{SS_{error}}{SS_{total}} \tag{1}$$

where SS_{error} is the sum of squares around the linearly regressed line, and SS_{total} the total sum of squares if you draw a horizontal line on the average value of the data. R^2 indicates to what extent the linear trend line explains the variation of the data. A high R^2-value (with a maximum of 1) indicates low variation. Low R^2 (with a minimum of 0) means that there is large variation around the linear trend line. A R^2 of zero means that there is no linear relation at all between time (x-axis) and the variable on the y-axis. The R^2-value thus gives information about the variation of the data.

Mann-Kendall trend analysis per month
The Mann-Kendall test is often used for trend analysis of environmental time series (Hipel and McLeod, 1994), because it is nonparametric and therefore the results are independent of the particular distribution of the data. The strength of this test is that it can identify all kind of monotonic (even non-linear) trends (Hisdal et al., 2001). This can also be seen from equation 2, as the result S is independent of the magnitude of $X_j - X_k$. One important assumption of Mann-Kendall test is that the data are independent (in particular uncorrelated) and homogeneous (in particular non periodic) (Kundzewicz and Robson, 2004). Below a description is given of the Mann-Kendall test, as described by Hirsch et al. (1982).

The test, that Mann described in 1945, tests randomness against trend. The null hypothesis H_0 is that the given data of length n are independent and random variables, with other words: there is no trend. The alternative hypothesis H_a is that the distribution of X_k and X_j are not identical for all $k, j \leq n$ with $k \neq j$.
The test statistic S, also referred to as MK's Tau, is:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sgn(X_j - X_k) \tag{2}$$

with

$$sgn(X_j - X_k) = \begin{cases} 1 & \text{for } X_j - X_k > 0 \\ 0 & \text{for } X_j - X_k = 0 \\ -1 & \text{for } X_j - X_k < 0 \end{cases} \tag{3}$$

Under H_0, the distribution of S is symmetrical and normal as $n \to \infty$. Kendall (1975) describes the mean (E) and the variance (Var) of S under H_0 when there is the possibility that there are ties (equal values in the data) in the X-values. He does that with the following equations:

$$E[S] = 0 \tag{4}$$

$$Var[S] = \frac{n(n-1)(2n+5) - \sum_t t(t-1)(2t+5)}{18} \tag{5}$$

where t is the number of X's involved in a given tie. Most probably the number of ties is minimal in the continue data.
Showed by Mann and Kendall is that even for n=10, S starts to show normal distribution.
Then the standard normal variate Z can be computed with S:

$$Z = \begin{cases} \frac{S-1}{(Var(S))^{0.5}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \frac{S+1}{(Var(S))^{0.5}} & \text{if } S < 0 \end{cases} \tag{6}$$

H_0 should be accepted if $|Z| \leq z_{a/2}$, with $F_N(z_{a/2}) = \alpha/2$. Herein, F_N is the standard normal cumulative distribution function, and α is the significance level. A positive test statistic (MK's Tau or S-value) indicates an monotonic upward trend, whereas a negative MK's Tau or S-value indicates a monotonic downward trend.
The Mann-Kendall trend test was applied to time series with monthly sums for each month separately, to avoid the effect of seasonality and to secure independence. For example, for Godawari 57 monthly sums for the month January were available. On this time series the Mann-Kendall was applied to find out if there is a significant trend (increasing or decreasing) in January monthly precipitation sums. For every conducted test, the test statistic and the statistical significance (P-value) were obtained. The P-value gives the probability of obtaining the observed test statistic, with a minimum of 0 and a maximum of 1. The significance level α is set to 0.05. If the P-value is below α the H_0-hypothesis should be rejected.

With Mann-Kendall it is only possible to determine if a trend is significant and in which direction, but it gives no indication of the magnitude of this trend. Therefore, the non-parametric Sen's Slope Estimator (Sen, 1968) was used for all the significant MK-tests, to determine the magnitude of the trend. The advantage of this method above a linear trend line is that it is not so heavily affected by outliers and data errors. Sen's Slope Estimator was calculated as follows (based on description of Kumar and Jain, 2011):
The Sen's Slope Estimator method assumes a linear trend line in time, where T_i is the slope between two different data points.

$$T_{j,k} = \frac{x_j - x_k}{j - k} \tag{7}$$

for i=1,2..n.
x_j and x_k are the data values at time j and k, where $j > k$. After sorting, the numbers of $T_{j,k}$ can

be written as $T_1 \leq T_2 \leq \cdots \leq T_n$ The median of $T_{j,k}$ for all n is Sen's Slope Estimator, obtained with:

$$\beta = \begin{cases} T_{\frac{n+1}{2}} & \text{if n=odd} \\ \frac{1}{2} * (T_{\frac{n}{2}} + T_{\frac{n+2}{2}}) & \text{if n=even} \end{cases} \tag{8}$$

A positive β implies an increasing trend, and a negative β a decreasing trend. This sign should be equal to the sign of MK's Tau. For all significant MK-tests, Sen's slope was calculated.

Seasonal Mann-Kendall trend analysis
The ordinary Mann-Kendall test could not be applied to monthly time series over all the subsequent years, because Mann-Kendall assumes independence of the data and no seasonality. In Nepal, there is a great seasonality in the precipitation data due to the monsoon period. Figure 6 shows the average daily precipitation per day of the year (grey dots) and the smoothed average (blue line) for Khumaltar, averaged over 43 years. A clear seasonality is recognizable.
To account for seasonality, Hirsch et al. (1982) proposed the Seasonal Mann-Kendall test (some-

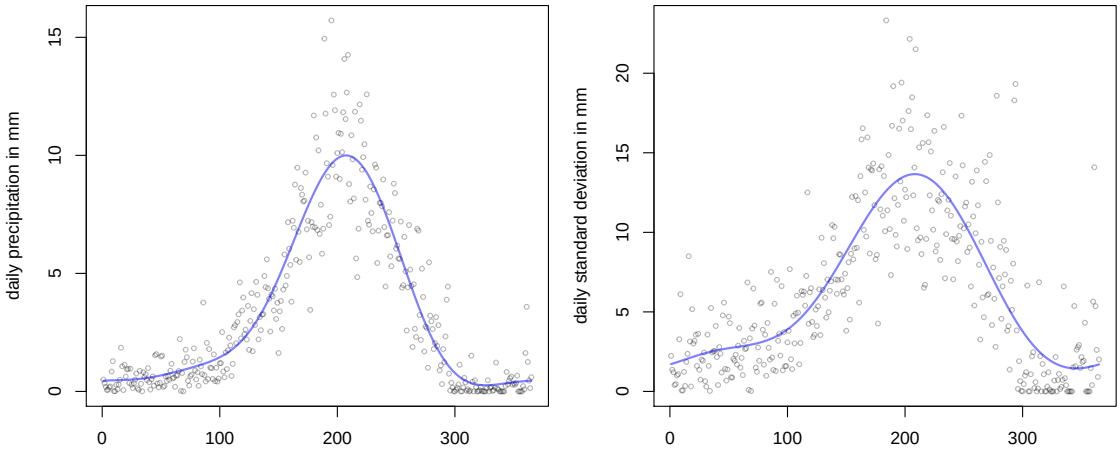

Figure 6: Left the mean daily (grey dots) and smoothed average (blue line) precipitation in Khumaltar station over a year, averaged over 43 years. Right the mean daily standard deviation (blue line) around the daily mean.

times referred to as the Hirsch-Slack test), which is adapted in such a way that seasonal data is no longer an obstacle if applied to the Seasonal Mann-Kendall test. The Seasonal Mann-Kendall, although corrected for seasonality, does still assume that the data are independent. Therefore, first the autocorrelation of the data should be checked. Autocorrelation for precipitation data implies that the amount of precipitation of the current day might depend on the precipitation of the days before. With an autocorrelation function it is possible to identify to what extent precipitation of day n depends on precipitation on day *n-1*, *n-2*, and so on, where these days back in time are called time lags.
Because for trend analysis it is particularly interesting how the measurements behave around the average (Hamilton, 1994), the autocorrelation function was applied to the data-residuals, defined as follows:

$$Res[n] = \frac{\text{data}[n] - \text{smoothed mean}[n]}{\text{smoothed st. dev.}[n]} \tag{9}$$

where the smoothed mean and smoothed standard deviation were obtained by Fourier transformation (FFT). Figure 6 shows for the case of Khumaltar the smoothed mean by the blue line in the left figure, and the smoothed standard deviation by the blue line in the right figure. After obtaining all the residuals, an autocorrelation function was applied to check to what extent precipitation on day n depends on precipitation on previous days. Figure 7 shows the correlation for different time lags. The blue lines are the boundary for significant autocorrelation ($\alpha = 0.01$).
Obviously time lag 0, so day n, depends completely on day n. The precipitation number of day n

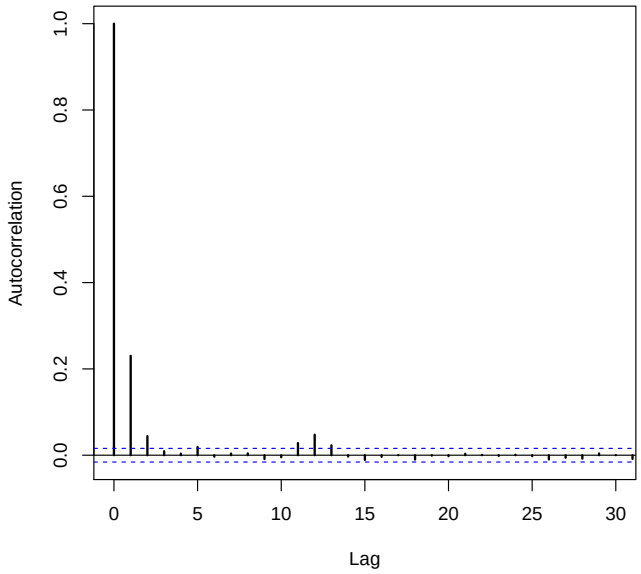

Figure 7: Autocorrelation between lags (days) of precipitation residuals for Khumaltar station.

depends much less on the precipitation of the day before, day *n-1*, although there is still a significant relation. Precipitation on day n also still depends on precipitation 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 the monsoon period, while outside the 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 can therefore be assumed free of correlation. The Seasonal Mann-Kendall was applied to the monthly data of every station for the full period. The full description of the test can be found in Hirsch et al. (1982), below a short summary is given.

For seasonal data, like the precipitation data in Kathmandu valley, the H_0 hypothesis as defined by Mann (1945) is too strict. For the Seasonal Mann-Kendall, the H_0' hypothesis is a more relaxed form of H_0. First assume

$$X = (X_1, X_2, .., X_{12}) \tag{10}$$

for the twelve months, and

$$X_i = (X_{i1}, X_{i2}, .., X_{in}) \tag{11}$$

where X_i is a subsample, i representing a month, and n representing the number of annual values available for month i. The H_0' hypothesis is then: X is a sample of independent random variables (X_{ij}) and X is a subsample of independent and identically distributed random variables $i = 1, 2, ..., 12$. The alternative hypothesis H_a' is that for one or more months the subsample is not distributed identically.
For the Seasonal Mann-Kendall, $X_1, ..X_{12}$ give monthly numbers for n annual values for every month i. S_i is the test statistic, also referred to as MK's Tau.

$$S_i = \sum_{k=1}^{n_i-1} \sum_{j=k+1}^{n_i} sgn(X_{ij} - X_{ik}) \tag{12}$$

with

$$sgn(X_{ij} - X_{ik}) = \begin{cases} 1 & \text{for } X_{ij} - X_{ik} > 0 \\ 0 & \text{for } X_{ij} - X_{ik} = 0 \\ -1 & \text{for } X_{ij} - X_{ik} < 0 \end{cases} \tag{13}$$

S_i having a mean (E) and variance (Var):

$$E[S_i] = 0 \tag{14}$$

$$Var[S_i] = \frac{n_i(n_i-1)(2n_i+5) - \sum_{t_i} t_i(t_i-1)(2t_i+5)}{18} \tag{15}$$

Where S_i is normally distributed if $n \to \infty$. S' is defined as the yearly sum of S_i:

$$S' = \sum_{i-1}^{12} S_i \tag{16}$$

S' and the variance of S' can be derived from S_i with

$$E[S'] = \sum_{i=1}^{12} E[S_i] = 0 \tag{17}$$

$$Var[S'] = \sum_{i=1}^{12} Var[S_i] + \sum_{i=1}^{12}\sum_{t=1}^{12} cov(S_i S_t) \tag{18}$$

For every data set it is now possible to determine the distribution of S' under H_0, based on n_i and t_i values, with a straight forward extension of the procedure to determine the distribution of S. The standard normal deviate Z' is defined as:

$$Z' = \begin{cases} \frac{S'-1}{(Var(S'))^{0.5}} & \text{if } S' > 0 \\ 0 & \text{if } S' = 0 \\ \frac{S'+1}{(Var(S'))^{0.5}} & \text{if } S' < 0 \end{cases} \tag{19}$$

The approximation is already adequate from $n_i = 3$ for all i, so three years of monthly data. The shortest time record available for the analysis of climate records in Kathmandu valley is 13 years (156 months) so this criterion is met for all seven stations. The Seasonal Mann-Kendall test was conducted with the monthly precipitation sums over the complete measurement period from all seven stations, with $\alpha = 0.05$. For every test the test-statistic (MK's Tau) and P-value were obtained. For all significant trends, Sen's slope was calculated.

3.2.2 Temperature

Below the description of the methodology used to discover changes and trends in the temperature data of Kathmandu valley are described.

3.2.2.1 Anomaly plots

For a first insight in the development of temperature over the last few decades, anomaly plots were drawn. In these plots, the 0-line is the average temperature over the complete period where data is available from. Per year, the percentage deviation from this average is calculated and displayed as a bar in a bar plot. Finally, a 5 years moving average line is drawn through these bars. This plot is drawn separately for minimum and maximum temperature, and a division is made between monsoon season and non-monsoon season.

3.2.2.2 Trend analysis on indices

Indices were defined to discover trends in temperature over the last few decades in Kathmandu valley. The indices were calculated per year, and the change in the indices was obtained using the slope of the linear trend line, as described in Section 3.2.1.3. A positive slope implies an increase in that particular index, and a negative slope implies a decrease. Also the R^2 was calculated for every trend line for all three indices described below.

Number of days below $0°C$

For all four stations, the number of days in a year with a measured minimum temperature

$T_{min} < 0°C$ were counted.

Number of hot days per year
For all four stations number of days in a year with a measured maximum temperature above $30°C$ were counted.

Yearly maximum and minimum temperature extremes
For every station for every year of the available record, the most extreme temperatures per year, based on daily data, were selected. This is done for the following four:

- The highest of the daily maximum temperature for year i (HiMa (i))
- The highest of the daily minimum temperature for year i (HiMi (i))
- The lowest of the daily maximum temperature for year i(LoMa (i))
- The lowest of the daily minimum temperature for year i (LoMi (i))

3.2.2.3 Trend analysis on the raw data

Like as for precipitation, also for temperature linear regression and the Mann-Kendall statistical test were applied to the data. Below one can find a description of the way the tests were applied to the data.

Linear trend analysis per month
The monthly averaged minimum and monthly averaged maximum temperature of succeeding years in a particular month were plotted as a time-line. A linear trend line (see Section 3.2.1.3) was drawn through these data to find whether there is an increasing or decreasing trend in minimum and maximum temperature in a particular month.

Mann-Kendall trend analysis per month
Also for the temperature data a Mann-Kendall trend analysis per month, to avoid seasonality, was carried out, according to the same procedure as described for the precipitation data (Section 3.2.1.3). For this analysis, monthly averaged maximum and minimum temperature measurements were used. For all significant trends, Sen's slope was calculated, as described in Section 3.2.1.3, to obtain the magnitude of the trend.

Block Bootstrap Mann-Kendall trend analysis
To find out if any significant temperature increase had taken place in Kathmandu valley, a statistical test was carried out over the complete data set. The ordinary Mann-Kendall test assumes that the data are independent and non-periodic. Figure 8 shows the smooth averaged temperature course in Khumaltar and the smooth average standard deviation from temperature, with a clear seasonality in minimum as well as in maximum temperature. For testing the autocorrelation of daily temperature data, the same procedure was applied as described in subsection 3.2.1.2 for Precipitation. With the residuals for maximum and minimum temperature, the autocorrelation function showed how many time lags significantly influence the temperature on day n. Figure 9 shows the autocorrelation for the minimum and maximum temperature. It is clear that the temperature data was much more autocorrelated than the precipitation data (Figure 7). Autocorrelation seemed even stronger for maximum temperature as compared to minimum temperature, T_{max} was significantly influenced by time lags of even more than 40 days. There is no means that the (Seasonal) Mann-Kendall can be applied to this data without correcting for autocorrelation.
Khaliq et al. (2008) described different procedures for correcting for autocorrelation. The Block Bootstrap (BBS) procedure is a resampling procedures that incorporates the effect of autocorrelation on the significance of, in this case, the MK-test. This goes even further, BBS not only accounts for autocorrelation, but for independence of the data in general. The idea of a resampling procedure is the following: if there is no trend (H_0), then it would only make little difference if the order of the data is changed. Shuffling the order of the data should not change the gradients very much (Kundzewicz and Robson, 2004). If there is a trend, increasing or decreasing (H_a), a change in order of the data would make a clear difference. By resampling the data several times, it can be seen if there is a significant difference in the test statistic if the order of the data is changed.
The difference between an ordinary Bootstrap and the BBS procedure is that the BBS procedure

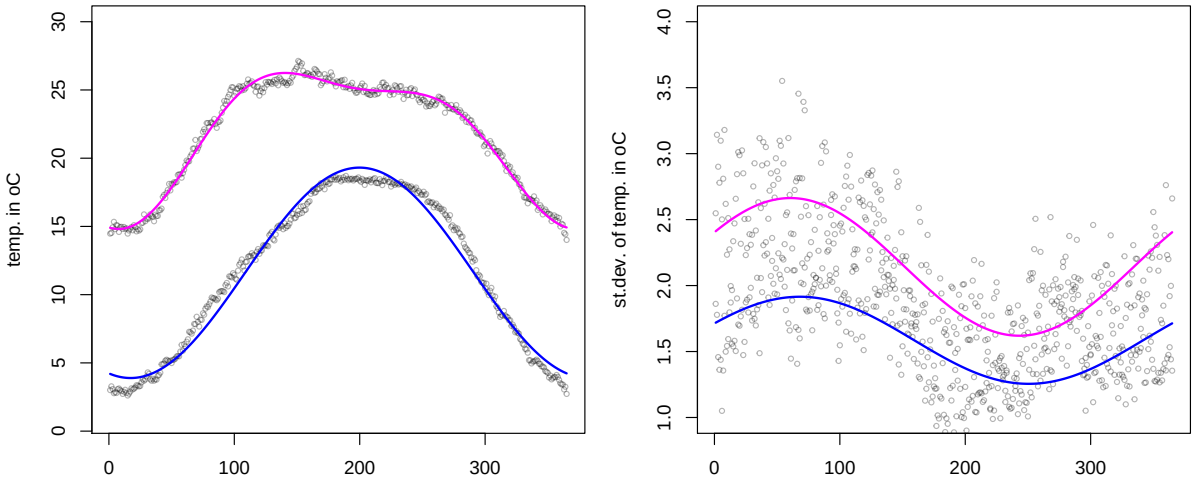

Figure 8: Left the daily mean minimum and daily mean maximum temperature (grey dots), and the smoothed average (pink line is T_{max}, blue line is T_{min} in Khumaltar for a year, averaged over 43 years. Right the smoothed average daily standard deviation around the mean for maximum (pink line) and minimum (blue line) temperature. Note the difference in y-axis.

divides the data in contiguous blocks, in stead of individual values. With these blocks the autocorrelated structure of the data can be taken into account. The advantage of the BBS is that it does not modify the original data. In this procedure, the original data is resampled x times in blocks with length k. For every sample the MK test statistic is determined, finally giving a range for MK's Tau. With the 95% Confidence Interval (CI) of MK's Tau, it can be determined whether a detected trend is significant. If Tau=0 is within the range of the 95% CI, there is no significant trend. Important to determine in the BBS-procedure is the number of repetitions x. Hedges (1992) defined that 2000 replicates is sufficient to have an error of ±2%. More repetitions lead to a higher accuracy, but demand a longer computing time. Therefore, for the BBS of the temperature data, 2000 repetitions were used. A more sophisticated approach in determining the number of repetitions is given by Andrews and Bushinsky (2000). Also the block-length has to be given as input for the BBS-procedure. The block length 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. As Figure 9 shows for Khumaltar, all the 41 time lags were significantly autocorrelated. Applying the autocorrelation function on the data of the other stations too, it illustrated that all locations have 41 significantly autocorrelated time lags for minimum as well as maximum temperature (for significance level $\alpha = 0.01$).
The BBS-procedure was conducted for all four stations for maximum and minimum temperature data on a *daily basis* with the block length equal to the number of autocorrelated time lags (41), and 2000 repetitions. Subsequently, for all significant tests (based on 95% CI, so $\alpha = 0.05$) Sen's slope was calculated.

3.2.3 Evapotranspiration

Evapotranspiration is an important process for crop growth. If a crop cannot transpire with optimal water availability, loss of yield will occur.
For Khumaltar and TIA PAN-evaporation data were available. PAN-evaporation can be considered as reference evapotranspiration (ET_0), so without limiting water availability. In evapo*trans*piration also water transpired by the crop is included. Potential evapotranspiration for a particular crop can be calculated by multiplying reference evapotranspiration with a crop factor K_c. For a reference crop, defined by the Food and Agricultural Organization (FAO) as *a crop with an assumed crop height of 0.12 m, a fixed surface resistance of* $70sm^{-}1$ *and an albedo of 0.23* (Allen et al., 1998), $K_c = 1$. Reference evapotranspiration, ET_0, can then be considered equal to ET_{pot} if there

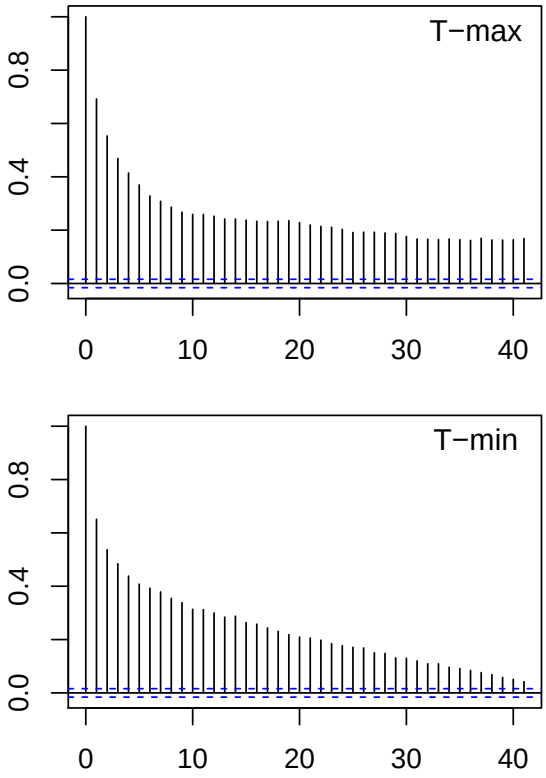

Figure 9: The autocorrelation for minimum and maximum temperature, for different time lags (in days).

are no water availability limitations. With the Penman-Monteith method ET_0 can be calculated. For this equation wind speed data is a prerequisite. This data was only available for two locations: Khumaltar and TIA (see Table: 2), and for a limited time period. By calculating $ET_{0Penman}$, it was possible to make a comparison between PAN-evaporation (ET_{0PAN}) and Penman-Monteith evapotranspiration ($ET_{0Penman}$).
Allen et al. (1998) propose the temperature-based Penman-Monteith method when radiation data are not available. The following description of the temperature-based Penman-Monteith is based on the description of Melsen et al. (2011).

The Penman-Monteith equation calculates reference evapotranspiration in mm per day. The formula is given below:

$$ET_{0Penman} = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T_{air}+273.15} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \tag{20}$$

Where:

$$\begin{aligned} ET_{0Penman} &= \text{reference evapotranspiration} && (mm/day) \\ Rn &= \text{net radiation} && (MJ/m^2/day) \\ G &= \text{soil heat flux} && (MJ/m^2/day) \\ (e_s - e_a) &= \text{vapor pressure deficit of the air} && (kPa) \end{aligned}$$

T_{air} = mean daily air temperature at 2 m ($^\circ C$)
$u2$ = wind speed at 2 m height (m/s)
Δ = slope of saturation vapor pressure curve ($kPa/^\circ C$)
γ = psychrometric constant = 0.067 ($kPa/^\circ C$)

The soil heat flux (G), is assumed to be zero. This is a good assumption if averaged out over a day. T_{air} is calculated as the average of the T_{max} and T_{min} of that day. γ is a constant. Wind speed u2 is available in the data for Khumaltar. At TIA, wind speed is measured at 10 m. This wind speed is converted to 2 m with the following equation (with $z = 10$):

$$u_2 = \frac{u_z * 4.87}{log(67.8 * z - 5.42)} \tag{21}$$

The slope of the saturation vapor pressure curve (Δ) is calculated as:

$$\Delta = 4098 * \frac{0.6108 * e^{17.27 \frac{T_{air}}{T_{air}+237.3}}}{(T_{air} + 237.3)^2} \tag{22}$$

The net radiation is not available in the data. Therefore, an approximation of net radiation is calculated, as described below. The net radiation is the net short wave radiation minus the net longwave radiation:

$$Rn = SW_{net} - LW_{net} \tag{23}$$

The net shortwave radiation depends on the reflection of the earth, the albedo α, which is 0.23 for the reference crop:

$$SW_{net} = (1 - \alpha) * SW_{down} \tag{24}$$

The short wave radiation that reaches the earth is estimated with the temperature difference between T_{min} and T_{max}:

$$SW_{down} = k_{SW_{down}} * \sqrt{T_{max} - T_{min}} * R_a \tag{25}$$

where:

SW_{down} = downwards shortwave radiation ($MJ/m^2/day$)
$k_{SW_{down}}$ = adjustment coefficient ($^\circ C^{-0.5}$)
Ra = extraterrestrial radiation ($MJ/m^2/day$)
T_{max} = maximum air temperature ($^\circ C$)
T_{min} = minimum air temperature ($^\circ C$)

The adjustment coefficient $k_{SW_{down}}$ is set to 0.16 (Allen et al., 1998). Then the Ra, the extraterrestrial radiation, can be calculated with:

$$R_a = \frac{24(60)}{\pi} * G_{sc} * d_r * [\omega_s sin(\varphi) sin(\delta) + cos(\varphi) cos(\delta) sin(\omega_s)] \tag{26}$$

where:

R_a = extraterrestrial radiation ($MJ/m^2/day$)
G_{sc} = solar constant = 0.0820 ($MJ/m^2/min$)
d_r = inverse relative distance Earth-Sun ($-$)
ω_s = sunset hour angle (rad)
φ = latitude (rad)
δ = solar declination (rad)

φ, the latitude, was known for both locations (see Table 2): 27.40 for Khumaltar and 27.42 for TIA. Converted to radians the latitudes were 0.4829 and 0.4835 respectively. d_r, δ and ω_s can be calculated with the following equations:

$$d_r = 1 + 0.033 * cos(\frac{2\pi}{365}J) \tag{27}$$

$$\delta = 0.409 * sin(\frac{2\pi}{365}J - 1.39) \tag{28}$$

$$\omega_s = arccos[-tan(\varphi)tan(\delta)] \tag{29}$$

In this equations J is the number of the day in the year (1-365 or 366). Ra can be inserted in equation 25. Finally, with SW_{down}, the net longwave radiation can be calculated:

$$LW_{net} = \sigma[\frac{T^4_{max,K} + T^4_{min,K}}{2}](0.34 - 0.14\sqrt{e_a})(1.35\frac{SW_{down}}{R_{s0}} - 0.35) \tag{30}$$

LW_{net} = net longwave radiation $(MJ/m^2/day)$
SW_{down} = downwards shortwave radiation $(MJ/m^2/day)$
α = albedo = 0.23 $(-)$
σ = Stefan-Boltzmann constant = $4.903 * 10^{-9}$ $(MJ/K^4/m^2/day)$
$T_{max,K}$ = max absolute temperature (K)
$T_{min,K}$ = min absolute temperature (K)
e_a = actual vapor pressure (kPa)
R_{s0} = clear-sky radiation (MJ/m^2)

R_{s0} is given by the Angström equation, as described by Nayava (1980):

$$R_{s0} = (a_s + b_s) * R_a \tag{31}$$

$a_s + b_s$ is the fraction of extraterrestrial radiation that is reaching the earth on days with a clear sky, where a_s and b_s are constants. Nayava (1980) determined a_s and b_s for Kathmandu; a_s equals 0.31 and b_s is 0.40. e_a is given by

$$e_a = 0.6180 * e^{\frac{17.27 * T_{dew}}{T_{dew} + 237.3}} \tag{32}$$

T_{dew} is the dew point temperature. This temperature was not available and is therefore replaced by T_{min} as proposed by Allen et al. (1998). e_a is also used to calculate the vapor pressure deficit of the air $e_s - e_a$. e_s can be calculated with:

$$e^0(t) = 0.6108 * e^{\frac{17.27T}{T + 237.3}} \tag{33}$$

$$e_s = \frac{e^0_{Tmax} + e^0_{Tmin}}{2} \tag{34}$$

Finally, net radiation and vapor pressure deficit can be incorporated in the Penman-Monteith equation (equation 20). The result is daily reference evapotranspiration in mm. $ET_{0Penman}$ was calculated over the period of available data, and compared to ET_{0PAN} for the period with overlapping data, to check if the data was in the same order.

3.2.3.1 Trend analysis on indices

Two indices were calculated to discover changes in the pattern of evapotranspiration.

Number of days that reference evapotranspiration exceeds precipitation in the monsoon period
Dry spells in monsoon can have implications for agriculture, but most important for the crop is

the availability of soil moisture. A soil moisture deficit will develop during days that evaporation exceeds precipitation. The poor quality of the PAN-data with large data gaps and the limited availability in only two stations, forced to calculate an average ET_0PAN per day for the monsoon period. With this evapotranspiration rate as threshold, the number of days per monsoon period per station was counted that the average ET_0PAN exceeded the precipitation of that day. Note that reference evapotranspiration is considered, so evapotranspiration without water limitations, and not actual evapotranspiration.

Evaporation sum per season
Thapa and Joshi (2011) defined the four different seasons in Nepal, as given in Table 5.

Table 5: Seasons in Nepal, defined by Thapa and Joshi (2011)

Winter	December	-	February
Spring	March	-	May
Summer	June	-	August
Fall	September	-	November

Due to the quality of the PAN-data, with large and consistent data gaps, it was not possible to do any seasonal analysis with these data. Therefore, $ET_{0Penman}$ was used, although these data only covered a short time period. For every season, the $ET_{0Penman}$ seasonal sum and seasonal mean was calculated per year. A linear trend line was fitted through these data to find out if the evapotranspiration might have increased or decreased in a particular season.

3.2.3.2 Trend analysis on the raw data

For Khumaltar, 10 years of data was available to calculate Penman-Monteith, and for TIA it was 16 years. These data series are not long enough to draw robust conclusions about climate change, but a linear trend line was plotted through the PAN-evaporation and the Penman-Monteith evapotranspiration to find out if there was an increase or decrease in the last years.

3.3 Human Perception

In the previous sections, the methodology was described to identify possible impacts of climate change (literature study), and to analyze a possible past climate change in Kathmandu valley (hydro-meteorological analysis). To find out which impacts really took place and have been perceived by the inhabitants of the areas, and to what extent they have adapted to climate change, research on the perception of the inhabitants of peri-urban areas was conducted. First a pre-survey was carried out, followed by Focus Group Discussions (FGDs).

3.3.1 Pre-survey

To get a first insight in the response of people to the terms 'climate change' and for example 'food-security', a pre-survey was held among the inhabitants of four different peri-urban sites around Kathmandu; Matatirtha, Lubhu, Dadhikot and Jhaukhel (see Figure 5). A basic setup of questions was made, related to rainfall, temperature, water sources, agriculture and the general perception of climate change. These questions served as a back-up, in this pre-survey the focus was mainly on letting people having their say. One day per location was spent with asking questions to and having discussions with the people that were in the streets. Lessons learned from this pre-survey were incorporated in the preparations for the FGDs.

3.3.2 Focus Group Discussions

After the pre-survey, a questionnaire was designed based on the pre-survey and the literature study, which served as a basis for the FGDs. In each field site a FGD was organized; a group discussion with a certain target group, providing aggregated information from the group as a whole. To invite

persons for the FGD, local key informants were approached with a proposed date and time for a FGD. The key informants thereafter collected people for the discussion and arranged a location for the FGD, sometimes in collaboration with the VDC-office. Minimal six and maximum ten participants is considered optimum group growth (Kumar, 1987), of mixed gender, occupation and age, although the participants should have been old enough to be able to observe any change in climate and almost all inhabitants in peri-urban areas have some agricultural background.
Before the discussion started, name and age of the participants was noted. People were asked to work on some Participatory Rural Appraisal Tools (PRA-tools), which for example included a trend line of perceived hotness and coldness, a scheme of monthly water use, and an hour to hour daily schedule of an average day. These tools could help in explaining the results of the discussion.
Starting the discussion, first the topic was introduced, explaining the scope and the purpose of the discussion. One person led the discussion, asked the questions and gave the word to persons. Two others persons served as a backup, to check if all questions were addressed, and wrote minutes during the discussion. Halfway the meeting, milk tea and biscuits were served.
It was important during the discussions to try to make the distinction between climate-induced impacts, and environmental change induced by urbanization and industrialization. It was also important to include the whole group in the discussion, and not to have the tendency to follow the opinion of the most dominant person present.

4 Results and discussion

This chapter presents the results from the application of the methodologies described in the previous chapter. First the possible impacts of a changing climate are described in the literature review. After that the results from the analysis of the meteorological data that were obtained are discussed, followed by the results from the pre-survey and FGDs.

4.1 Literature Review

The possible impacts of climate change on Kathmandu valley, with particular focus on the peri-urban areas, are discussed below separately for precipitation and temperature.

4.1.1 Impacts of changes in Precipitation

According to IPCC (Cruz et al., 2007) there is an *'Increase in intensity or frequency of extreme weather events.'* The total amount of precipitation and the number of rainy days in South-Asia has decreased. For the case of Nepal, Shrestha et al. (2000) did not find any changing precipitation pattern over the period 1970-2000.
According to IPCC, the projected decrease in precipitation in South-Asia will be on average 0.8% taking the highest future emission trajectory into account (Cruz et al., 2007). On the contrary, Meehl and Washington (1993) found that precipitation in South-Asia will increase by 6.3% if atmospheric CO_2 doubles. The contradicting projections confirm what is stated by Lobell and Burke (2008): *"Leading climate models often disagree on the sign of precipitation change."*. Shrestha et al. (2000) states that changes in precipitation may, in the mid latitude regions, even be more important than changes in temperature, because of the vulnerability to water shortage and quality. Livelihood in Kathmandu valley is interwoven with the annual rainfall pattern in the valley. Changes in precipitation, whether an increase, a decrease or a change in pattern, has large impacts on the livelihood, health and agriculture in the valley. Below, a description of possible impacts is given.

Livelihood
Changes in precipitation have direct impact on the available water. The main purposes of water use are irrigation, hydro-power, drinking water and sanitation. The strong urbanization and subsequent increase in water demand in the valley leads to the drying of wells (Shukla et al., 2010). Irregularities or decrease in precipitation can further stress the drinking water availability. Lack of drinking water and unequal distribution of water can lead to tensions and equity concerns. Shukla et al. (2010) already describes how Dadhikot, one of the field sites in this research, is debating with Gundu, an upstream village in the valley (see Figure 5), about available water.
91% of the electricity in Nepal comes from hydro-power. The hydro-electric plants highly depend on predictable runoff patterns (Agrawala et al., 2003). Increasing variability and unpredictability of rainfall can negatively affect the availability of electricity, which is currently already under stress during the dry season.

Agriculture
Change in precipitation quantity and pattern also has clear impact on agriculture in the valley. More intense rains can cause severe damage to the crop (Ulsrud et al., 2008). Joshi et al. (2011) found a significant *positive* relation between paddy yield and increased monsoon rain.
Unpredictability of rainfall can make the initially rain-fed farming dependent on irrigation. Decrease in monsoon-rainfall can have as a consequence that irrigation has to start earlier after monsoon, due to a soil moisture deficit (Shukla et al., 2011). On top of that, FAO (2003) states that increased irrigation is necessary for sustained productivity, and irrigation schemes are vulnerable to climate change (Shrestha and Aryal, 2011).
If no fresh irrigation water is available, waste-water is used for irrigation. The quality of the irrigation water has many direct effects on the crop yield and enhances pests and pathogens (Chakraborty and Newton, 2011). Next to that, if more droughts occur, drought stress of the crop can affect the disease resistance and further enhance the development of pests and pathogens. Chakraborty and Newton (2011) also found an increasing risk for plant diseases if at a critical growth stage

the number of rainy days increases. Increase in precipitation and a wetter environment are also likely to contribute to the success of invasive pathogens (Ziska et al., 2011). Ziska et al. (2011) also state that the biological success of insects is likely to be altered by climate change. The role of precipitation herein can go two sides. Floods might negatively impact soil-dwelling insects, while drought could increase the plants carbohydrate concentrations, making them more attractive for insects.

Human Health
The impact of precipitation on water *quality* has direct implications for human health, not only in the case of drinking water. If there is lack of fresh water, waste-water is used for irrigation in Kathmandu valley. Rutkowski et al. (2007) found that 55% of the interviewed farmers in Kathmandu valley had personally experienced, or had a family member experiencing skin problems as a result of irrigating with wastewater.
Kovats et al. (2003) describe that the relation between the transmission of vector-borne diseases and rainfall is well established. Changes in precipitation might increase the competence of the climate for vector-borne diseases.

Hazards
Cruz et al. (2007) mention that the combination of an increasing temperature and decreasing precipitation can trigger forest fires.
Heavy intense rainfall can lead to landslides, especially in combination with the steep slopes caused by sand mining activities e.g. in Jhaukhel.

4.1.2 Impacts of changes in Temperature

Shrestha et al. (1999) found an annual increase in temperature in the middle mountains of Nepal of $0.075°C$ per year. Projections described in Cruz et al. (2007) tell that for the highest future emission trajectory, temperature in South-Asia will increase with $0.87°C$ in the period 2010-2039. The possible impacts of an increasing temperature are again subdivided into four different areas: Livelihood, Agriculture, Human Health and Hazards. They are discussed one by one below.

Livelihood
An important impact of an increasing temperature is increase of glacier melt (Shrestha and Aryal, 2011), which already takes place for some tens of years. This initially increases river discharge, but eventually decreases the supply of water, impacting the people who depend on melting water for drinking and irrigation purposes. The most important energy source of Nepal, hydro-power, depends on predictable runoff patterns (Agrawala et al., 2003) and can be impacted by irregular glacier melt.
Kalnay and Cai (2003) describe that cities are even more vulnerable to temperature increase than rural area. Climate change induced temperature increase further strengthens the urban heat island effect, which especially in the night exacerbates temperature increase (Mitchell, 1961).

Agriculture
Lal (2011) described how the stagnation of rice and wheat yield in the recent decades can be assigned for a significant part to the rising temperatures during the cropping season. Increase in minimum temperature increases the respiration requirements of the crop. This shortens the time to maturity and thus reduces net growth and productivity. Malla (2008) states that early maturity of the crops due to increase in temperature may help to have more crops in the same crop cycle. Malla (2008) also describes that an increasing temperature in combination with increasing $C0_2$-levels can right enhance the crop growth. The optimal temperature for rice is $25°C$, and per degree Celsius increase, rice yield is declined by 10% (Luo, 2011), until zero yield at 35-36$°C$ mean daily temperature. Joshi et al. (2011) found a significant negative relation between increase in maximum summer temperature and maize yield, the second major summer crop in Nepal after paddy.
Wheeler et al. (2000) point out that variability of temperature also plays an important role in crop growth. Doubling the standard deviation of temperature on a daily basis, while keeping the mean temperature the same, reduced grain yields with 7%.

Mild winters due to an increased temperature can have large effects on pathogens and insects. In winter, more than 99% of pathogen population dies (Burdon and Elmqvist, 1996). Mild winters can decrease this winter kill and enhance pathogens. In controlled studies at high humidity, damage to the crop by pathogens increased exponentially with temperature, up to $27°C$ (Ziska et al., 2011). Climate warming is also likely to increase geographical distribution and the capacity of over-wintering for insects (Ziska et al., 2011).
Invasive weeds commonly have a long distance dispersal. Dukes and Mooney (2000) state that this suggests that invasive weeds will probably be the fastest to migrate with increasing temperature.

Human Health
Increasing temperatures have several impacts on human health. Patz et al. (2000) give a clear list:

- Temperature-related morbidity and mortality
- Vector and rodent-borne diseases
- Air-polluted related health effects
- Water and food-borne diseases

Patz et al. (2005) state that the effect of heat waves is exacerbated in large cities, the vulnerability of urban population to heat-related mortality seems likely to increase in the future.
Kovats et al. (2003) mention that both precipitation and temperature are closely linked to the transmission of vector-borne diseases. In epidemic fringe regions, malaria transmission is restricted by climate. Small changes in the environmental conditions can trigger an epidemic (Kovats et al., 2003). Higher temperatures have also been associated with an increase in diarroeha, mild winters tend to increase rodent-borne diseases, and can also increase dengue-fever which is transmitted by mosquito's (Kovats et al., 2003).
Increased temperatures may enhance the formation of ground-level ozone, particularly in urban areas (Patz et al., 2000). Air quality is currently already the most highlighted environmental problem of Kathmandu (Thapa et al., 2008), which due to its geographical position in a bowl shaped valley is even more vulnerable to air-pollution.
An increase in the risk of plant diseases also is a direct impact on human and animal health (Chakraborty and Newton, 2011).

Hazards
Cruz et al. (2007) describes an increase in forest fires in South-Asia due to a decrease in precipitation and a rise in temperature. Shrestha and Aryal (2011) say the risk of Glacier Lake Outburst Floods (GLOFs) increases with the glacier melt. These GLOFs are lakes that have formed from melting water below the end of a glacier. When the end moraine that functions as a dam breaks, a huge amount of water is suddenly released. These GLOFs can be devastating; in 1985, a GLOF destroyed a complete hydro-power plant (Shrestha and Aryal, 2011).

4.2 Hydro-meteorological Analyses

In this section the results will be presented and discussed of the analyses carried out on precipitation data, temperature data, and evaporation data.

4.2.1 Precipitation

For the precipitation pattern different analysis-methods were conducted (Section 3.2.1). First the anomaly plots will be discussed, followed by trend analysis applied on the previously described indices, and finally the trend analysis of the raw data will be described.

4.2.1.1 Anomaly plots
Figure 10 gives the anomalies of precipitation and the 5 year moving average over the 43 year average precipitation in Khumaltar. The first impression from the figure is that both in the monsoon and non-monsoon period there is no clear pattern recognizable. Shrestha et al. (2000) assigned large temporary variation in precipitation in Nepal to the El Niño-Southern Oscillation (ENSO). The deviation-figures of the other stations (except Naikap because of short data series) can be

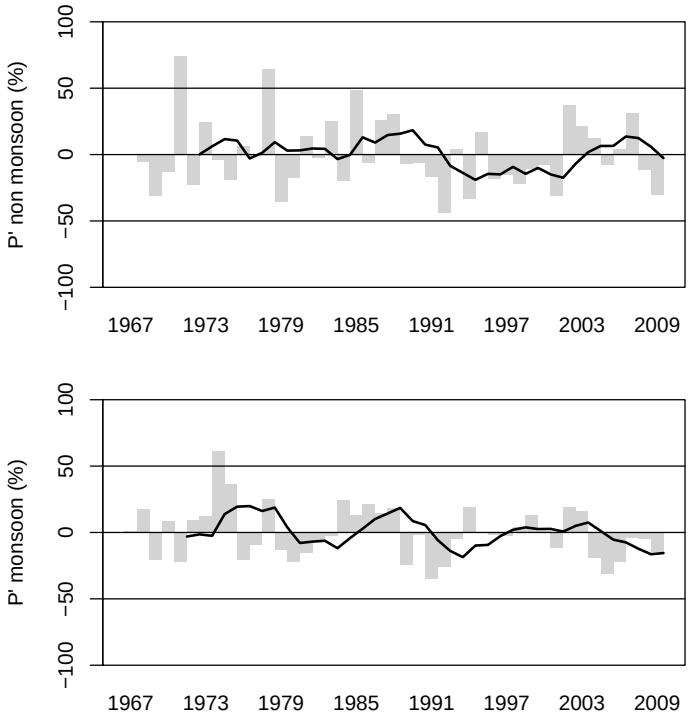

Figure 10: Deviation (%) from long-term annual mean precipitation. The line gives the 5 year moving average.

found in Appendix C.1.

Table 6 gives a brief overview of the average yearly precipitation sum per station. Also the min-

Table 6: Average yearly precipitation sum (mm) and minimum and maximum measured yearly precipitation sum (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

imum and maximum measured precipitation sum and the year are given. Kripalani et al. (1996) found, based on data from 1851-1900 and from 1921-1975, measured in Kathmandu, a mean annual rainfall of 1404 mm with a maximum of 1794 mm in 1948 and a minimum of 842 mm in 1864. These numbers found by Kripalani et al. (1996) are in the same range as the numbers given in Table 6.

4.2.1.2 Trend analysis on indices

Below the discovered trends in the different indices are presented.

Number of rainy days in and outside monsoon period

For every station for every year the number of days with rainfall was counted for the monsoon and non-monsoon period. Table 7 gives the slope of the trend line through this index. Next to that, R^2 is given. Figure 11 gives the moving average for the number of rainy days in Khumaltar. The

figures from the other stations can be found in Appendix C.2.

Table 7: 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

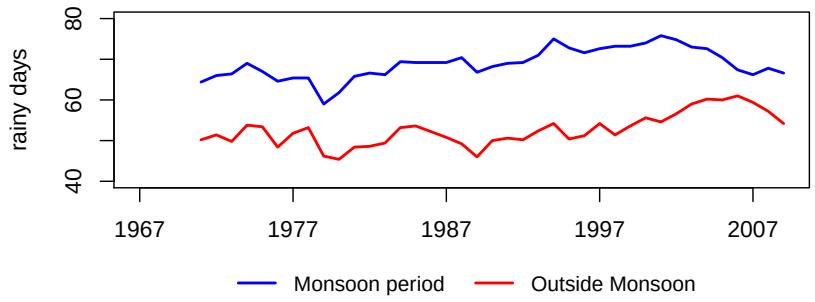

Figure 11: Five years moving average of number of rainy days in Khumaltar.

From Table 7 it can be seen that four out of seven stations have a decrease in number of rainy days in the non-monsoon period. Although this is not really convincing (also with very low R^2-values), the pattern can be recognized that negative directions (decrease in number of rainy days) seems to be stronger than the positive directions. For the 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. The Naikap station seems to give the strongest decrease in number of rainy days, both in and outside the monsoon period. However, from the Naikap station only 13 years of data is available, 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. 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). With the results given in Table 7, it seems that the risk on vector-borne diseases or pests and pathogens will not likely increase in Kathmandu valley as a consequence of changes in the number of rainy days.

The daily intensity index for monsoon period
The Standard Daily Intensity Index (SDII) was calculated for every station for every year *only for the monsoon period*. Table 8 gives an overview of the slopes of the trend lines, Figure 12 gives the moving average for the SDII in Khumaltar, to show the magnitude of the SDII during the monsoon (average mm precipitation/rainy day).

Table 8: Slope of trend line through SDII for monsoon period

Station	SDII	R^2
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

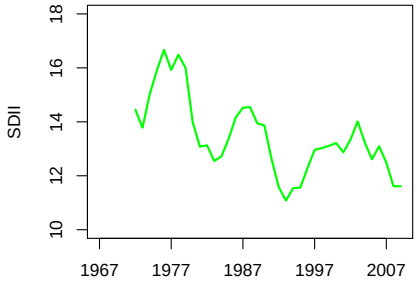

Figure 12: The five years moving average for the SDII in Khumaltar.

Four stations had a decreasing trend, three stations an increasing trend. There is no clear pattern recognizable, so it is not possible to draw any conclusions concerning the SDII during the monsoon period for Kathmandu valley. The low R^2-values indicate a large variation over the years. Baidya et al. (2008) also did not find any significant trend for the SDII applied to precipitation data covering the whole of Nepal. It would be too quick to conclude from these that rainfall had not intensified; this analysis is based on daily numbers and not on individual rain events, see Discussion.

Number of extreme events

For all seven stations the number of days was counted within the monsoon period, that precipitation exceeded 50, 100, and 150 mm per day. The slope of the trend line can be found in Table 9 for the number of days with more than 50 mm rainfall. Figure 13 shows the moving average of the number of events for Khumaltar. From the data of Godawari it seemed that the number of extreme events had increased after the 1970s. Because the other data series were not long enough this cannot be confirmed.

Because there was only a limited number of days with more than 100 mm, no linear trend line was plotted through these data. Events with more than 150 mm precipitation 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 precipitation.

Table 9: Slope of trend line through number of extreme events per year

Station	$>$ 50 mm	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

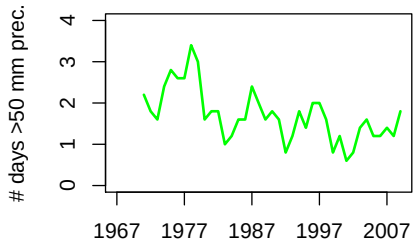

Figure 13: The five years moving average for number of days with $>$ 50 mm precipitation in Khumaltar.

Most of the stations find an increase in the number of days with $>$ 50 mm rainfall in monsoon period (averaged out over all the stations, except Naikap because of short data series, an increasing slope of 0.02). The low R^2-values show that there is large variation in the yearly number of $>$ 50 mm precipitation 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 to the 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 9 imply a larger increase in events with more than 50 mm precipitation than found by Baidya et al. (2008), but this is only for the monsoon period and only for Kathmandu valley. Notice that these

numbers are based on precipitation per aggregated day. It might be that a heavy rainfall event started in one day and ended in the next day, but that is not identifiable with the available data (see Discussion).
An increase in extreme events, in this case defined as > 50 mm precipitation per day, has serious consequences for the peri-urban areas in Kathmandu valley. These areas are situated in a mountainous environment and vulnerable for landslides and erosion. Urbanization enhances the impacts of increasing extreme events: sand mining activities make the soil even more vulnerable for landslides and erosion.

Number of dry spells in the monsoon
For every year for every station, the number of days without rainfall in the monsoon period was counted, and how long this dry spell lasted. Obviously, 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 (see Table 7) and thus also did not show a unambiguous pattern. But in this section, also the length of the dry spells was studied. Appendix C.3 gives an overview per station, giving the number and length of dry spells per year. Figure 14 shows the number of dry spells per year and their length for Khumaltar station. Each grey bar represents one year. The first graph shows the number of individual dry days in the monsoon. The second

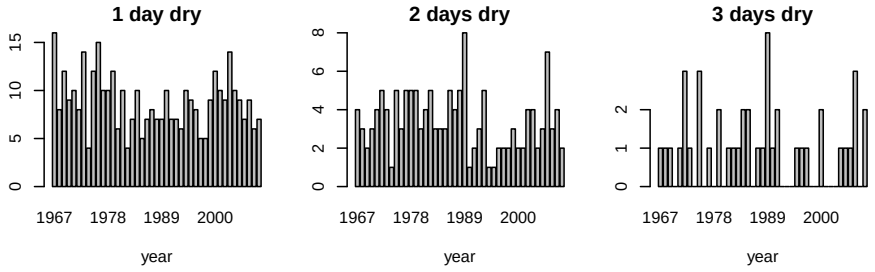

Figure 14: The number and length of dry spells in the monsoon period in Khumaltar.

graph shows the number of dry spells where it did not rain for two successive days. The most right graph shows the number of dry spells in the monsoon where it did not rain for three days in a row. It is hard to find a pattern in Figure 14. Appendix C.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.
The rain-fed crops in monsoon-season are especially vulnerable to dry spells. In a moist 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 yield decline. 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). But the results show no clear pattern; there is no clear tendency that the number of dry days in monsoon had increased over the last years, and there are no implication that dry spells became longer. Dry spells are individual events that occur irregularly, and the agriculture in Kathmandu valley will stay, especially in combination with the increasing water demand as a consequence of urbanization, vulnerable to dry spells.

4.2.1.3 Trend analysis on the raw data

Here below the results from linear trend analysis and the Mann-Kendall statistical test are shown.

Linear trend analysis per month
A linear trend line was plotted through the graphs with monthly precipitation sums. The slopes of this line can be found in Table 10.

There is no clear trend identifiable, three stations have on average an increasing trend, and three stations have on average a decreasing trend (station 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 station Naikap), an increasing trend of 0.06 is

Table 10: Slope of trend line through monthly sum of precipitation

Month	Khumaltar	TIA	Godawari	Panipokhari	Changu.	Sankhu
Jan.	0.02	-0.03	-0.15	-0.11	0.02	0.15
Feb.	0.12	0.12	0.27	0.07	-0.19	-2.01
Mar.	0.28	0.08	-0.07	-0.22	0.17	-0.31
Apr.	0.04	0.40	0.46	0.11	-0.06	-0.29
May	1.00	0.88	1.32	0.55	1.12	1.30
Jun.	-1.30	-0.46	0.55	0.60	2.77	-3.59
Jul.	-2.03	0.12	1.23	1.45	0.93	-0.61
Aug.	0.08	1.64	0.63	2.15	-2.06	1.19
Sep.	-0.18	0.87	0.90	1.66	-0.84	-0.38
Oct.	-0.51	-0.80	0.19	-0.55	-1.85	-1.16
Nov.	0.04	0.04	0.14	-0.14	-1.02	-0.11
Dec.	-0.10	-0.00	0.28	-0.10	-0.10	-0.12

found, implying that precipitation on average had increased. Precipitation decreased mainly in the months October to March, increase in precipitation took place from April to September, except for June. June is the month with the onset of the monsoon. This average decrease can imply that the onset of the monsoon had shifted to later in the season. Changunarayan had a strong increase in precipitation in June, probably here the monsoon had shifted to earlier in the season. In May all stations but Naikap had an increase in precipitation.
Appendix C.4 gives the R^2's for all months for all stations. On average (ignoring station Naikap) the highest R^2-values, so the lowest variation, is found in the pre-monsoon and monsoon months May, June, July and August.
Shrestha et al. (2000) found a lack of long-term increasing trend in precipitation over Nepal.
It is difficult to define impacts for the peri-urban areas in Kathmandu valley based on the results of Table 10. There seems to be a tendency that precipitation increased especially during pre-monsoon and at the end of the monsoon. A result for agriculture might be that paddy rice can only be planted later in the monsoon season. Increase in precipitation 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 precipitation in those months. This all comes down to a shift in time of water use.

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 either an increasing or decreasing trend.
Table 11 shows the results for Khumaltar. A negative Tau implies a decreasing trend, which was the case for six out of twelve months. But, none of the trends is significant. The P-value is for all trends above the significance level of 0.05. This means that for Khumaltar no significant increasing or decreasing trends were found.
Appendix C.5 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 precipitation 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 precipitation of 0.36 mm/year) and two decreasing trends in July and November in Naikap. Take into account here that for Naikap station only 13 years of data is available and that it is impossible to draw any conclusion concerning climate from this short time series. For November in Naikap, only precipitation in the first two years of the data series was 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 precipitation distribution over time had changed (considering the six stations with time series long enough). This means that the possible impacts of a change in precipitation timing, as was conducted in Sections 4.2.1.2 and the beginning of Section 4.2.1.3, are very uncertain. This conclusion only holds on a monthly level, it might be that precipitation distribution within the

Table 11: Kendalls' Tau and two sided P-value per month for Khumaltar

Month	Tau	P-value
Jan.	-0.07	0.514
Feb.	0.01	0.942
Mar.	0.12	0.281
Apr.	0.07	0.537
May	0.19	0.069
Jun.	-0.11	0.295
Jul.	-0.17	0.107
Aug.	0.02	0.892
Sep.	-0.05	0.630
Oct.	-0.01	0.958
Nov.	0.01	0.928
Dec.	-0.03	0.776

months had shifted.

Seasonal Mann-Kendall trend analysis
The Seasonal Mann-Kendall (SMK) test was applied to monthly sums of the precipitation data for the complete available period. The data did not show any autocorrelation (see Section 3.2.1.3). After applying the SMK-test, for none of the data series a significant trend was found. Table 12 gives an overview of the SMK results. Because all the P-values were above the significance level ($\alpha = 0.05$), the H_0 hypothesis cannot be reject: there was no significant trend. These findings confirm the conclusion of Shrestha et al. (2000) that there is no significant long-term trend in precipitation.

Table 12: Kendalls 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

4.2.1.4 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 variation among the stations.
An increase of events with > 50 mm of precipitation was found for most stations, which might lead to floods, landslides and erosion. The possible impacts in the peri-urban area are further emphasized by the threat of urbanization, putting pressure on water resources and industrialization leading to soil degradation, increasing the risks of erosion. There were no significant (based on Seasonal and ordinary Mann-Kendall test) increasing or decreasing trends in total precipitation.

4.2.2 Temperature

This section contains the analysis of the temperature data. First the anomaly plots are shown and discussed, followed by a discussion of the trend analysis on indices and on the raw data.

4.2.2.1 Anomaly plots

Anomaly plots from temperature were plotted to explore the temperature development in the Kathmandu valley over the last years. Figure 15 shows the temperature development over 43 years

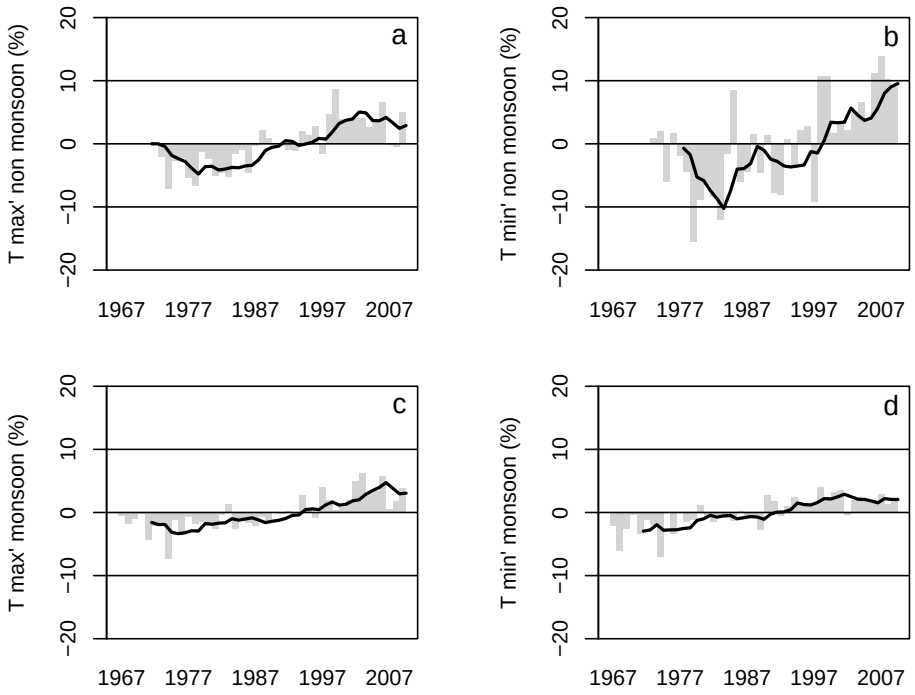

Figure 15: Deviation (%) from long-term annual mean maximum (a and c) and mean minimum (b and d) temperature in the non-monsoon (a and b) and the monsoon (c and d) period in Khumaltar. The line gives the 5 year moving average.

in Khumaltar. The line shows the 5 year moving average. 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 1970s. This pattern is also recognizable in Figure 15. Appendix D.1 gives an overview of the temperature-deviation plots for the other stations.
Remarkable is the 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 (Godawari is the highest station for temperature data, see Table 1) or a difference in environment (Godawari is furthest away from urban area).

4.2.2.2 Trend analysis on indices

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

Number of days below $0°C$
For every year, the number of days that T_{min} was below $0°C$ were counted. Table 13 gives an overview of the slope of the trend line and the R^2. For all the stations, the number of days with $T_{min} < 0°C$ seemed to have decreased quite drastically, especially in Khumaltar and TIA. Figure 16 shows the five years moving average for the number of $< 0°C$ days per year. This figure 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

Table 13: Slope of trend line through number 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

Godawari is the station furthest away from the urban core. This might be caused by 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.
A decrease in the number of $< 0°C$ days can cause an increase in pathogens and insects because of lower winter mortality (Ziska et al., 2011), and this can be a serious threat for the peri-urban areas in Kathmandu.

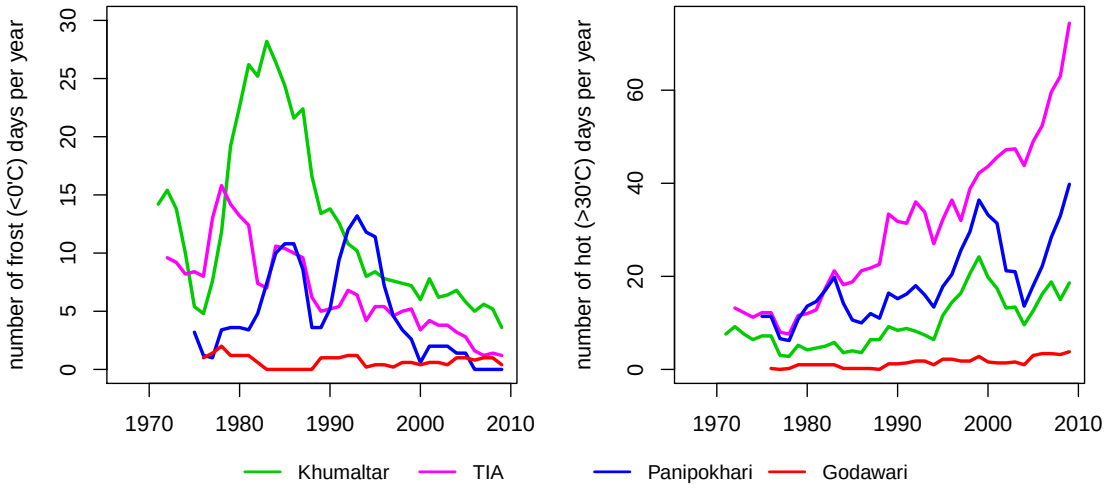

Figure 16: Five years moving average for the number of $< 0°C$ days (left) and the number of hot days (right) per year.

Number of hot days per year
For every year the number of days that maximum temperature was above $30°C$ was counted. In

Table 14: 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

Table 14 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 16 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 $< 0°C$ days. It is also striking that again station Godawari, the station furthest away from the urban core, is showing the lowest increase.

The increase in number of hot days can have serious impacts for the people of Kathmandu valley. It can decrease yield (Porter and Gawith, 1999), but increase in number of hot days can also increase heat-related mortality (Patz et al., 2000). On top of that, warm weather stimulates the use of more (drinking)water and can increase evapotranspiration, leading to higher water stress for both humans and crops.

Yearly maximum and minimum temperature extremes
Per station the most extreme temperature measurements per year were selected, based on daily data. Table 15 gives the slope of the linear trend line through the four mentioned temperature

Table 15: The slope of the trend line through the most extreme temperatures per year for the whole record period

Station	HiMa[1]	R^2	HiMi[2]	R^2	LoMa[3]	R^2	LoMi[4]	R^2
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	

extremes (Section 3.2.2.2). The results in the table illustrate that the yearly highest measured temperature (HiMa) seems to have increased on all four stations. The lowest maximum temperature (LoMa) measured also seems to have increased for all four stations, which implies that both the coldest day and the warmest day of the year had become warmer.
In general, the coldest minimum temperature (LoMi) and the warmest minimum temperature (HiMi) also both had become warmer, although this signal was less clear and not visible for all stations. Baidya et al. (2008) found comparable results for stations all over Nepal. They found an increase in warm nights and warm days and a decrease in cool nights and cool days. For data of station TIA that Baidya et al. (2008) used, an increase of 0.071 was found in the maximum of the daily maximum temperature (MaMa). For the minimum of the maximum temperature (MiMa), an increase of only 0.008 was found, MaMi=0.031 and MiMi=0.031. The numbers of Baidya et al. (2008) are in the same range as found in this research, but here a stronger increase in the lowest of both minimum and maximum temperatures is found.
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). 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. Patz et al. (2000) think that the absence of nighttime relief 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 the coming years, making the risks coming with an increasing temperature even a bigger threat.

4.2.2.3 Trend analysis on the raw data

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

Linear trend analysis per month
Per month the mean monthly minimum and mean monthly maximum temperature of succeeding years were plotted and a linear trend line was fitted to discover the trend in minimum and maximum temperature per month.
Table 16 gives an overview of the slope of the trend lines through the monthly average maximum

[1]Slope of Highest of maximum temperature
[2]Slope of Highest of minimum temperature
[3]Slope of Lowest of maximum temperature
[4]Slope of Lowest of minimum temperature

Table 16: Slope of trend line through monthly mean of T_{max} (top) and monthly mean of T_{min} (bottom)

Tmax	Khumaltar	TIA	Godawari	Panipokhari
Jan.	0.06	0.10	0.09	0.06
Feb.	-0.01	0.11	0.08	0.02
Mar.	-0.01	0.08	0.05	0.04
Apr.	0.03	0.07	0.05	0.06
May	0.03	0.05	0.04	0.07
Jun.	0.03	0.06	0.04	0.04
Jul.	0.03	0.05	0.04	0.03
Aug.	0.02	0.05	0.04	0.04
Sep.	0.03	0.08	0.07	0.06
Oct.	0.04	0.09	0.07	0.05
Nov.	0.05	0.08	0.09	0.06
Dec.	0.02	0.07	0.09	0.05
T_{min}	Khumaltar	TIA	Godawari	Panipokhari
Jan.	0.02	0.05	0.00	0.04
Feb.	0.07	0.09	0.03	0.09
Mar.	0.10	0.07	0.01	0.06
Apr.	0.05	0.04	-0.01	0.06
May	0.08	0.03	0.01	0.02
Jun.	0.05	0.02	0.02	0.07
Jul.	0.06	0.02	0.03	0.01
Aug.	0.08	0.03	0.04	0.03
Sep.	0.07	0.03	0.04	0.08
Oct.	0.08	0.05	0.01	0.12
Nov.	0.05	0.06	-0.01	0.09
Dec.	0.07	0.08	0.01	0.11

and minimum temperatures. Appendix D.2 contains the R^2-values for every month for every station for both temperatures.

First the trends in the maximum temperature will be discussed. 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 T_{max} 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), who 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 the pre-monsoon. For the period 1977-1994 he found an increasing trend of 0.094 for the months October and November. Averaged out for all stations here an increasing trend of 0.07 was found for the months October and November. Baidya et al. (2008) did a comparable analysis for stations spread over whole Nepal. 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), it increases the risk on vector borne and rodent borne diseases (Patz et al., 2000), and it increases air pollution (Patz et al., 2000). This last point is important to mention from the perspective of the peri-urban areas. Due to industrialization the air quality of the areas is already threatened. This can be further strengthened by the effect of increasing temperature. 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 lower part of Table 16 gives the slope of the trend line through the monthly averaged minimum temperatures. Also here, except from two months in Godawari, all numbers demonstrate 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 core of Kathmandu, while Godawari is situated in rural area. Because the urban heat island effect is especially pronounced in minimum temperature (Mitchell, 1961), this result might confirm that an urban heat island had developed in Kathmandu.
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 the lowest value of minimum temperature.
Increase in minimum temperature can lead to yield decline due to early maturity of the crop (Lal, 2011), and increase pathogens and insects because of less winter kill (Ziska et al., 2011). If the increase in minimum temperature is less strong than the increase in maximum temperature, the daily variability of temperature increases. This also can decline crop yields (Wheeler et al., 2000).

The R^2-values given in Appendix D.2 provided 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), minimum temperature showed the highest variation in January and the period April to June.

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 test-results can be found in Appendix D.3. For all significant trends, Sen's Slope Estimator was calculated, and is given in Table 17. Compared to the slopes obtained with linear regression in the previous section (Table 16), there are only small differences.
Unlike the lack of significant trends in the precipitation data, for the temperature data many significant trends were found ($\alpha = 0.05$). For the maximum temperature in Godawari and TIA a significant increasing trend was found for *all twelve* months. Also for minimum temperature many significant trends were found: all increasing without any exception. For T_{max} a significant increasing trend was found for all four stations in the month January and the period July to November. For T_{min} a significant increasing trend was found at all four stations only in the month September. 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, T_{max} had an average increase of $0.05°C$ per year. The average slope of T_{min} 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 T_{max} more significant trends are found in summer), as also was found in Section 4.2.2.3 and by Cruz et al. (2007) and Shrestha et al. (1999). Table 18 gives the average slope per season (as defined by Thapa and Joshi, 2011) over all months with significant trend.

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 $25°C$[1] (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, although one should realize that rice growth has different development stages demanding their own particular optimal conditions.
Wheat is the most common winter crop. The optimal temperature for wheat growth is, depending on the development stage, between $20.3°C$ and $22.0°C$[1] (Luo, 2011). Long-term average winter

Table 17: Sen's Slope of significant trends through monthly averaged maximum (top) and minimum (bottom) temperature

Tmax	Khumaltar	TIA	Godawari	Panipokhari
Jan.	0.05	0.09	0.08	0.06
Feb.		0.10	0.06	
Mar.		0.08	0.05	
Apr.		0.07	0.05	0.06
May		0.05	0.04	0.07
Jun.		0.06	0.04	
Jul.	0.03	0.05	0.03	0.03
Aug.	0.03	0.06	0.04	0.04
Sep.	0.03	0.08	0.06	0.06
Oct.	0.04	0.09	0.07	0.04
Nov.	0.06	0.08	0.09	0.06
Dec.		0.07	0.09	0.04
T_{min}	Khumaltar	TIA	Godawari	Panipokhari
Jan.				
Feb.	0.07	0.06		0.09
Mar.	0.09	0.05		0.08
Apr.	0.05			0.06
May	0.07	0.03		
Jun.		0.02		
Jul.	0.02	0.02	0.02	
Aug.	0.06	0.02	0.03	
Sep.	0.07	0.03	0.03	0.08
Oct.	0.09	0.04		0.11
Nov.	0.06	0.05		0.10
Dec.	0.06	0.07		0.10

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, 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 18: Average Sen's Slope per season

Season	Months	T_{max}	T_{min}
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

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 T_{max} in summer and 0.05°C for T_{max} in winter, which is respectively equal and slightly lower than the numbers given in Table 18. For T_{min} in summer they found an increase of 0.01°C, and a *decrease* in winter T_{min} of 0.001°C. Both numbers are lower than given in Table 18, and could indicate that Kathmandu valley is under the influence of

[1]Note that the optimal growth temperatures are daily averages calculated as $(T_{max} + T_{min})/2$, and in the above analysis T_{max} and T_{min} are considered separately.

an urban heat island, which is an effect of urbanization.

Block Bootstrap Mann-Kendall trend analysis
The temperature data showed strong autocorrelation and seasonality(see Section 3.2.2.3), so the Mann-Kendall and Seasonal Mann-Kendall test were not applicable. To account for both autocorrelation and seasonality, the Block Bootstrap procedure has been applied.
A BBS procedure (2000 repetitions, block length of 41) was conducted for all four stations for maximum and minimum temperature. Table 19 gives an overview of the calculation results. The

Table 19: 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	T_{min}	0.049	$< 2.22 * 10^{-16}$	0.0350	0.1625
	T_{max}	0.097	$< 2.22 * 10^{-16}$	0.1364	0.2534
TIA	T_{min}	0.065	$< 2.22 * 10^{-16}$	0.0653	0.1951
	T_{max}	0.149	$< 2.22 * 10^{-16}$	0.2378	0.3559
Godawari	T_{min}	0.024	$3.15 * 10^{-5}$	-0.0201	0.1151
	T_{max}	0.097	$2.22 * 10^{-16}$	0.1300	0.2569
Panipokhari	T_{min}	0.050	$< 2.22 * 10^{-16}$	0.0323	0.1672
	T_{max}	0.112	$2.22 * 10^{-16}$	0.1598	0.2866

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, the significance of the results could not be assessed. The last two columns of Table 19 give the upper and lower boundary of MK's Tau for a 95% Confidence Interval (CI, $\alpha = 0.05$), obtained with the BBS procedure. This technique avoided the problems generated by dependency and all conclusions should be based on these two columns. The 95% CI was based on the assumption that MK's Tau was normally distributed after repeating the procedure 2000 times. Figure 17 shows the distribution of Tau after the BBS conducted for T_{max} in Khumaltar. This figure shows that MK's Tau was clearly approaching a Gaussian distribution (the line in the figure).
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. This was the case for all stations, except for T_{min} in Godawari (Table 19). This example showed why the BBS procedure was necessary: based on the ordinary Mann-Kendall test the conclusion would have been that T_{min} in Godawari had increased significantly, while after applying 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 T_{min} in Godawari. This confirms the findings of the linear trend line through the data (Section 4.2.2.3), where T_{min} 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 the Sen's Slope Estimator was calculated based on monthly values. Therefore the slope gives the temperature increase per month. By multiplying this number with 12, the slope on yearly basis is obtained and given in Table 20. The temperature increase for T_{max} is the strongest in TIA. The increase in T_{min} is strongest in Khumaltar. Khumaltar, TIA and Panipokhari are three stations located within urban area. Godawari is a rural station. 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 had 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 (e.g. the bowl shape of the valley).

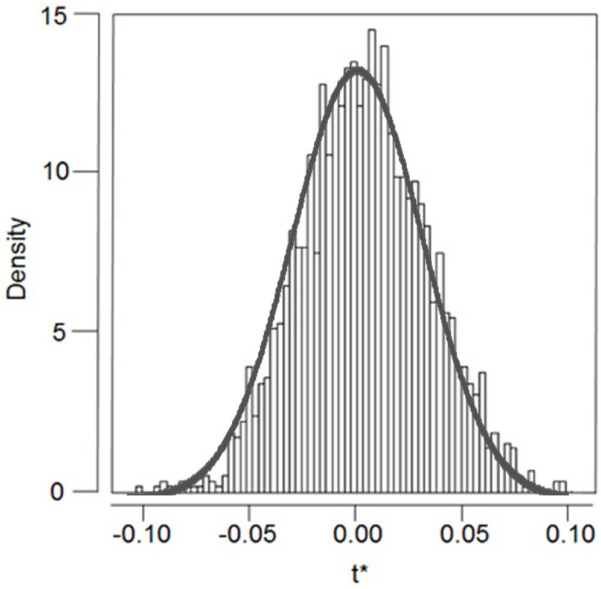

Figure 17: The frequency distribution of t* (bars) after 2000 repetitions for T_{max} in Khumaltar, and a normal distribution (line).

Table 20: Sen's Slope on yearly basis per station

Station	T_{max}	T_{min}
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 the minimum temperature, and an increase of $0.05°C$ per year for the 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, 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 temperature increase obtained in this study 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 obtained temperature increase is high, confirming the statement of Chaulagain (2006) that climate change is emerging faster in Nepal than the global average.

4.2.2.4 Summary

A decrease in number of $< 0°C$ days found in all four stations. This decrease was more pronounced in the stations settled in the urban area. The decrease in $< 0°C$ days can increase the presence of pests, pathogens and insects due to a decreased winter kill (Ziska et al., 2011). There was an increase in all four stations in the number of hot days ($> 30°C$), again more pronounced in the urban stations. The highest T_{max} of the year had become higher, and the lowest T_{max} also had become higher. The same counts for the highest T_{min} of the year and the lowest T_{min} 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 T_{max}-values. Increase in temperature extremes can lead to yield decline (Porter and Gawith, 1999), and might increase mortality due to extreme heat (Patz et al., 2000). Urbanization can further strengthen heat-related mortality, making peri-urban

areas more vulnerable.
Increase in temperature was lowest in summer season and highest in fall and winter season for both T_{min} and T_{max}, which again can decrease winter kill and increase the risk on pests, pathogens, and insects (Ziska et al., 2011). Increase in temperature can negatively influence the air quality due to the production of ozone (Patz et al., 2005). This effect is strengthened by urbanization, further threatening the peri-urban area. On the other hand, increasing temperature during the monsoon season can have a positive effect on rice yield and increase in winter temperature can positively affect wheat yield (Malla, 2008). But it depends on the temperature increase relative to the development stage of the crop if the effect turns out positive, and increase of minimum temperature enhances early maturity and thus yield decline (Lal, 2011).
Based on Sen's Slope applied to the complete data series, T_{min} showed an average increase of $0.04°C$ per year and T_{max} 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 variation in temperature have increased. This has a negative impact on the yield (Wheeler et al., 2000). It can be concluded that there are some serious concerns for the peri-urban areas as a result of the observed significant temperature increase. These concerns are further emphasized by urbanization.

4.2.3 Evapotranspiration

For this section, Penman-Monteith (PM) evapotranspiration for a reference crop ($ET_{0Penman}$) was calculated, and PAN-evaporation data (ET_{0PAN}) were available for TIA and Khumaltar. First the difference between both methods was studied. After having insight in the differences, some indices were calculated and a linear trend analysis was carried out.

For the period where overlapping data was available for PAN-evaporation and PM-evapotranspiration, the difference between both was calculated with $ET_{0Penman} - ET_{0PAN}$. The overlapping period was 2002-2009 for Khumaltar and 1999-2009 for TIA.
The mean absolute difference is 0.8 mm/day. Most of the differences 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, because the average daily PAN-evaporation during monsoon was 4.3 mm (see Table 21). Noticeable is that there was clear seasonality visible in the differences, see Figure 18 for Khumaltar (the differences for TIA follow the same pattern). During summer season, PM's $ET_{0Penman}$ was higher, while during winter season the ET_{0PAN} had the highest value of both. Striking is that 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.
The large differences between both methods that were found, should raise awareness for the rest of

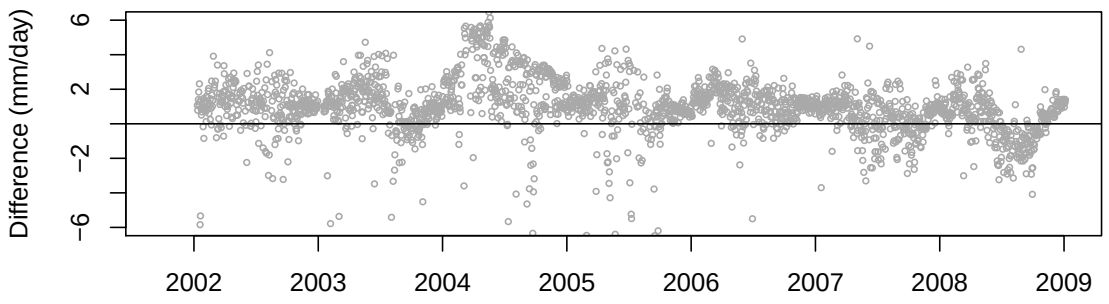

Figure 18: Difference between daily PM-evapotranspiration and PAN-evaporation.

this section that the data (whether ET_{0PAN} or $ET_{0Penman}$) was uncertain and maybe unreliable. Table 25 gives the correlation between the two different methods. This correlation was slightly higher for Khumaltar than for TIA.

4.2.3.1 Trend analysis on indices

With the available ET_{0PAN} data and the obtained $ET_{0Penman}$ data, two indices were calculated for evapotranspiration; the number of days that evaporation exceeds precipitation, and the evaporation sum and mean per season (Section 3.2.3.1).

Number of days that reference evapotranspiration exceeds precipitation in the monsoon period
With the PAN-evaporation from TIA and Khumaltar, an estimation could be made of the daily evaporation during the monsoon period. Table 21 shows the average daily evaporation for both stations.

For all stations, 4.3 mm evaporation per day in the monsoon is assumed. The number of days was counted that precipitation was less than 4.3 mm during the monsoon. The slope of the trend line through this number of days is given in Table 22.

Table 21: Average evaporation in mm/day

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

Table 22: Slope of trend line through number of days that evapotranspiration (ET) exceeded precipitation (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 22 were positive for all seven stations, implying that the number of days that *reference* evapotranspiration exceeds precipitation had increased for all seven stations. The signal was sometimes very weak. For example, for TIA the slope is almost a horizontal line with a slope of 0.004 (and R^2=0.00). It is still remarkable that all seven stations showed the same direction. Naikap had the strongest signal, probably because this station had only 13 year of data. In this analysis, ET_{0PAN} was used, measured PAN data. In an agricultural field reference 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.
There are several impacts if the number of days that evaporation exceeds precipitation had increased. Rain-fed agriculture might need additional irrigation, or irrigation should start earlier after the monsoon due to soil moisture deficit (Shukla et al., 2011). And as mentioned before, drought stress 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 22 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 results of the strong population growth and urbanization.

Evaporation sum per season
For the seasons as defined by Thapa and Joshi (2011) given in Table 5, $ET_{0Penman}$ sums and mean

were calculated. Disadvantage of the $ET_{0Penman}$ data was that it was only available for a really short period (Section 2.1). The average evapotranspiration per season was calculated to minimize the effect of data gaps.
The slope of the trend line is given in Table 23. As visible in Table 23, it seems that evapotran-

Table 23: Slope of trend line through seasonal PM-evapotranspiration sums and means

	Khumaltar		TIA	
	sum	mean	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

spiration 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 (10-16 years). Still this signal is visible in both stations and for both the sum and the mean, which gives at least an indication, and development should be carefully monitored.

4.2.3.2 Trend analysis on the raw data

A linear trend line was plotted through 41 and 40 year of ET_{0PAN} data for Khumaltar and TIA respectively. These data contained large gaps.
Also a linear trend line was drawn through $ET_{0Penman}$-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 24. The low slope values show that no

Table 24: Slope of linear trend line through evapotranspiration for given period

Station	Period	ET_{0PAN}	R^2	Period	$ET_{0Penman}$	R^2
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

increase nor a clear decrease in ET_{0PAN} and $ET_{0Penman}$ took place over the period given in the table. Since evapotranspiration depends on temperature (see Equation 20), and a significant increase in temperature was found, an increase in evapotranspiration was expected. In literature on climate, it is more often found 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 the same holds for reference evapotranspiration $ET_{0Penman}$. With regression analysis Chattopadhyay and Hulme show that the increase in relative humidity had the strongest correlation with the decrease in ET_{0PAN}. 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 25 gives the Pearson's correlation coefficients between different climatic variables. The correlation coefficients differed 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 ET_{0PAN} and $ET_{0Penman}$ is on actual evapotranspiration ET_a (Cong and Yang, 2008). For agricultural crops, the ratio ET_a/ET_{0PAN} is important and determines to a large extent the crop growth.

4.2.3.3 Summary

Substantial differences were found between PAN-evaporation ET_{0PAN} and Penman-Monteith

Table 25: 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

evapotranspiration $ET_{0Penman}$. The quality of the data is not optimal to draw any robust conclusion.
An increase was found for number of days that evaporation exceeds precipitation during the 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 10-16 years. Linear trend analysis through both ET_{0PAN} and $ET_{0Penman}$ showed, against the expectation based on the temperature increase, no increase. This phenomenon is in literature known as 'The Evaporation Paradox'. It is unknown what the effect is on actual evapotranspiration.

4.2.4 Discussion

Some changes in climate that were found in literature could not be confirmed by this research because the available data was aggregated (daily data) in this study. For example, Cruz et al. (2007) found an increase in rainfall intensity. Precipitation data was only available on a daily basis, measured once a day, so it was not possible to analyze individual rainfall events from a couple of hours in this study. Intense rain showers can precipitate a lot of rain in a short period, but the daily precipitation sum might not differ significantly from a full day of not intense rainfall. For the number of extreme rainfall events, here defined as > 50 mm precipitation per day, only daily precipitation sums were considered. 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.
For all three climate variables (rainfall, temperature, evaporation) linear trend analysis was conducted. Next to that, the R^2 was given. This R^2 is often used in literature (e.g. Joshi et al., 2011) to indicate to what extent the linear model is able to describe the variation of the data. Both the R^2 value and the linear regression line are very sensitive to outliers, which may affect the trend line and R^2 in both directions (Rousseeuw and Leroy, 2003). Therefore, Sen's Slope was used to calculate the slope of the trend after testing the significance with Mann-Kendall. Another point of discussion of R^2 is that this R^2 indicates to what extent the line $y = ax + b$ fits the data. In this trend study the slope of the line, a, is actually the only interesting variable, but R^2 also depends on the 'b', which was not interesting in this study. An other possibility in further research would be to check the significance of 'a' by determining the standard deviation of the slope of the trend line.

For the precipitation and temperature data, a linear trend analysis on monthly basis was conducted. For the precipitation the conclusion is that there was no temporal change in distribution. This means that there is no temporal change at the monthly level, it might be that precipitation distribution within the months had shifted. According to the (Seasonal) Mann-Kendall test, there

was no significant increase or decrease in precipitation. This conclusion is valid for the statement that the total precipitation had not significantly increased or decreased. There are a lot of other factors important in precipitation, like a possible change in distribution in time varying from a daily to a monthly scale. So although no long-term trend in precipitation was found, this does not mean that there are no changes in precipitation, with the subsequent impacts.

For the temperature analysis only four stations had available data, of which three were located in urban area and only one in rural area. There were indications for a developed urban heat island around Kathmandu, but this presumption could only be validated with one station. More elaborate research is necessary to give scientific proof for a clear urban heat island in Kathmandu.

For both temperature and precipitation data, a statistical test was conducted to test the significance. The significance level was set to $\alpha = 0.05$. This implies that potentially in 5% of the cases a TYPE-I error could be made: the null-hypothesis (no trend) is rejected, while it is actually true (Yue et al., 2002). This means that from the results, one out of twenty of the significant trends that were found is probably not significant.
There is also the chance for a TYPE-II error: accepting the null-hypothesis when it is actually false (Yue et al., 2002). The chance to make a TYPE-II error is β, dependent on the power of the test. The power P of a statistical test is defined as

$$P = 1 - \beta \tag{35}$$

Yue et al. (2002) found out that the power of the MK-test increases when the trend has a steeper slope, and when the sample size is bigger. If the amount of variation increases, the power of the test decreases. And, against the expectations for a distribution free statistical test, the power of the test does also depend on the distribution type of the data. There thus might be a chance that the null-hypothesis, no trend, was accepted when there was actually a trend in the data. For the monthly analysis carried out with MK, temperature and precipitation had more or less equal sample size. But the SMK conducted with precipitation data on monthly basis (result: out of seven stations, zero significant trends) had a much smaller sample size than the BBS MK conducted with daily temperature data (result: seven out of eight had significant trend). Next to that, variation in precipitation data (zero mm per day up to more than 150 mm per day) is bigger than the variation in temperature data (varying from a few degrees below zero up to around thirty degrees above zero). The power of the trend test applied to precipitation data was lower than the power of the temperature test, due to the smaller sample size and higher variation.
The detectability of changes with statistical tests is in debate. Radziejewski and Kundzewicz (2004) wrote that even if a climate change component is present in the data, it does not need to be detected by a statistical test at a satisfactory significance level. The conclusion from Radziejewski and Kundzewicz (2004) is that MK is not able to detect weak changes, or changes which have not lasted long enough. On the contrary, Cohn and Lins (2005) state that statistics often discover a trend too fast. Another discussion going on in literature about applying statistical tests to hydroclimatological data is the violations of statistical assumptions (Stahl et al., 2010). The MK-test assumes no seasonality and no autocorrelation, and both assumptions have been taken into account in this study by choosing adapted tests. But the MK-test claims to be distribution free, while Yue et al. (2002) found that the power of the test depends on the distribution of the data. After all, seen our limited knowledge on the complexity, long-term persistence, and non-linearity of the climate system, Cohn and Lins (2005) made the following important statement:

> *The concept of statistical significance is meaningless when discussing a poorly understood system.*

And this statement is particularly true in the context of the complex geography in Kathmandu valley. The mountainous area causes orographic and rain shadow effects on precipitation (Islam, 2009). There are many small scale weather systems leading to high spatial variations. This variation was visible in the data from the meteorological stations used in this research (see Table 2), which were located at a maximum distance from each other of less than only 25 km (see Figure 4). Lang and Barros (2002) found in the Marsyandi River basin close to Kathmandu valley extremely large gradients over small spatial scales (10-20 km), and Baidya et al. (2008) and Islam (2009)

describe that there is a relation between rainfall, temperature and altitude. In the above discussed results, some numbers were averaged out for the complete valley, but the practical value of this average number is debatable if there is such high spatial variation.

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 ET_{0PAN} and $ET_{0Penman}$, the data showed substantial differences. The analysis of these data could only raise some suspicions, but it was impossible to draw any firm conclusions.

4.3 Human Perception

Both in Dadhikot and Jhaukhel a Focus Group Discussion (FGD) was organized. But before that, a pre-survey was carried out in the two field sites for a first insight in the perception of the inhabitants of Dadhikot and Jhaukhel. The first section presents the results of the pre-survey.
After the pre-survey, using the obtained information and the literature study, a questionnaire was designed, which served as a basis for the group discussions. This questionnaire will be discussed in the second subsection. Finally, the results from the FGDs will be presented.

4.3.1 Pre-survey

Here below the results from the pre-survey are presented. Several challenges to tackle came forward from these visits. The first challenge was that it was impossible to ask respondents for instance exact years and how they experienced changes 5 or 10 years ago. The second finding was that it was hard to distinguish changes induced by climate change from changes induced by local effects, like pollution from industries and urbanization. These results helped in designing the questionnaire for the FGDs.

Rainfall
Three middle-aged men from Dadhikot mentioned that until ten years ago, rainfall was more predictable than it is now. The same is stated by farmers from Jhaukhel. Because of this unpredictability, they first wait for the rainfall to start before starting with planting the paddy. The men in Dadhikot say monsoon rain had become more intense and that the number of dry spells had increased, the farmers in Jhaukhel confirm this, saying that intensity had increased but the number of rainy days had decreased. Striking is that the farmers from Jhaukhel perceived that the onset of monsoon had moved earlier, from Shrawan (July/August) to Ashad (June/July), which they perceive as a positive change. Fields with irrigation channels normally start paddy production in Ashad (June/July), but Jhaukhel is a water scarce area and there are many *bari* (fields without irrigation), so farmers start the paddy planting in Shrawan (July/August), when monsoon has really started. The farmers mention that in the last years also the fields without irrigation could start paddy planting already in Ashad (June/July)
An older man, farmer and social activist aged 64, from Dadhikot had a clear opinion about environmental change. He says precipitation had decreased: *"Shrawan mahina ma auta tara dekhyo vane ek lakh muri anna ghatcha"*, meaning *"If a single star could be seen at the sky during the month of July- August, the crop yield gets reduced by a hundred thousand times."* According to him, it was a decade with very poor winter rain, which had been a problem for the winter crops because the irrigation canal Mahadev Khola Raj Kula was no more a reliable source for fresh water. Contrarily, the farmers in Jhaukhel experiences the last eight to ten years as a decade with good rain. A women-group working in a office in Dadhikot did not perceive any significant change in precipitation.

Temperature
The women from the women-group in Dadhikot perceived an increase in temperature. Some men in Dadhikot also perceived this temperature increase, mentioning that there is no more formation of ice film on water surfaces. This same example is given by farmers from Jhaukhel: *"When we were young, we used to play breaking the icy film on the water surface"*. The men from Jhaukhel blame urbanization for this temperature increase. They say the days are getting hotter, and the chill days have decreased. The frost days have reduced. The men in Dadhikot say that frost used to start from Kartik (October/November), and remained until Falgun (February/March), while in the recent years frost only appears from Poush to Magh (December to February).

Changes in Cropping System
The main crops in Dadhikot used to be paddy (rice) and wheat, in Jhaukhel paddy and maize were the main crops. The three middle-aged men and the older man from Dadhikot mentioned that until the beginning of the 1990s, they used to grow wheat during winter. After that, vegetable farming became more and more important with the growing shift from traditional to chemical fertilizer and increasing urbanization and economic benefits. In the last four to five years, commercial farm-

ing increasingly grew vegetable crops, like pumpkin and cucumber, that have a higher demand and because they can be harvested faster than wheat (one month versus four to five months), thus having a higher profit. Also in Jhaukhel, where rice/wheat is grown on irrigated fields and maize/soybean/chilly/mustard/millet rain fed, the shift had gone to more vegetable cropping in the last ten years. According to a women-group in Jhaukhel, the mustard yield declined because of early flowering leading to smaller seeds. They give three possible causes; climate change, pollution from the brick kilns or the chemical fertilizer that is used the last years.

Changes in Crop Cultivars
The 64-year old man from Dadhikot explained that he used to grow indigenous paddy crops; *Thapchini* (which could be harvested during Ashoj, Aug./Sep), and *Marsi* (harvested during Kartik, Sept./Oct.). In 1968 chemical fertilizer was introduced. In that same year, a new rice variety was introduced, named *Taichini*, increasing the yield more than 2.5 times! In the consecutive years, the man replaced the indigenous variety with the new variety, and in 1971 he only cultivated the new variety. In this period also a High Yield Variety (HYV) of wheat was introduced, dwarf wheat, or in Nepali *Baunna gahu*.

Insects and Pests
Nowadays, with the use of chemical fertilizer, the use of pesticides and insecticides is mandatory. The interviewees mention that pests in wheat had increased and also the use of pesticides had increased. The farmers in Jhaukhel explain that since the introduction of chemical fertilizer in the mid 1960s, biological and chemical pest control have overtaken conventional practices. They say that there is almost no vegetable production without the application of pesticides.

Weeds
The women-group and the old man from Dadhikot told that they have observed new weed species in the last 5 to 10 years. The older man mentioned an unknown weed species, which in the recent years appeared in the paddy fields and grows just as high as the paddy plants. In 1983 another invasive weed species was observed, probably influencing the declining yields ever since.

Productivity
The farmers in the Dadhikot VDC distinguish three phases in their crop yield. In the 1950s, crop production was only approximately 2000 kg. paddy and 700 kg. wheat per hectare. During the Green Revolution from the end of the 1960s to the beginning of the 1980s, crop yields increased to 7400 kg. paddy and 5000 kg. wheat per hectare. But ever since the 1980s, production is following a consistent declining trend, now being 5400 kg. paddy and 2550 kg. wheat per hectare.

Natural Resources
The three men from Dadhikot mention that the drinking water sources are drying. Before, the shallow wells (10-15 m) contained enough water to meet the demand, but right now even the deeper wells (20-25 m) do not yield enough water. Currently, deep boring takes place to abstract enough groundwater. According to the men, this is due to urbanization. Jhaukhel is from its own already a water scarce area. The water availability from the drinking water scheme in the village (Changunarayan- Jhaukhel-Duwakot) had declined, water in the stone prouts had decreased drastically, leaving some almost non-functional. On the contrary, there is an increased effort in Jhaukhel to install individually based dug-wells.

4.3.2 Questionnaire

With the findings of the pre-survey and the literature study on impacts, a questionnaire was designed to function as a basis for the FGDs. The final questionnaire is discussed below, part by part.

Time-Line
To tackle the first problem that popped up during the pre-survey, that it is hard to place observations in time, the time-line method is developed. It is often easier for people to remember a certain event, and link that to the climate and the crop production. Important events in the

village (e.g. the construction of a road), that all the participants of the discussion can remember, are kept as a reference. Based on a few events, a time-line is developed for which the group can answer the questions; the group is asked to answer the questions according to the situation during that particular event.
The questionnaire-sheet with the time-line can be found in Appendix E.1.

Perceptions on Change in Climate
The first questions are about the perception of people on the changing climate. This section is divided into three subparts: Rainfall, Temperature and Wind, see Appendix E.2. Per time frame based on the time-line, the group can indicate if a particular phenomenon had a large increase (2), small increase (1), no change (0), small decrease (-1) or large decrease (-2), compared to the oldest point in the time-line.
In the parts of Rainfall and Temperature, also questions on consequences for agriculture and livelihood are included.

Perceived Consequences to Agricultural Production System and Productivity
This part of the questionnaire, Appendix E.3, exists of five subparts:

- Changes in the cropping system
- Changes in the crop cultivars
- Dominant insects/pests
- Dominant weeds
- Productivity of crops

In the first subpart, Changes in the cropping system, the grown crop per cropping season is asked for the different time frames. There are three cropping seasons defined: Monsoon crop, winter crop and spring crop. This part of the questionnaire is to find out if farmers shifted from certain crops to other crops.
In the second subpart, Changes in the crop cultivars, the crop varieties are asked per cropping season for the different time frames. This is to find out if farmers have changed their crop cultivar. Manandhar et al. (2011) found, for example, that farmers in the west of Nepal have shifted from local rice varieties to hybrid rice varieties.
The third subpart focuses on insects and pests. Per cropping season for every time frame, the names of the occurred insects and pests are asked. This is to find out if new insects and pests have occurred and if the number had increased. The fourth subpart is the same, but then applied to weeds. It is also asked if people have observed new weed-species in the crops.
The last part asks for the productivity. Most important here is if the productivity had increased, decreased or was steady over the last few decades. Of course productivity depends on a lot of factors, not only on climate. The last question asked is to what extent the group thinks climate is responsible for the increase or decrease in crop productivity.

Degradation in Natural Resources and occurrence of Disaster Events
In this section of the questionnaire, which can be found in Appendix E.4, the group is asked about their perception concerning natural resources. This, for example, includes the quantity of water in the rivers and the depth of the groundwater table. Next to that, questions about disastrous events are included, for example, about the occurrence of forest fires. For every phenomenon for every time frame, people can answer if there was a large increase (2), small increase (1), no change (0), small decrease (-1) or large decrease (-2), compared to the oldest point in the time-line.

Perceived Consequences to Livelihood
This last part of the questionnaire goes deeper into practical consequences due to a changing environment. It especially focuses on the availability of water for drinking and household, and the quality of the water. Again these questions can be answered on a scale from large increase to large decrease for every time frame. The complete questions of this part can be found in annex E.5.

4.3.3 Focus Group Discussions

Two FGDs were organized: one in Dadhikot (Figure 19), which took place on Sunday 12 February 2012, and one in Jhaukhel (Figure 20) on Monday the 13^{th} of February 2012. The discussions had an open character and people freely walked in and out. In Dadhikot, between five and ten persons were attending the discussion, of which two third were men. Jhaukhel had a higher turnout, with 15 to 20 attendants of which more or less half were men. It took a long time to work through the designed questionnaire: about 2.5 hour. Next to that, it was hard to have everyone involved in the discussion, and the time-line did not work yet as planned. In Jhaukhel, the observations were only based on two times: 40 years ago and now, in Dadhikot it was not even possible to divide any times. Therefore, from Dadhikot only some general statements can be mentioned.

Figure 19: FGD in Dadhikot.

Figure 20: FGD in Jhaukhel.

Perceptions on Climate Change
First the perception on climate change will be discussed. These perceptions will be compared with the results from the hydro-meteorological analysis.

Rainfall
Table 26 shows the occurred changes in rainfall as perceived by the inhabitants of Jhaukhel.
The inhabitants observed a decrease in total amount of rainfall, as well in the monsoon- as in winter rainfall. This statement came also forward in the trend line the participants drew during the FGD, see Figure 21 and Figure 22. In general, no significant decreasing trend was found in the precipitation data. Figure 6 in Appendix C shows the deviation from long-term average precipitation in and outside monsoon for Changunarayan station, the most representative station. This figure does not show a long-term decrease in precipitation, also no statistically significant decreasing trend was found in Changunarayan. But, averaging out the linear regressions per month (Table 10), a slope of -0.09 is found. That the people perceive a decrease in precipitation, and only a small insignificant decrease can be found in the data, can be an indicator that people are very well aware of the changes in climate, but might also show their vulnerability if this trend really continues. Another possible explanation, probably more important, for this perceived strong decrease in precipitation could be the declining water availability in general, and in water availability not only changes in precipitation but also the effects of urbanization are visible.
The inhabitants perceived that the number of rainy days had stayed the same as 40 years ago. For Changunarayan station a strong decrease in number of rainy days was found (Table 7), both in and outside the monsoon, but averaged out over all the stations no clear change in the number of rainy days was found. Noticeable is the perceived decrease in extreme rainfall events. Table 9 shows an increase in extreme events in most stations, also in Changunarayan. No change in number of dry spells was perceived, and this was also not found in the hydro-meteorological analysis.
Very striking here is that, according to the participants of the FGD, the onset of the monsoon had delayed (-1) with fifteen days. During the pre-survey in Jhaukhel, farmers were telling the contrary: according to them, onset of the monsoon had moved to earlier in the year. For Changu-

Table 26: Perceived changes in rainfall in Jhaukhel, compared to 40 years ago.
+2 large increase, +1 small increase, 0 stayed the same, -1 small decrease, -2 large decrease

Rainfall attribute	Observed change
Total amount of rainfall	-2
Number of rainy days	0
Monsoon rainfall	-1
Winter rainfall	-1
Extreme rainfall events	-1
Persistence in monsoon rainfall	-1
Period/frequency dry spells	0
Time onset of monsoon	-1
Timeliness of cessation monsoon	+1
Timeliness winter rainfall	-1

narayan station, a large increase in June rainfall was found (Table 10), which could confirm the statement that the monsoon is starting earlier nowadays, and not later.
In the FGD the farmers also mentioned that the onset of monsoon had become less dependable. 40 years ago there used to be a few days of heavy rainfall marking the onset of monsoon, nowadays these heavy rainfall days are less reliable. The same was mentioned during the pre-survey in Dadhikot. An adaptation in practice they implemented as a consequence of this change was the shift from massive paddy planting in all fields at the same days, to planting in patches according to the water availability. The beginning and end of rice planting had shifted from Jestha to Ashad (June) to from Ashad to Shrawan (July). The farmers observed a decrease (-1) in residual soil moisture at the time of rice-harvest, leaving less for the following crops. But, the farmers stated, this had not yet reached such a level that it is a limiting factor for the production of winter and spring crops.
Clearly the perception on rainfall is not unambiguous, the results of the FGD are on many issues in contrast with the results from the pre-survey and many observations are only partly supported by the results from the hydro-meteorological analysis. Asking for the adaptations in agriculture as a consequence of changing precipitation, the farmers found no other noticeable change in cultivation practice, apart from the patch planting of rice.
Chaudhary and Bawa (2011) did 250 household surveys in India and Nepal (Ilam district) about perception on climate change. Almost 70% of the respondents perceived the onset of monsoon had moved to earlier in the year. On average, 46% of the respondents found that there was less snow in the mountains. Only 31% thought there was an increase in frequency of drought. Manandhar et al. (2011) interviewed Nepalese farmers about climate change in the lowland (Terai) region and the middle-mountain region, both in the West of Nepal. At both locations, farmers had experienced an increasing trend in untimely and erratic rainfall. Manandhar et al. (2011) found that farmers had adapt their cropping calendar, cropping sequence and planting methods. For example, as a response to late rainfall, transplanting of rice happens in the third week of August in stead of the third week of June, and harvesting takes place in November in stead of October. Important note from Manandhar et al. (2011) is that these changes in practices not only occurred as a response to climate change, but also as a response to a growing population and the availability of new technology.

Temperature
Table 27 shows the perceived changes in temperature according to the participants of the FGD in Jhaukhel. Figure 22 shows the trend lines drawn by the participants of the FGD. Remarkable is that the persons found that both the duration of summer and winter season have increased. In Figure 22 they also drew that both 'hotness' and 'coldness' have increased, meaning that it had become warmer in summer and colder in winter. They explained this with the change in house-types. The traditional houses are built of mud and have good isolation, keeping warmth outside is summer and warmth inside in winter. But nowadays, many houses are made of concrete, which heats immediately in summer, and is cold during winter.
No increase in hot days was perceived, while this was clearly present in the hydro-meteorological

Figure 21: Drawing of PRA-tools during FGD Jhaukhel.

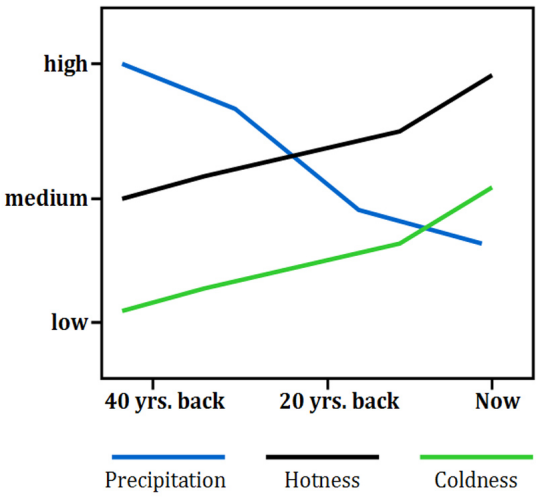

Figure 22: Trend lines according to the participants of the FGD in Jhaukhel.

data (see Table 14), although the rural station Godawari had the weakest trend. A perception that is supported by the data is the decrease in number of frost days. Table 13 shows a decrease in the number of $< 0°C$ days, which is one of the conditions necessary for a frost days. Other requirements for frost are high humidity, a clear sky, and no wind. It was mentioned by the participants of the FGD that visible frost (*tusaro*) used to occur from the second week of Mangshir (beginning of December) to the second week of Falgun (beginning of March), while nowadays *tusaro* only occurs from Poush (December/January) to Falgun. In the pre-survey, the farmers from Dadhikot also mentioned the later entry of frost. The farmers mentioned during the FGD a decrease in incidences of frost damage to winter crops.

The participants perceived an increased amplitude between day and night temperatures. It was

Table 27: Perceived changes in temperature in Jhaukhel, compared to 40 years ago
+2 large increase, +1 small increase, 0 stayed the same, -1 small decrease, -2 large decrease

Temperature attribute	Observed change
Duration of summer season	+1
Duration of winter season	+1
Number of extreme hot days	0
Number of extreme cold days	0
Number of frost days in winter	-1

found in the hydro-meteorological analysis that the minimum temperature had increased less than the maximum temperature in the rural station Godawari (see Table 20) which could confirm this observation. They observed a decrease in number of fog days during winter, and also a decrease in fog hours per day. This could be the result of an increasing temperature. It seems the participants of the FGD had quite a good feeling about the changes in temperature that occurred over the last few decades, apart from the persistent belief that temperature had decreased in winter (This statement was not made during the pre-survey: During the pre-survey, the interviewees from Jhaukhel said that the number of chill days had decreased, they perceived an overall temperature increase. This is also in line with the findings of the hydro-meteorological analysis, see Table 18.).

From the respondents in the field survey of Chaudhary and Bawa (2011), 73.2% thought that there is an overall temperature rise. The upland-farmers from the West of Nepal, interviewed in the research of Manandhar et al. (2011), also observed "an unusual rise in both summer and winter temperatures".

For Wind, no changes were perceived.

Consequences for Agriculture
Because agriculture depends to a large extent on climate, it is likely that agricultural practices and patterns have to be adapted as a response to climate change (Chhetri et al., 2012). In this section the changes in cropping systems, changes in crop cultivars, insects and pests, weeds and crop productivity will be discussed respectively .

Changes in Cropping System
The main monsoon crops in Jhaukhel are still the same as 40 years ago; paddy and maize. The winter crops also did not change: potato, wheat/barley and mustard. The main spring crops were and are still chilly and maize.
Since ten years or so, some farmers have started tomato cultivation during spring on a commercial scale, since three years some farmers have shifted from wheat to cabbage as a winter crop. In the pre-survey it came forward several times that farmers have shifted to vegetable farming during winter and spring. This had mainly economic reasons, and can be linked to the increasing demand due to urbanization.

Changes in Crop Cultivars
Although no clear changes in cropping systems have occurred, there are changes in crop cultivars. 40 years back, the farmers of Jhaukhel cultivated traditional rice varieties: *Tauli*, *Thapchini*, *Marsi* and *Masino*. Despite the advantage that these traditional varieties are drought-resistant, they do not give a high yield. Nowadays only one rice variety is cultivated, named *Taichini*, a High-Yielding Variety (HYV). A famous Nepali story tells that the Nepali king Mahindra was visiting China in the 1960s and saw this high-yield rice variety. He brought the seeds to Nepal, which is considered one of his benevolent acts. The disadvantage of this HYV is that it requires specific climatic circumstances and is therefore more vulnerable for climate variability (Adams et al., 1998) than the traditional varieties.
The main maize varieties used to be *Tin* and *Aiñgle*, but is replaced by a *Hydrid*, giving taller plants with longer leaves. The advantage of the HYV and hybrid crops is that they give a higher yield, but a disadvantage is their sensitivity to climatic variability. It is also a remarkable change that the farmer used to cultivate several varieties, and now cultivate only one.
Manandhar et al. (2011) describes how the interviewed farmers slowly shift from local rice varieties to modern hybrid varieties.

Insects and Pests
According to the participants, the incidences of damaging insects and pests to the crops had strongly increased (+2), and therefore also the use of pesticides and insect/pest-controlling features had increased (+2). They said that 40 years ago, no pest controllers were available and also were not necessary. Table 28 gives the current insects/pests per crop that have been observed. For wheat, no pesticide is currently used according the the farmers of the FGD. This is striking, because during the pre-survey the interviewed farmers in Jhaukhel mentioned that pests in wheat had increased.
Increase in temperature, especially winter temperature, can enhance insects and pests. The observed increase in insects and pests might very well be the results of climate change.

According to Manandhar et al. (2011) insects and pests have become resistant due to the repeated

Table 28: Current insects/pests per crop

Crop	Insect/pest
Rice	*Patera*
Maize	*Gobre*
Potato	*Khumre*
Mustard	*Aphids*

application of pesticides, increasing the demand for pesticides even further. From the respondents of Chaudhary and Bawa (2011), 54% has observed new crop pests. The upland-farmers from the research of Manandhar et al. (2011) blame the increase in temperature for the by them observed increase in crop diseases and pests.

Weeds
Chaudhary and Bawa (2011) found that 30.4% of the respondents in their research had observed new weeds. The participants of the FGD in Jhaukhel did not observe any new weed species. During the pre-survey, some interviewees from Dadhikot mentioned that they had observed some new species.

Productivity
During the pre-survey, the farmers from Dadhikot distinguished three stages in productivity. According to them, productivity is decreasing since the eighties. The same was mentioned by the participants of the FGD in Jhaukhel.
40 years ago, rice yield in Jhaukhel was 30 pathi to 2 muri per Ropani (approximately 1500 kg/ha). Then, with the introduction of HY-Varieties, fertilizer and pesticides, the production increased to 5-7 muri rice per Ropani (6000 kg/ha), but is now decreasing to 3-4 muri per Ropani (3500 kg/ha). These numbers are slightly lower than the numbers given by the farmers in Dadhikot during the pre-survey, but show the same trend of decreasing yields in the last twenty years.

Degradation in Natural Resources
The general picture from the participants of the FGD in Jhaukhel is that available water is decreasing. They observed a decrease (-1) in the quantity of water in the rivers and streams, a decrease (-1) in the duration of reliable flow in the rivers and streams, and the groundwater level declined (-1). Subsequently, they observed an increase (+1) in the drying of dug wells and spring sources. The participants mention that this decline had to do with decreasing rainfall, but they consider the brick kilns which extract loads of water as the main cause.
The participants did not perceive any increase or decrease in fire hazards, inundations, or landslides.
In the research of Chaudhary and Bawa (2011), 70% of the respondents observe drying up of water sources. In the research of Manandhar et al. (2011), farmers in a lowland village reported that in the past there used to be more than ten artesian wells in the area, but now only three or four are left due to the persisting drought.

Consequences for Livelihood
Despite the observed decrease in natural resources, the people found a strong decrease (-2) in the scarcity of drinking water, and a strong decrease (-2) in time spent on managing daily supply of water. The main reason for this is the increased effort to install private dug wells, and the participants also mentioned a better pipe supply. This is in contrast with what the interviewees in the pre-survey told: they found a decline in available water from the drinking water scheme.
All the farmers observed that they need increased input (like fertilizer, plant protection, irrigation) to maintain their agricultural productivity (+2). The economic return of the land had declined (-2), and also the number of months that the farmer had sufficient production to provide his own household had declined (-2).

4.3.4 Summary

The observations made by the inhabitants of the peri-urban areas during the pre-survey and the FGD about the changing climate broadly follow the results from the hydro-meteorological analysis. For precipitation, no clear trend was found in the hydro-meteorological analysis. Also the perceptions about changes in precipitation vary widely, even within the same village people do not agree whether precipitation and the number of rainy days had increased or decreased, although during the FGD it was stated firmly that precipitation had decreased. No significant decreasing trend was found in precipitation in Changunarayan, although there was a decreasing tendency. This observation is maybe emphasized by the strong decrease in available water, but can also be an indicator for the sensitivity and therefore vulnerability of the inhabitants of the peri-urban areas

for changes in precipitation pattern.
For temperature, a significant increasing trend was found. In the pre-survey, many interviewees mentioned increasing temperatures and less frost. Also during the FGD the participants observed an increase in temperature, but remarkably the statement was made that winters have become colder despite the fact that they observed a decrease in frost. The increase in temperature and the decrease in frost can be supported by the hydro-meteorological analysis, but the increase in coldness goes against the finding that temperature increase is most pronounced during winter. The participants explained this observation with the different type of houses that are built nowadays, which have bad isolation.
As adaptive strategy to a less reliable onset of monsoon, farmers do the rice planting now in patches according to the available water, in stead of planting the complete fields in a few days. The increase in temperature had caused the farmers less frost damage.
The only change in cropping pattern that had occurred over the last years is an increase in vegetable farming. This is mainly for economic reasons and probably more the result of urbanization. There are changes in crop cultivars. The farmers have shifted to HYV and hybrid varieties which give a higher yield. Important remark here is that these modern varieties are more sensitive to climate variability than the traditional varieties.
A strong increase in insects and pests was observed, and therefore also pesticides use had strongly increased. This increase in insects and pests can very well be the result of increasing temperature. During the pre-survey, several interviewees had observed new weed species, during the FGD this was not mentioned. After a strong productivity-increase during the 'Green Revolution', production is now declining ever since the '80.
Degradation in natural resources, like in spring flow, is observed. But, according to the participants, the main cause for this degradation is the industry and thus an indirect consequence of urbanization. According to them, the perceived decrease in precipitation is only emphasizing this effect.

4.3.5 Discussion

As already mentioned in the discussion of the hydro-meteorological analysis, there is large spatial variation in climate variables within the valley. For Dadhikot and Jhaukhel, Changunarayan station is considered most representative because this one is located closest to the villages, but with the spatial variation that is found it can very well be that the situation in the villages is different from the situation in Changunarayan. On top of that, Changunarayan station only had precipitation measurements. For the temperature comparison Godawari station and Khumaltar station are situated closest to the villages, but Khumaltar is in city core and therefore probably not representative for peri-urban area. It is thus hard to determine whether the meteorological stations, where the observations of the inhabitants were compared with, are representative.
Also the representativeness of the FGD is discussable. Dadhikot has over 7000 inhabitants (Table 3), but during the FGD only five to ten persons were present. Jhaukhel counts over 8000 inhabitants (Table 4), only fifteen to twenty persons were attending the FGD. There are considerable differences in the statements made during the FGD and the perceptions that came forward from the pre-survey. It would therefore be good to repeat the FGDs several times in both villages with different persons.
The time-line method which was developed to place the information of the people in a time perspective did not yet work as planned. It was difficult to ask questions about, for example, rainfall perception and lead the discussion in such a way that a time-line developed. Probably this problem can be solved by taking a stronger lead during the discussion, but obtaining time aggregated information will always be one of the hardest parts of this study.

5 Conclusion

Precipitation did not show any clear trend. There was no indication that the number of dry spells in the monsoon had increased, nor that the length of dry spells had increased. There was no clear increasing or decreasing trend visible in the number of rainy days and the daily intensity index. In most of the stations, an increase in number of extreme events (> 50 mm precipitation per day) was found. This might increase the risk on floods, landslides and erosion.
There was no significant increasing or decreasing trend found in the total long-term precipitation.

For temperature, a decrease in the number of $< 0°C$ days and an increase in number of hot days ($> 30°C$) was found. The yearly highest T_{max} and T_{min} had increased, and also the yearly lowest T_{max} and T_{min} had increased. This can imply that the coldest day of the year had become warmer, and the warmest day of the year had become warmer.
On the long-term a significant increasing trend was found for both T_{max} and T_{min}, which was more pronounced during winter. There were indications that an urban heat island had developed around Kathmandu. There was a significant increase in minimum temperature of the urban stations, while no significant increase in minimum temperature was found for the rural meteorological station. T_{max} showed an average increase of $0.05°C$ per year, T_{min} had an average increase of $0.04°C$ per year. This increase is higher than South-Asian and global average temperature increase.
The decrease in $< 0°C$ days and increase in winter temperature might decrease winter kill and therefore increase the presence of pests, pathogens and insects (Ziska et al., 2011). On the other hand, an increasing winter temperature can positively affect wheat yield and an increasing summer temperature might positively affect rice yield (Luo, 2011).

The quality of the data was not optimal, but potential evapotranspiration did not show any increase or decrease, despite the increase in temperature. It is unknown what the effect on actual evapotranspiration is.

In general, the inhabitants of the peri-urban areas perceive climate change to a large extent conform the hydro-meteorological analysis. But, even within the same village completely opposite opinions exist.
During the FGD in Jhaukhel, the people clearly perceived a decrease in precipitation. This was not supported by an observed significantly decreasing trend, but precipitation in Changunarayan station showed a decreasing tendency. On top of that, the decrease in available water might strengthen the feeling of less precipitation. This strong perception combined with the weak decrease in precipitation found in the data, can indicate the great vulnerability of the peri-urban inhabitants for changes in precipitation or water availability.
The people perceived a decrease in extreme rainfall events, while in the data an increase was found. But also no increase in landslides was perceived, which could occur as a result of the extreme events. People perceived no increase or decrease in dry spells, which also was not found in the hydro-meteorological data.
Many participants of the FGD experienced an increase in summer temperature and a decrease in frost days. This was both supported by the hydro-meteorological data. During the pre-survey the people mentioned that also winter temperature had increased, while during the FGD the statement was made that winters had become colder (despite the decrease in frost). According to the data, winters had not become colder, temperature increase was even more pronounced during winter. The participants explained this observation with the different type of houses that are built nowadays, which have bad isolation.
Degradation in natural resources, like springs and sprouts, was observed. But, according to the participants, the main cause for this degradation is the industry and this thus is an indirect consequence of urbanization. The perceived decrease in precipitation was only further emphasizing this effect.

The only change in cropping pattern that occurred over the last years is that more and more farmers started cultivating vegetables as winter and spring crop. The reason given by the farmers is that vegetables can be harvested in a month, while wheat takes around four months. Moreover,

vegetables have a short market and a high market price. This change in cropping pattern seems the be mainly caused by economic reasons and as a result of urbanization, and not due to a change in climate.
In the cropping scheme some adaptations were implemented for the rice planting. As adaptive strategy to a less dependable onset of monsoon, farmers plant the rice now in patches according to the available water, in stead of planting the complete fields in a few days. This is clearly an adaptive strategy to climate change.
Since 'The Green Revolution' in South-Asia in the 1970s (Khan and Shah, 2011), farmers shifted from traditional varieties to HYV and hybrids. Also in the peri-urban areas of Kathmandu, the farmers are now cropping a HYV rice variety and a hybrid maize variety. Although these varieties give higher yields than the traditional ones, they are more sensitive for climatic variability (Adams et al., 1998). This increases the vulnerability of food-security in the area.
A strong increase in insects and pests was observed, and consequently, also the use of pesticides had strongly increased. Some new weed species were observed. Both this increase in insects/pests and these new weed species, can very well be a result of the increased temperature, thus climate change.
The farmers said they needed to increase inputs like irrigation, fertilizer, and plant protection, but still the productivity was showing a declining trend. Lal (2011) assigns this stagnation or even decrease in productivity to the rising temperature during the cropping seasons, but on the other hand monsoon temperature is currently lower than the optimal temperature for paddy cultivation (Luo, 2011; Malla, 2008). It seems that the agricultural sector in the peri-urban areas perceive urbanization as the dominant threat for agriculture, but the less dependable onset of monsoon, the sensitivity of HYV and hybrid varieties to climate variability, the increase in insects/pests and new weeds probably as a result of climate change, and the further emphasized decrease in water availability due to climate change, certainly also play a role in agricultural productivity and food security.

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Appendices

A Definitions

Literature review helps to define the different terms in the research questions, and to raise expectations for the result of the research by noticing comparable studies conducted in the field of perception of climate change and impact on agriculture.

Climate Change
Climate Change is defined by UN (1992) as follows: *"Climate change" means a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.* Climate is the average weather over a longer period, often 30 years (WMO, 1966). Bernstein et al. (2007), from IPCC, gives a different definition for Climate Change: *Climate change in IPCC usage refers to a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activity.* This definition is different from UN (1992), because here also climate change not induced by human activity is considered as climate change. In this report, the definition of IPCC will be applied.

Food Security
The definition of Food Security has developed over the past few decades, after being first defined by the World Food Summit (UN, 1975) in 1974 as:
"Availability at all times of adequate world food supplies of basic foodstuffs to sustain a steady expansion of food consumption and to offset fluctuations in production and prices".
The most recent broadly accepted definition of Food Security is given by FAO (2001):
"Food security is a situation that exists when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life".
The availability of sufficient and safe food is closely related to agricultural production, and therefore relevant in this research.

Peri-urban area
The definition of Peri-urban, as adopted by Shukla et al. (2010) for the 'Water-Security in Peri-urban South Asia'-project is defined by Rohilla (2005) as:
An area with the mix of urban as well as rural development processes, economy and livelihood, situated on the periphery of the cities.

B Conversion Table

Often different units are used in Nepal to express quantities. Also a different calendar is used. The calendar in Nepal is named Bikram Sambat (B.S.). This calendar is 56 to 57 years ahead of the calendar based on the birth of Christus. The Nepali calendar depends on the moon, and the months have different lengths every year. A Nepali month falls more or less in between two months of the conventional calendar. The table below gives the name of the Nepali months relative to the conventional calendar.

Baisakh	April	-	May	January	Poush	-	Magh
Jestha	May	-	June	February	Magh	-	Falgun
Ashad	June	-	July	March	Falgun	-	Chaitra
Shrawan	July	-	August	April	Chaitra	-	Baisakh
Bhadra	August	-	September	May	Baisakh	-	Jestha
Ashoj	September	-	October	June	Jestha	-	Ashad
Kartik	October	-	November	July	Ashad	-	Shrawan
Mangshir	November	-	December	August	Shrawan	-	Bhadra
Poush	December	-	January	September	Bhadra	-	Ashoj
Magh	January	-	February	October	Ashoj	-	Kartik
Falgun	February	-	March	November	Kartik	-	Mangshir
Chaitra	March	-	April	December	Mangshir	-	Poush

Monsoon is in the months Shrawan, Bhadra and Ashoj, in the conventional calendar from the 15th of June until the 15th of September. Also other units are used to express surface area and yield. The table below gives conversions from Nepali units to conventional units:

1 ropani	=	0.05 Ha.	1 Hectare	=	19.66 ropani
1 muri wheat	=	65 kg.	1 kg. wheat	=	0.015 muri
1 muri maize	=	65 kg.	1 kg. maize	=	0.015 muri
1 muri rice	=	50 kg.	1 kg. rice	=	0.02 muri
20 pathi	=	1 muri	1 pathi	=	0.05 muri wheat
20 pathi	=	65 kg. wheat	1 pathi	=	0.05 muri rice
20 pathi	=	65 kg. maize	1 pathi	=	3.25 kg. wheat
20 pathi	=	50 kg. rice	1 pathi	=	2.50 kg. rice

Other terms often used in Nepali agriculture are:

Khet - agricultural field where irrigation is possible
Bari - field with only rain fed crops

C Precipitation

C.1 Deviation from long-term annual precipitation

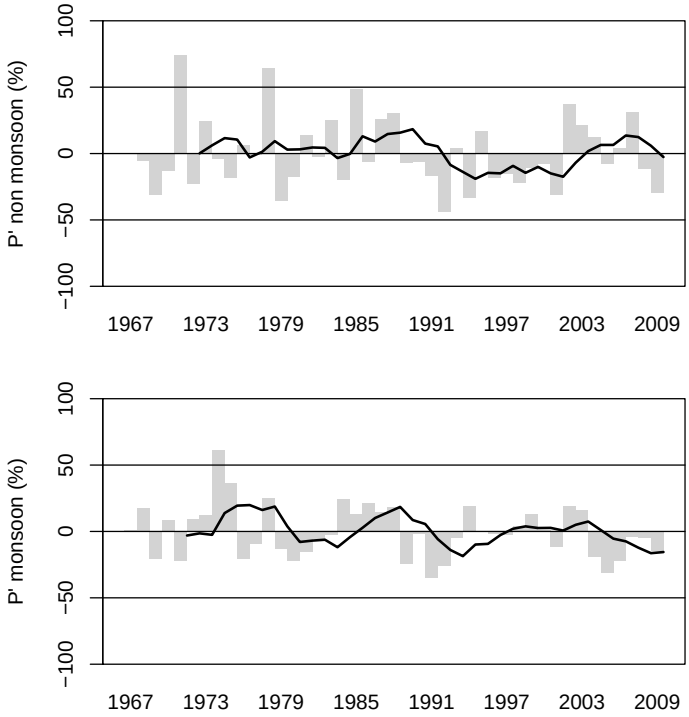

Figure C.1: Deviation (%) from long-term annual mean precipitation in Khumaltar. The black line gives the five year moving average.

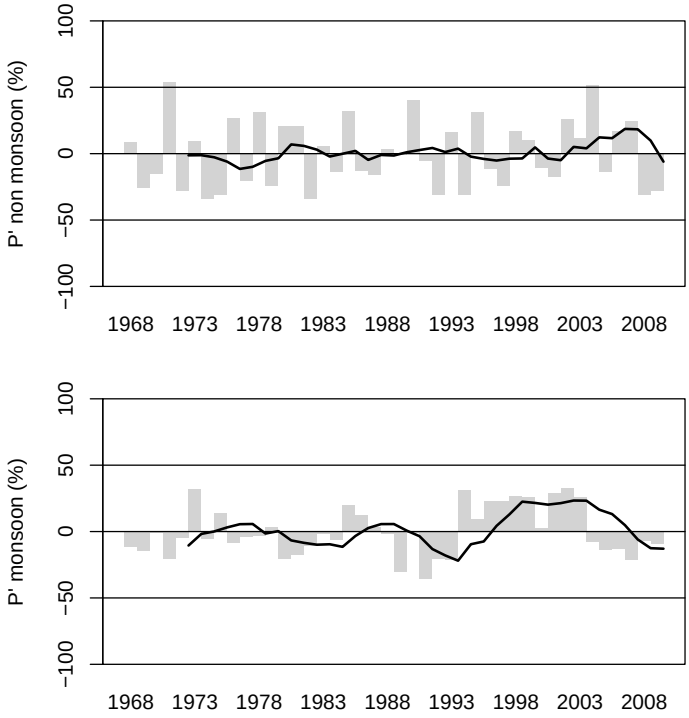

Figure C.2: Deviation (%) from long-term annual mean precipitation in TIA. The black line gives the five year moving average.

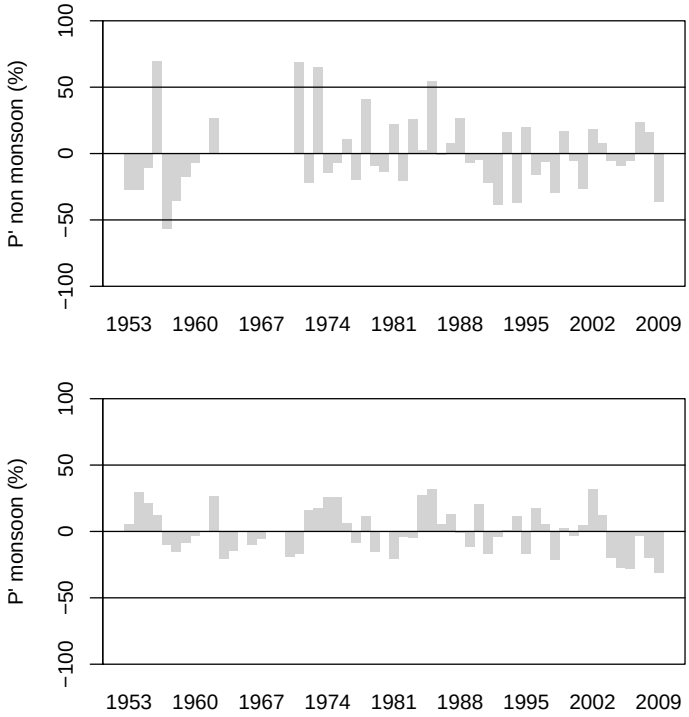

Figure C.3: Deviation (%) from long-term annual mean precipitation in Godawari. No 5 years moving average line is drawn due to years with Not Available data.

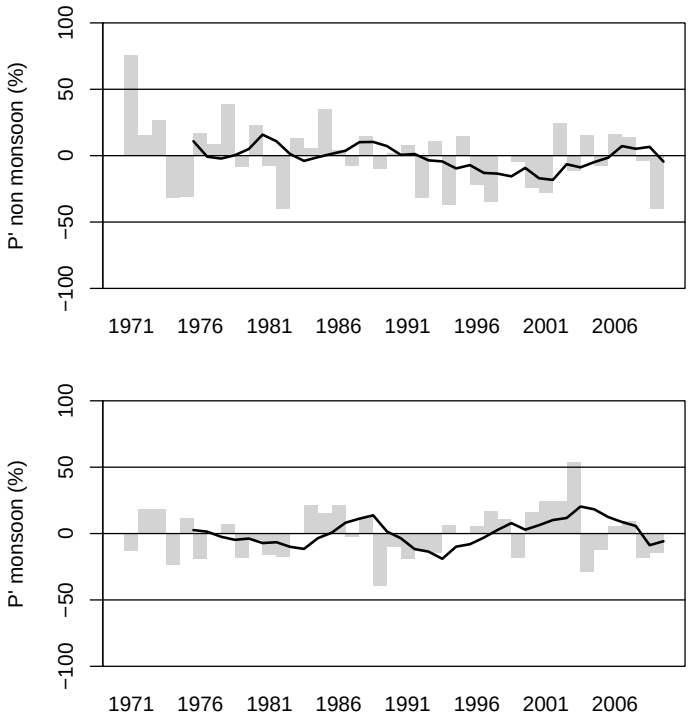

Figure C.4: Deviation (%) from long-term annual mean precipitation in Panipokhari. The black line gives the five year moving average.

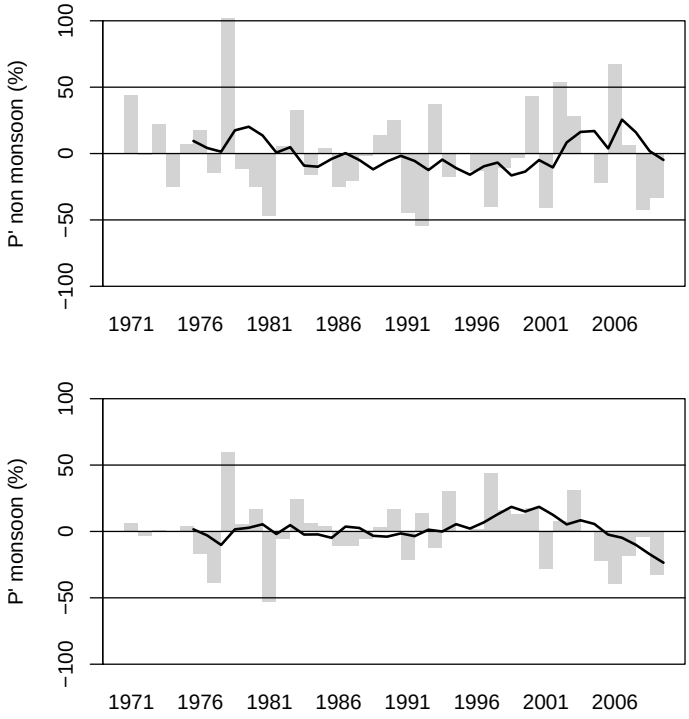

Figure C.5: Deviation (%) from long-term annual mean precipitation in Sankhu. The black line gives the five year moving average.

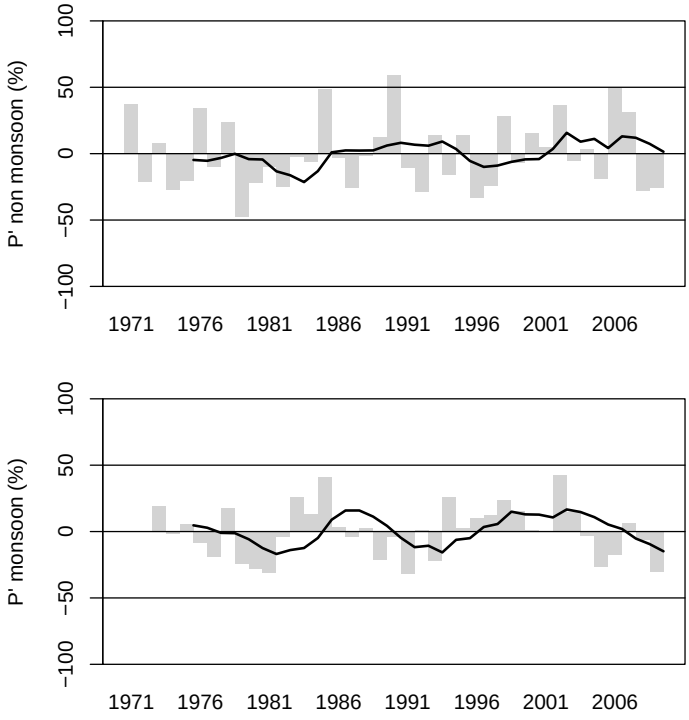

Figure C.6: Deviation (%) from long-term annual mean precipitation in Changunarayan. The black line gives the five year moving average.

C.2 Number of rainy days

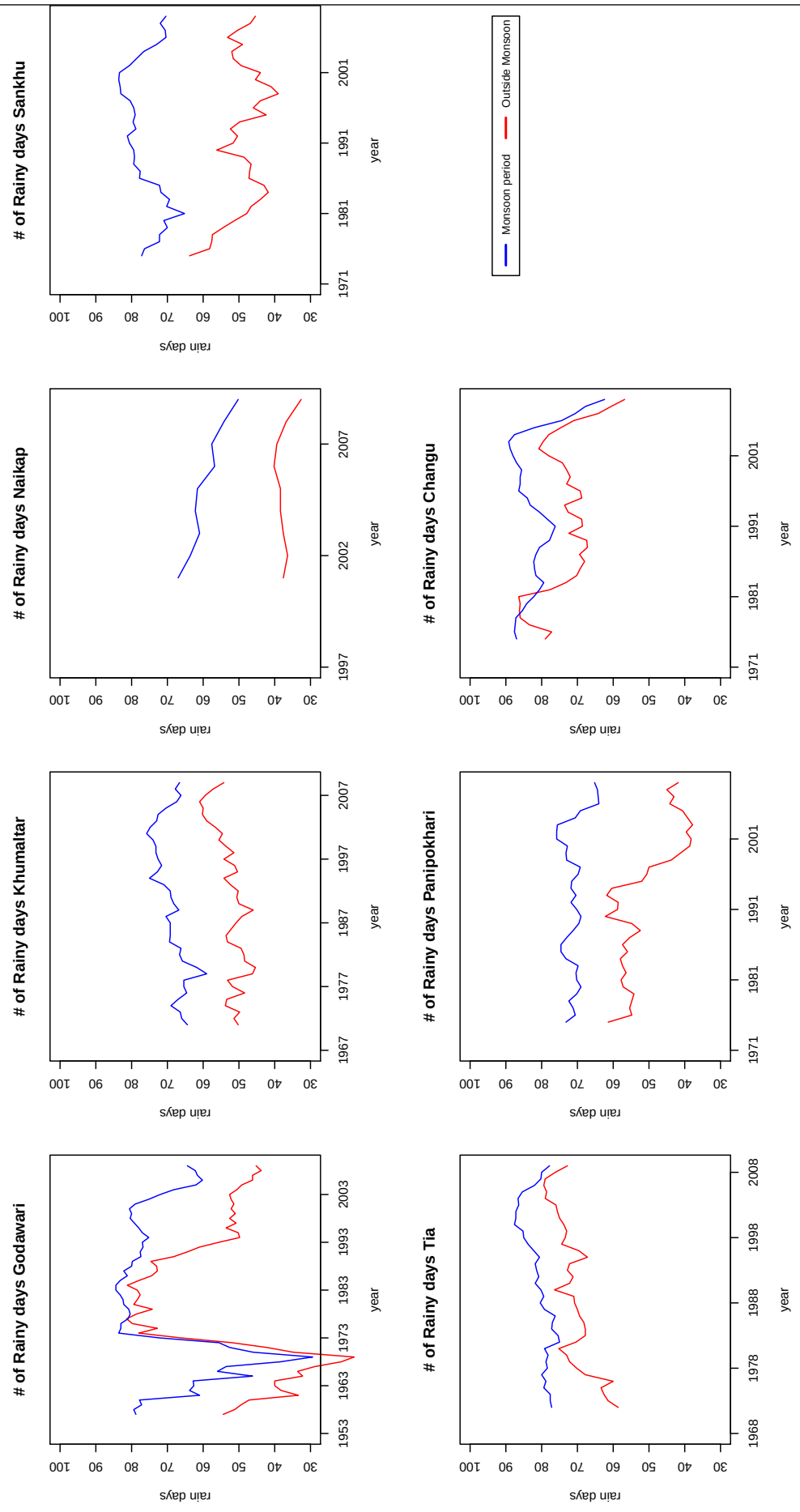

Figure C.7: Number of rainy days per year per station for monsoon and non-monsoon period.

C.3 Dry Spells

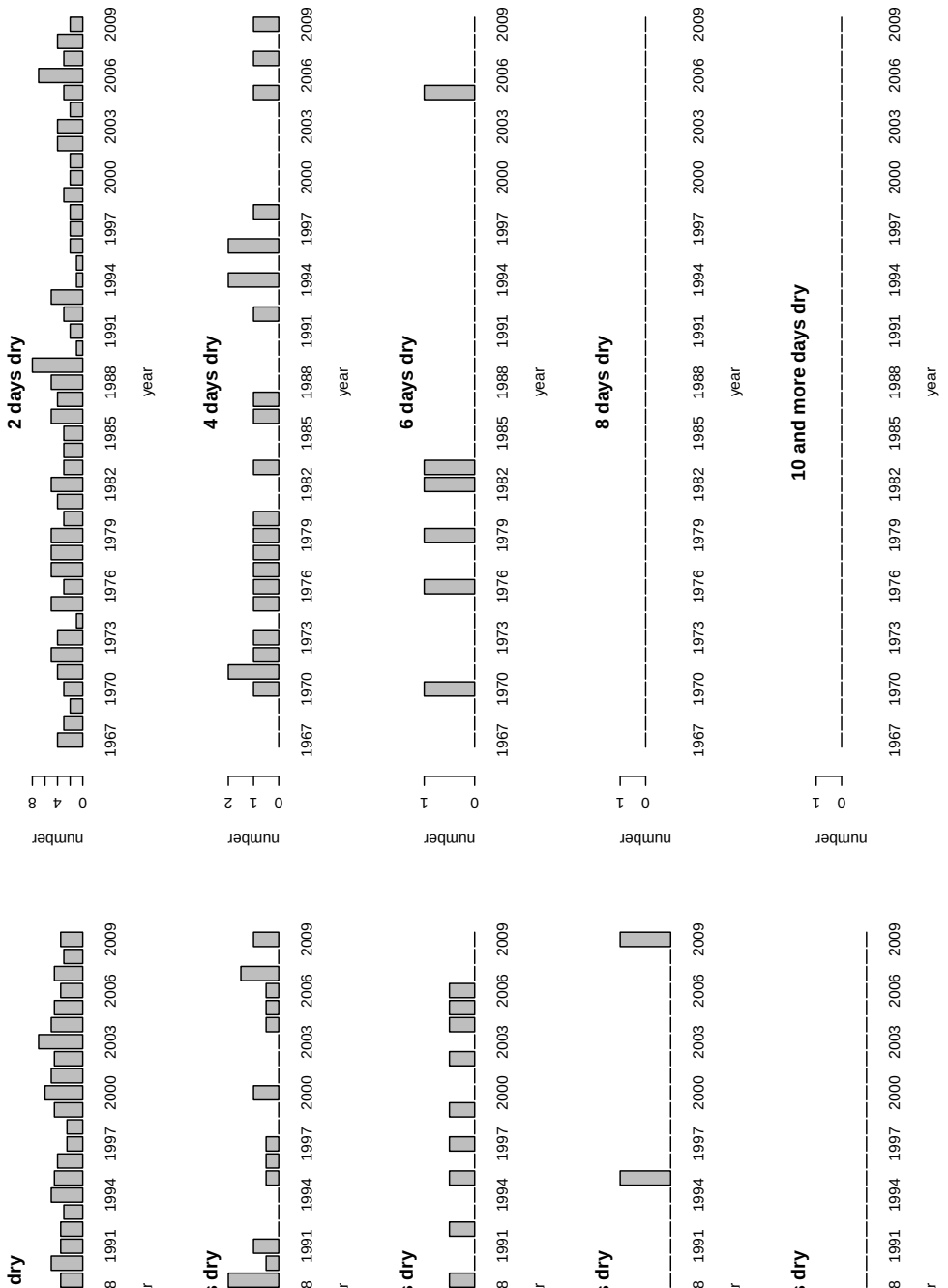

Figure C.8: Number and length of dry spells in Khumaltar.

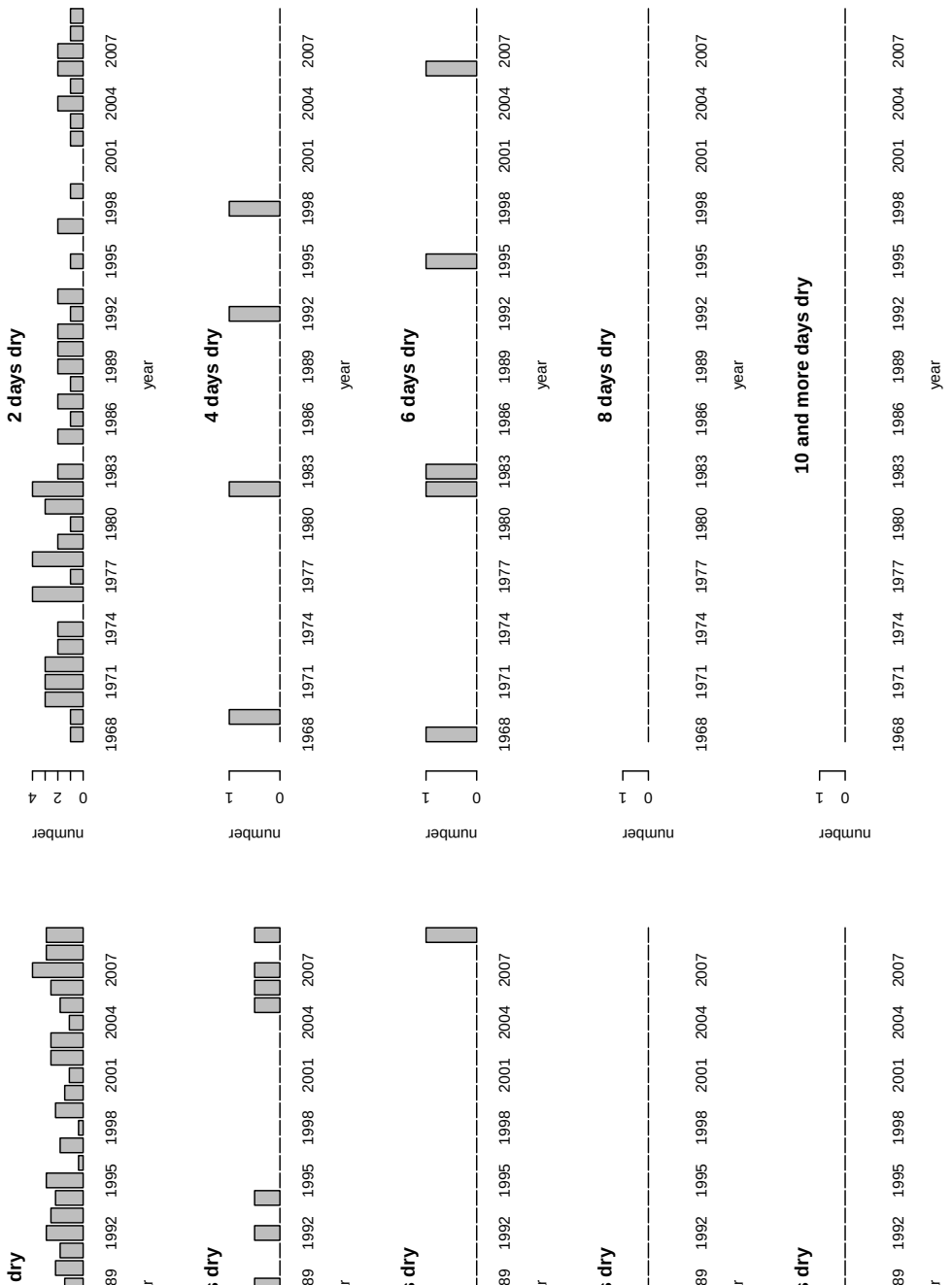

Figure C.9: Number and length of dry spells in TIA.

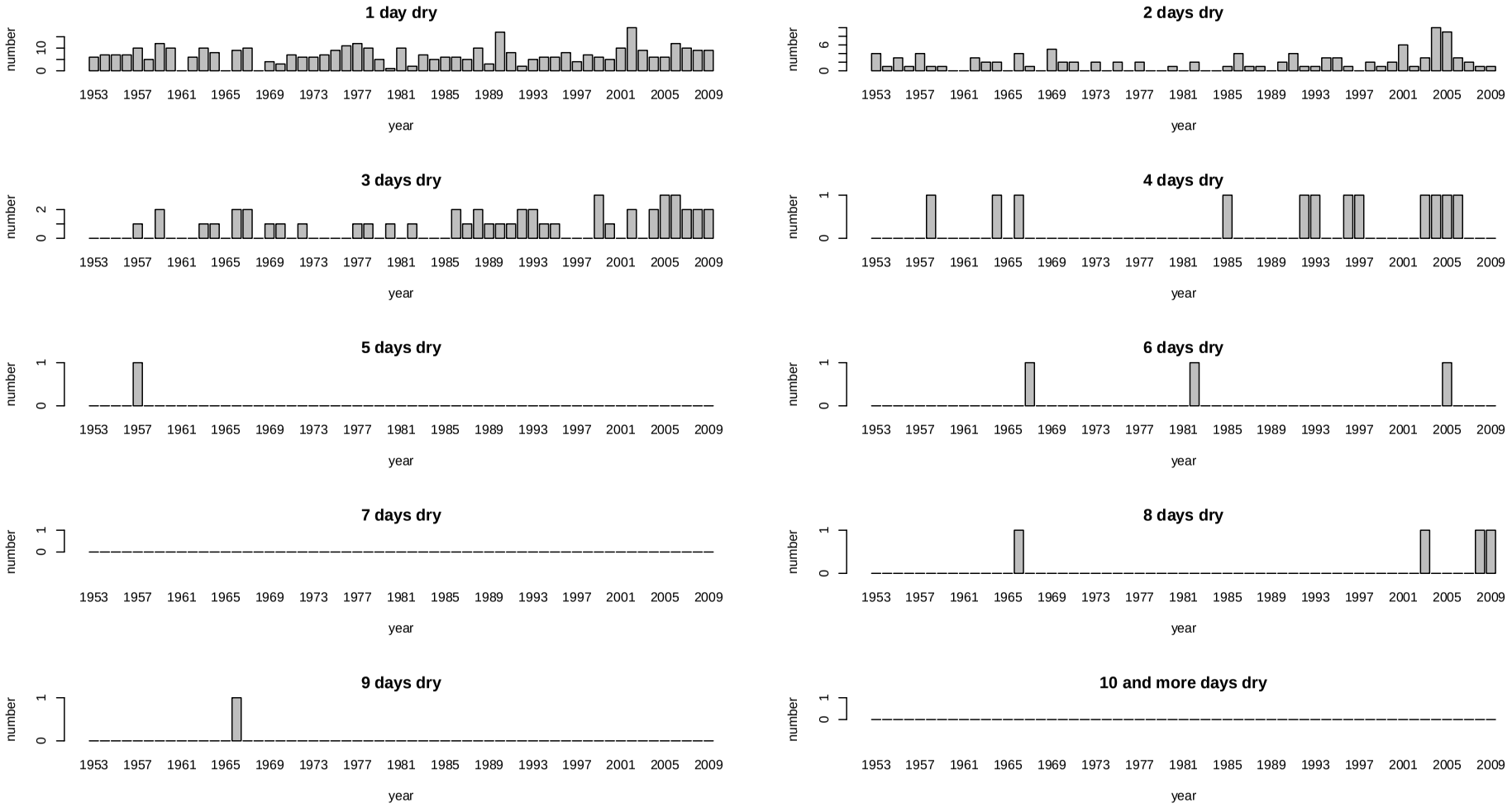

Figure C.10: Number and length of dry spells in Godawari.

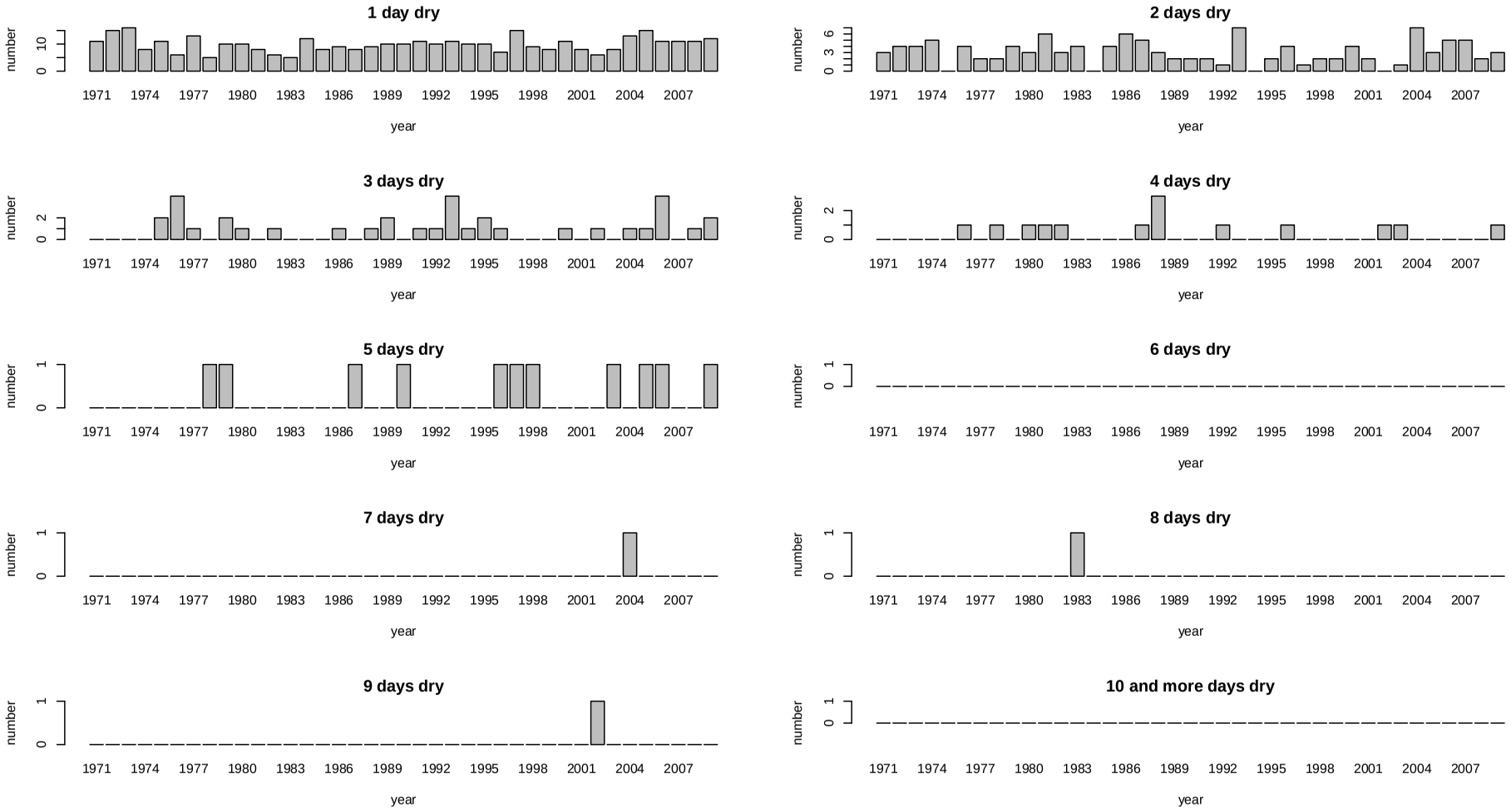

Figure C.11: Number and length of dry spells in Panipokhari.

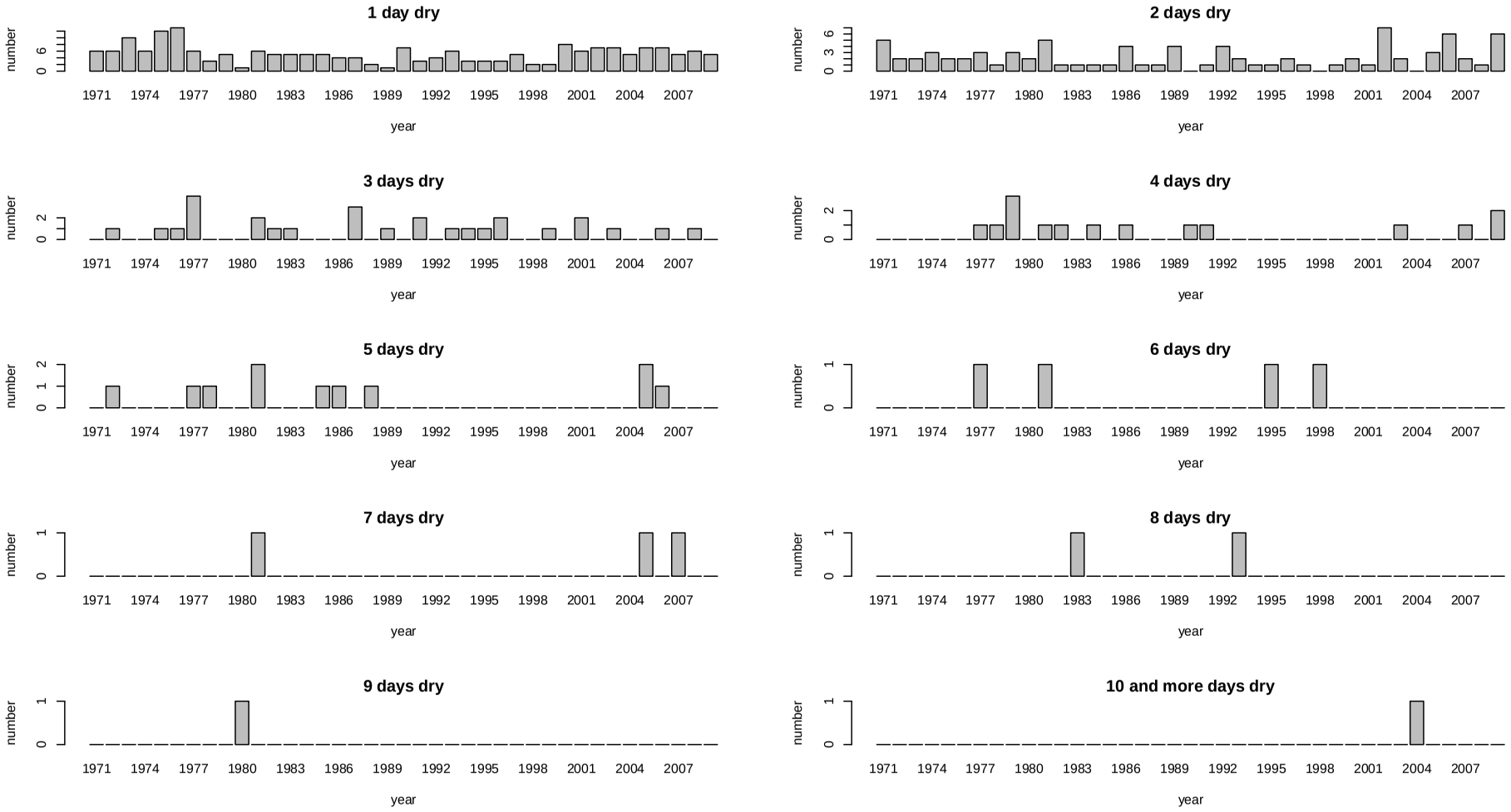

Figure C.12: Number and length of dry spells in Sankhu.

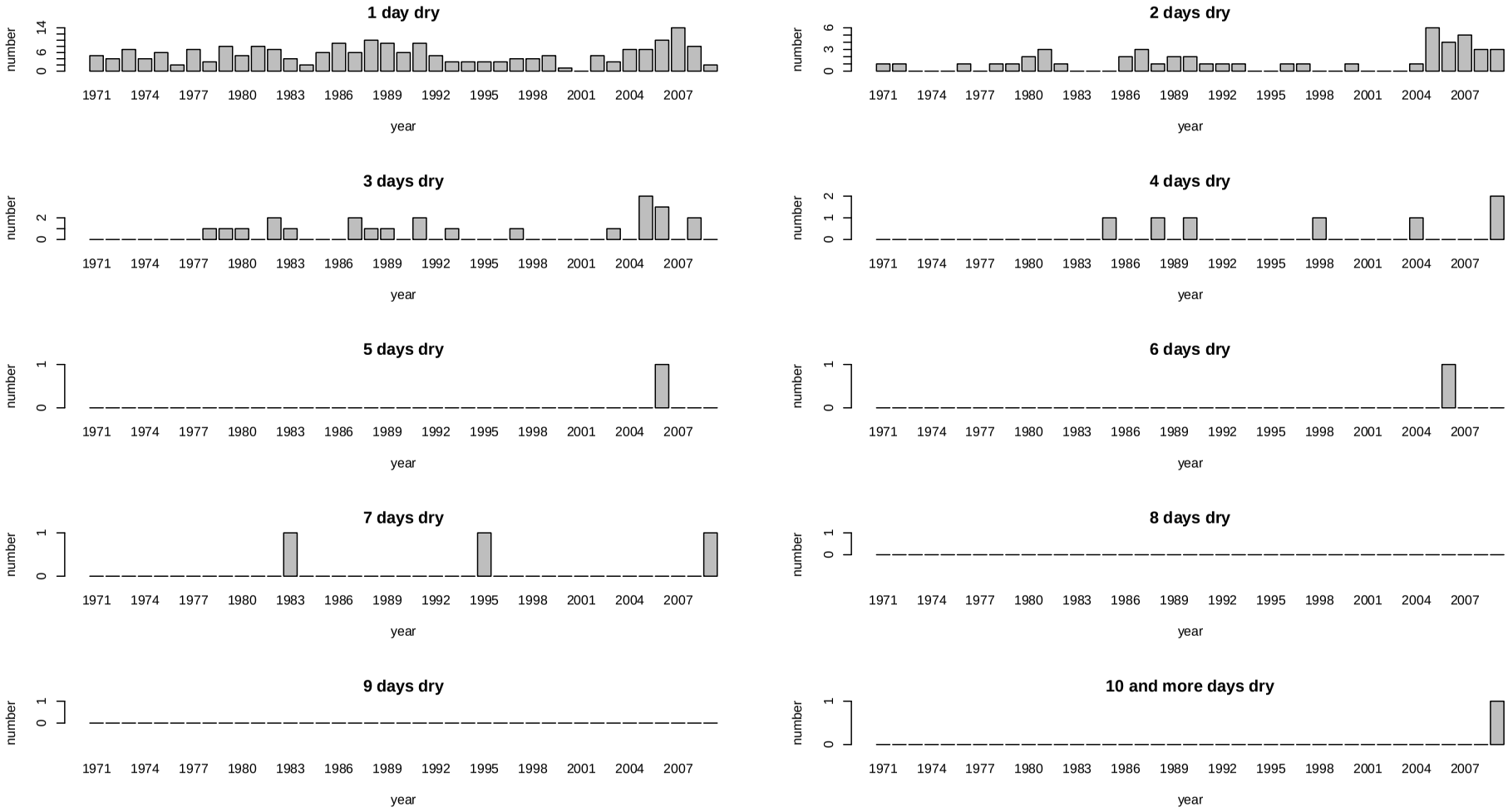

Figure C.13: Number and length of dry spells in Changunarayan.

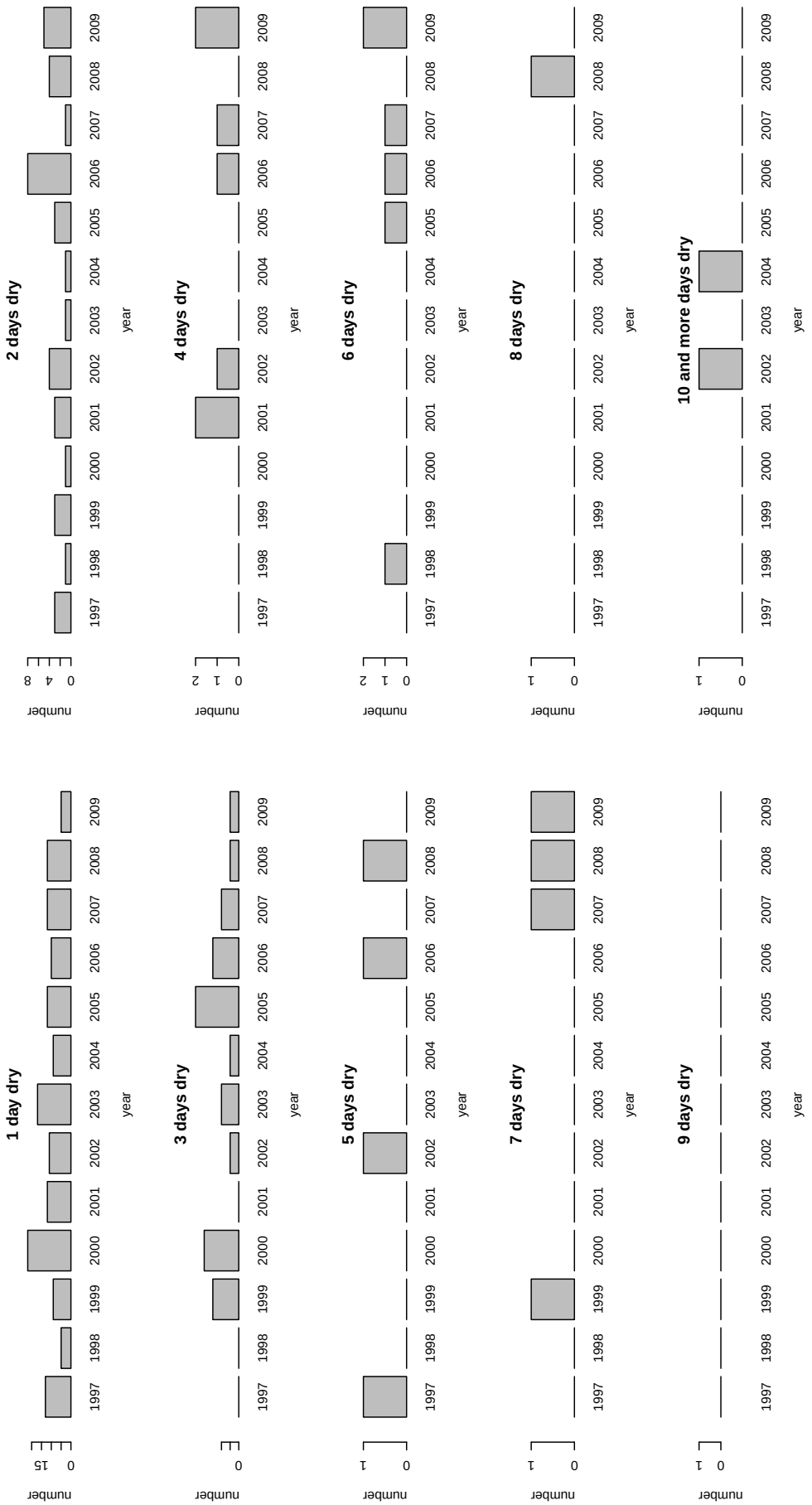

Figure C.14: Number and length of dry spells in Naikap.

C.4 R^2 linear trend analysis per month

Table C.1: R^2 trend line through monthly sum of precipitation

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

C.5 Mann-Kendall trend analysis per month

Table C.2: Kendalls' Tau and two sided P-value per month per station

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

D Temperature

D.1 Deviations in minimum and maximum temperature

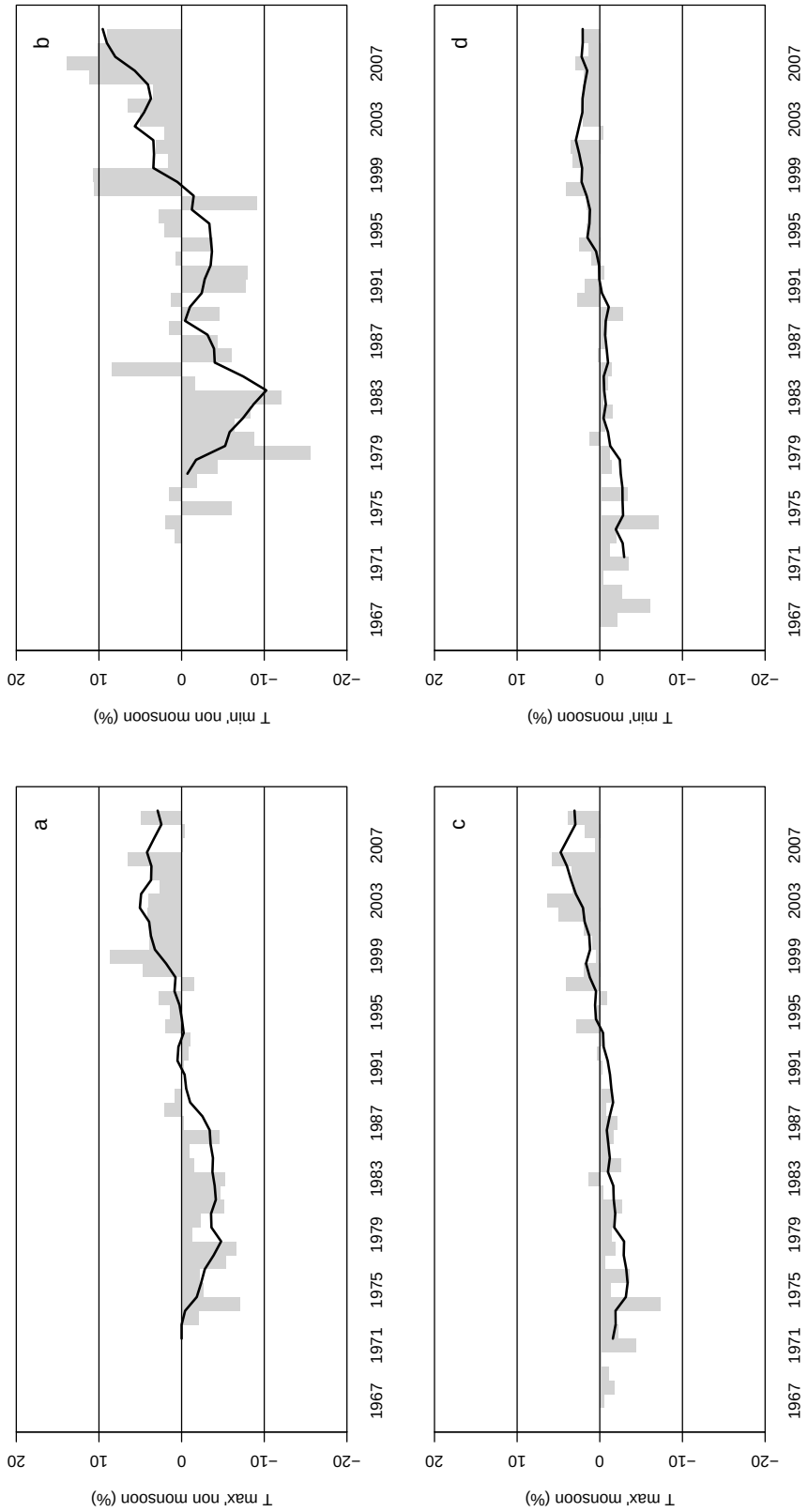

Figure D.1: Deviation (%) from long-term annual mean maximum (a and c) and mean minimum (b and d) temperature in the non-monsoon (a and b) and the monsoon (c and d) period in Khumaltar. The line gives the 5 year moving average.

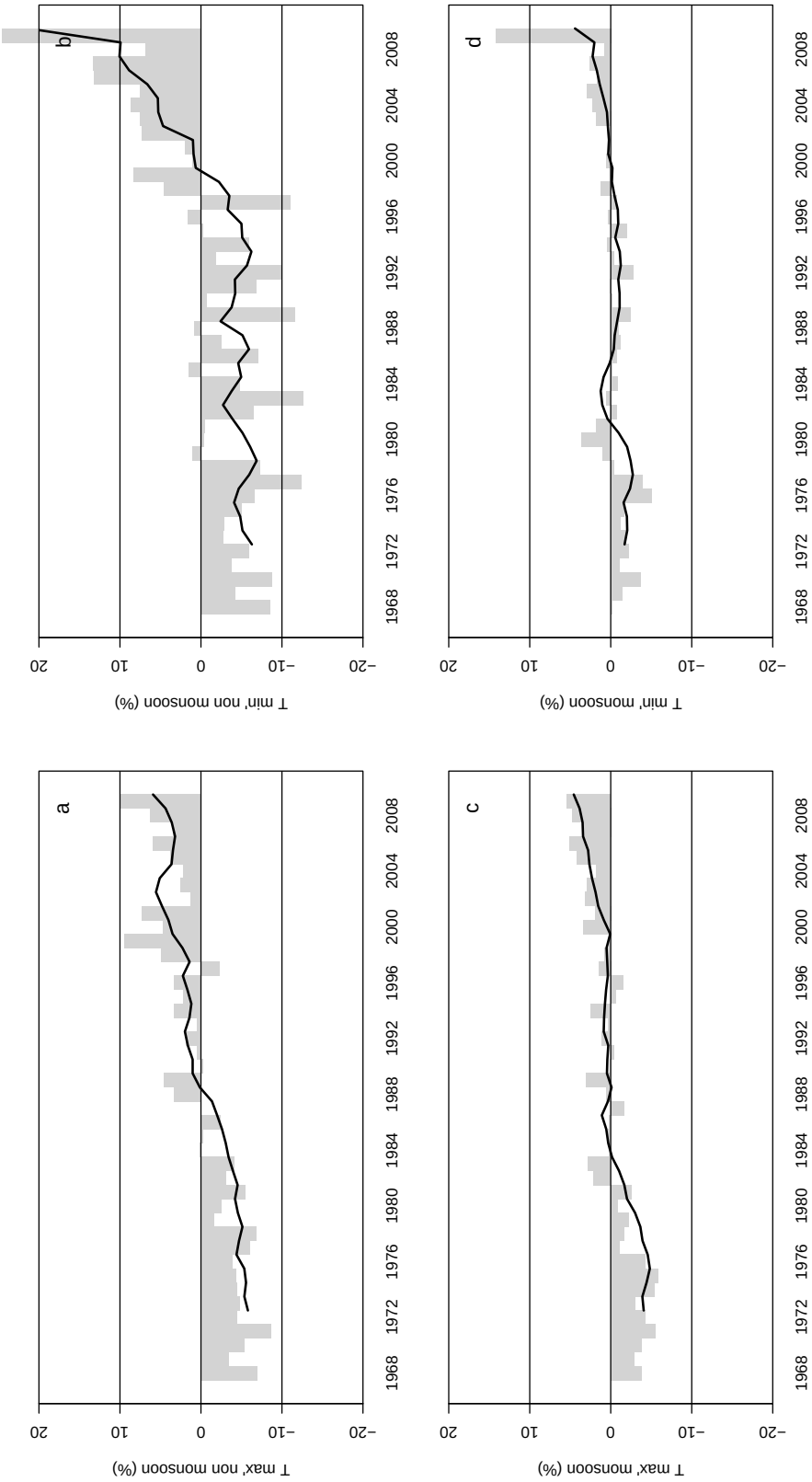

Figure D.2: Deviation (%) from long-term annual mean maximum (a and c) and mean minimum (b and d) temperature in the non-monsoon (a and b) and the monsoon (c and d) period in TIA. The line gives the 5 year moving average.

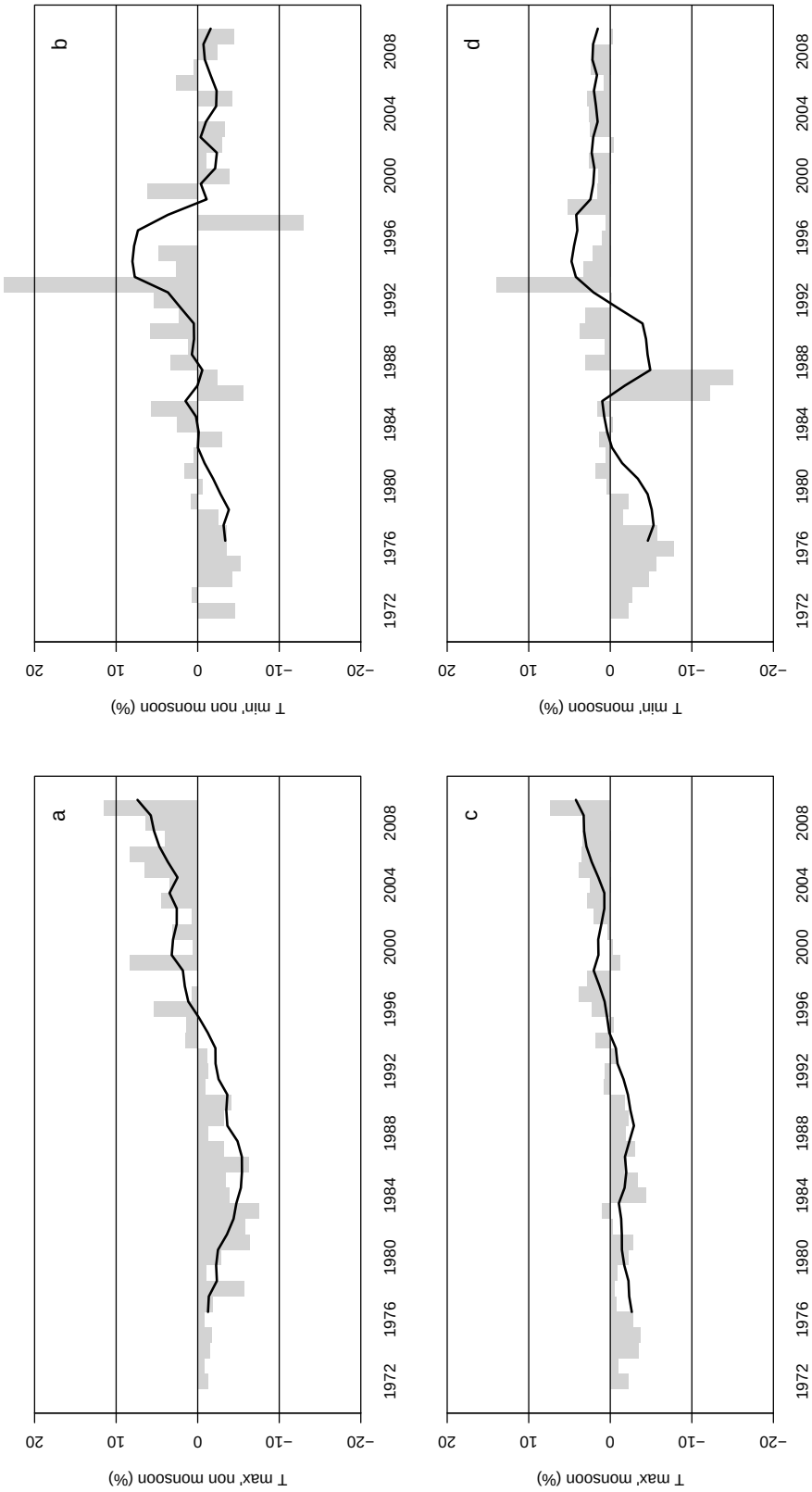

Figure D.3: Deviation (%) from long-term annual mean maximum (a and c) and mean minimum (b and d) temperature in the non-monsoon (a and b) and the monsoon (c and d) period in Godawari. The line gives the 5 year moving average.

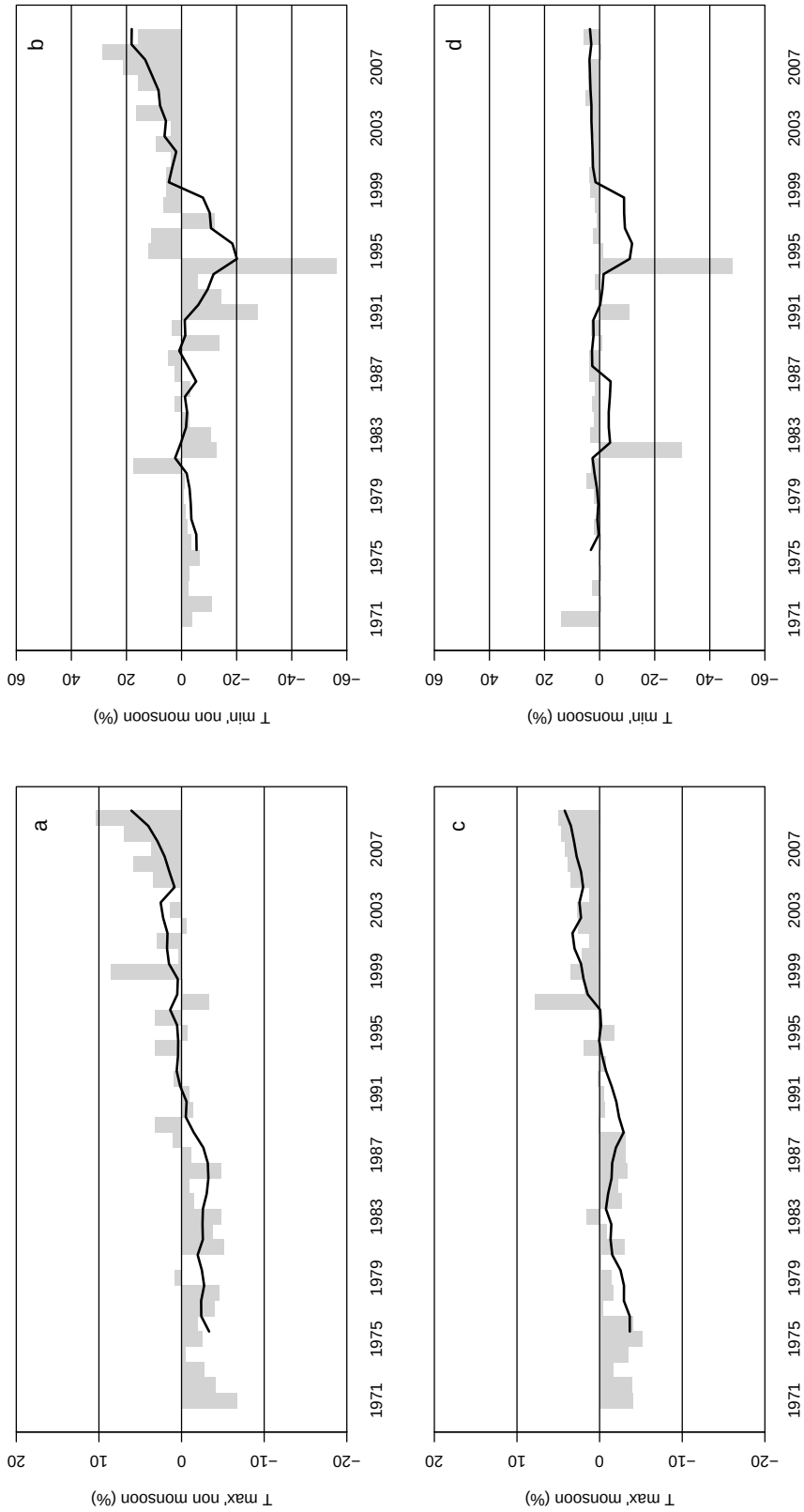

Figure D.4: Deviation (%) from long-term annual mean maximum (a and c) and mean minimum (b and d) temperature in the non-monsoon (a and b) and the monsoon (c and d) period in Panipokhari. The line gives the 5 year moving average.

D.2 R^2 linear trend analysis per month

Table D.1: 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

D.3 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 D.2: 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 D.3: 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 D.4: 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 D.5: 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

E Questionnaire

Center for Postgraduate Studies - Nepal Engineering College
Peri-Urban Water Security Project
Assessment of Climate Change Perception of the People

General information

Date:

Location:

Name:

Age:

Sex: Male / Female

Caste/Ethnicity:

Occupation:

Educational Attainment:

1. Illiterate
2. Below class 5
3. Class 6-10
4. Class 11 to Bachelor
5. Above Bachelor

E.1 Time-line

Try to develop a time-line of major events that people in the area can easily remember and recall. These events may include extreme climatic events in the past, major changes in the infrastructure and services (e.g. road, electricity, telephone etc.), disease epidemic, catastrophes or any other events that might have produced significant shock/changes in the study area for people to remember. It would be useful to begin with major events to develop a picture of a broader time-line and then exploring those in between. The idea with this exercise is to make the people base their responses specific to these time-lines in order to capture time series information on people's perception to climate change. After you complete the time-line, pick those events that are more prominent and easy for the people to remember.

When?	What happened?	What was the consequence? (positive or negative)	Were all the people affected the same way?

E.2 Perceptions on Change in Climate

Rainfall

Base the perceived changes to scale, as: large increase (2), small Increase (1), no change (0), small decrease (-1), large decrease (-2). Also ask the respondents to provide their indicators for assigning specific scale to the attributes specific to the time frame. It is always useful to begin with the past and move to the present time. In doing so, changes at the present context must be based in reference to those in the past.

Rainfall	Time-0	Time-1	Time-2	Time-3	Remarks
Total amount of rainfall					
Number of rainy days					
Amount of monsoon Rainfall					
Amount of Winter Rainfall					
Number of extreme rainfall events causing inundation on duration exceeding one day					
Persistence in rainfall during monsoon					
Period of prolonged dry spell (longer than 7 days) in between monsoon rainfall					
Timeliness/dependability of onset of monsoon					
Timeliness/dependability of cessation of monsoon rainfall					
Timeliness/dependability of winter rainfall					

What have been the consequences for the agricultural system, perceived by the people as a result of the changes in the rainfall? For those consequences marked (*) assess the perception to a scale, as: large increase (2), small increase (1), no change (0), small decrease (-1), large decrease (-2).

Perceived consequences	Time-0	Time-1	Time-2	Time-3	Remarks
Beginning and end of rice planting (specify the days/dates)					
Beginning and end of rice harvesting (specify the days/dates)					
Frequency of dry spells during monsoon*					
Need of supplemental irrigation for successful crop production*					
Water flow in the stream and spring sources available for supplemental irrigation*					
Residual soil moisture at the time of harvest of rice for use in the following crops*					
Any noticeable change in the cultivation practices of rice resulting from the changes in the timing, amount and distribution of rainfall					
Any noticeable change in the cultivation practices of winter crops resulting from the changes in winter rainfall					

Temperature

Base the perceived changes to scale, as: large increase (2), small Increase (1), no change (0), small decrease (-1), large decrease (-2). Also ask the respondents to specify their indicators for assigning specific scale to the attributes specific to the time frame.

Temperature	Time-0	Time-1	Time-2	Time-3	Remarks
Duration of summer season					
Duration of winter season					
Number of extreme hot days during summer					
Number of extreme cold days during winter					
Days of frost during winter					
Any other perceived change in temperature					
Difference between day and night temperatures					

Assess the perceived consequences to a scale, as: large increase (2), small increase (1), no change (0), small decrease (-1), large decrease (-2).

Perceived consequences	Time-0	Time-1	Time-2	Time-3	Remarks
Consequences to Human Comfort:					
Periods requiring use of fan during summer					
Periods requiring use of room heater during winter					
Number of days with fogs during winter					
Hours of fog per day during winter					
Occurrence of mosquito and use of mosquito nets/repellents					
Agricultural Consequences:					
Drying of soil becoming limiting factor for the production of winter crops					
Drying of soil becoming limiting factor for the production of spring crops					
Early maturity of winter crops (specify the crops)					
Early maturity of spring crops(specify the crops)					
Incidences of frost damage to the winter crops					
Any other perceived consequences to agriculture resulting from temperature change					

Wind

Assess the perceived consequences to a scale, as: large increase (2), small increase (1), no change (0), small decrease (-1), large decrease (-2)

Wind attributes	Time-0	Time-1	Time-2	Time-3	Remarks
Days with dry intense wind during summer					
Days with intense chill winds during winter					
Abnormal wind causing damage to crops and physical infrastructures					
Any other observation relating to wind pattern					

E.3 Perceived Consequences to Agricultural Production System and Productivity

Changes in the Cropping System

Specify the crops by area coverage - may be in percentage.

Crops by season	Time-0	Time-1	Time-2	Time-3	Remarks
Monsoon Crops					
Winter Crops					
Spring Crops					

Changes in Crop Cultivars

Specify the traditional and modern crop cultivars by area coverage - may be in percentage.

Crop Cultivars by Season	Time-0	Time-1	Time-2	Time-3	Remarks
Monsoon Crops; rice, maize,..					
Winter Crops; wheat, potato, mustard,..					
Spring Crops; maize, potato, vegetable,..					

Dominant Insects/Pests in the crops by season

Specify the insects/pests causing damages to the crops by their order of prevalence by time frame specified.

Insects/pests in crops by Season	Time-0	Time-1	Time-2	Time-3	Remarks
Monsoon Crops; rice, maize,..					
Winter Crops; wheat, potato, mustard,..					
Spring Crops; maize, potato, vegetable,..					

Perceived changes in the occurrence of insects/pests: Base the perceived consequences to a scale, as: large increase (2), small increase (1), no change (0), small decrease (-1), large decrease (-2)

Insects and pests	Time-0	Time-1	Time-2	Time-3	Remarks
Incidences of damaging insects/pests to the crops					
Need of insect/pest control and in the expenses incurred thereto					

Dominant weeds by season and crops

Specify the dominant weeds by specified time frame.

Weeds by Season	Time-0	Time-1	Time-2	Time-3	Remarks
Monsoon Crops; rice, maize,..					
Winter Crops; wheat, potato, mustard,..					
Spring Crops; maize, potato, vegetable,..					

Perceived changes in the occurrence of weeds: Base the perceived consequences to a scale, as: large increase (2), small increase (1), no change (0), small decrease (-1), large decrease (-2)

Weeds	Time-0	Time-1	Time-2	Time-3	Remarks
Incidences of occurrence of new weeds in the crops					
Damages to crop growth and production caused by weeds					
Need of weed control and the expenses incurred thereto					

Productivity of Crops

Try recording the productivity (production per unit area) of the monsoon, winter and spring crops as perceived by the farmers in the area in a unit convenient to them.

Crops per season	Time-0	Time-1	Time-2	Time-3	Remarks
Monsoon Crops; rice, maize,..					
Winter Crops; wheat, potato, mustard,..					
Spring Crops; maize, potato, vegetable,..					

In the crop productivity information above, have the changes in climate been responsible in any ways in the increase or decrease in the crop productivity? If yes, in which crops and in what way?

E.4 Perceived Changes in the Natural Resources and Incidences of Disastrous Events

Base the perceived changes to scale, as: large increase (2), small Increase (1), no change (0), small decrease (-1), large decrease (-2). Also ask the respondents to provide their indicators for assigning a specific scale to the attributes specific to the time frame. While a particular scale is assigned also try obtaining as to in what way the people perceive climate change being responsible for the change together with other factors.

Natural Resources Degradation/Events of Disasters	Time-0	Time-1	Time-2	Time-3	Remarks
Quantity of water in the rivers/streams					
Duration of dependable water flow in the rivers and streams					
Depth to groundwater table					
Drying of dug wells and spring sources					
Incidences of forest fire					
Incidences of fire hazards in the neighborhood					
Incidences of crop inundation for longer duration					
Incidences of damaging flood events					
Incidences of landslide and mass wasting					
Accelerated erosion of soil from crop fields					
Availability of forage and fodder for livestock form forest and agricultural lands					
Availability of wild vegetables and medicinal herbs from forest					
Any other events of natural resources degradation or disastrous events observed by the people in the area					

E.5 Perceived Consequences to Livelihood

Base the perceived changes to scale, as: large increase (2), small increase (1), no change (0), small decrease (-1), large decrease (-2). Also ask the respondents to provide their indicators for assigning a specific scale to the attributes specific to the time frame. While a particular scale is assigned, also try obtaining as to in what ways the people perceive climate change being responsible for the change together with other factors.

Perceived Livelihood Consequences	Time-0	Time-1	Time-2	Time-3	Remarks
Scarcity of drinking water					
Time spent and/or increased drudgery in managing daily supply of water					
Dependence on poor quality water to meet the domestic needs					
Occurrence of diseases (specify the diseases occurring at different periods of time)					
Expenses on medicines/health care					
Need of increased inputs (fertilizer, plant protection, irrigation) to maintain agricultural productivity					
Return from farming per unit of land					
Number of months of sufficiency of own farm produce					
Any other perceived livelihood consequences by the people in the area					