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Climatic trends and variability in South Asia: A case of four peri-urban locations

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Abbreviations

BIWTA	Bangladesh Inland Water Transport Authority
BMD	Bangladesh Meteorological Department
BWDB	Bangladesh Water Development Board
GCM	Global Climate Model
GWT	Ground Water Table
IDRC	International Development Research Centre
IMD	Indian Meteorological Department
IWFM	Institute of Water and Flood Management
NCR	National Capital Region
NCSA	National Capacity Self-Assessment
PRA	Participatory Rural Appraisal
SPSS	Statistical Package for Social Sciences
TIA	Tribhuwan International Airport
VDC	Village Development Bank

Preface and Acknowledgements

This report provides climatic trends and variability as assessed in four peri-urban locationsin South Asia. These locations represent the diversity in climatic and physiographic settings as well as the similarity in peri-urban contexts and processes across South Asia. Long-term secondary data on selected climatic variables, mainly temperature and rainfall, are analyzed using standard statistical techniques to understand their trends and variability. Analysis results indicate a rising trend in temperature at annual, monthly and seasonal scales, while seasonal and other short-term variability are also evident. Although the annual number of rainy days has an increasing trend in all locations, annual rainfall has either a decreasing or almost static trend in two locations namely, Gurgaon and Kathmandu, and an increasing trend in Khulna and Hyderabad. Variability in temperature and rainfallin Hyderabad and Gurgaon appears to have changed in the recent years as indicated by the calculated standard deviation of pre- and post-1980 data.These changes are likely to have impactson water availability and balance in the hydrologic cycle, and affect irrigation, crop growth and yield, drinking water, rainfall flooding, and human health and wellbeing. The perception of peri-urban residents is in general agreement with the climatic changes assessed from secondary data analysis, and the inferred impacts and implications.

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June, 2013

1 INTRODUCTION


মুক্তিযোদ্ধা পল্লী

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1. INTRODUCTION

Global climate change caused by enhanced greenhouse effect has been a major worldwide concern for about two decades. Significance of the anthropogenic factors driving these global changes is now evident in the regional impacts. Increased emission of greenhouse gases has resulted in an increase in global mean surface temperature, which is projected to increase by 1.1 to 6.4 oC during the 21st century. At the same time the global mean sea level is projected to rise by 18 to 59 cm under a set of emission scenarios (IPCC 2007). The projections also indicate that there will be more frequent warm spells, heat waves and intense rainfall. These projections are based on Global Climate Model (GCM) simulations for a wide range of emission scenarios. There are, however, high uncertainties involved in the GCM projections, particularly at smaller resolutions of regional and sub-regional scales.

Climatic changes are projected to have severe impacts on water resources. Changes in the global mean temperature and CO2 concentration are likely to change the global precipitation and evapotranspiration patterns. These will affect other processes in the hydrologic cycle such as infiltration, surface and sub-surface runoff, and groundwater recharge. Thus soil moisture and water availability may be significantly altered. Sea level may rise due to thermal expansion of sea water and melting of ice and snow and, consequently, will increase tidal and storm surge inundation, and salinity intrusion into coastal aquifers and water bodies. Changes in the monsoon patterns and increases in the frequency and severity of floods, droughts, storm surges and intense rainfall are likely to have significant impacts on the water resources.

Water resources play a key role in the lives, livelihoods and agro-ecosystems in South Asia, one of the most densely populated regions of the world (Mirza and Ahmad 2005). There is a wide variation in water availability and consumption across this region shaped by large river basins such as the Ganges, Brahmaputra, Meghna and Indus. Most of the water is generated in the monsoon when surplus water flows to the sea while water scarcity is acute in the dry season. There is also a wide variation in rainfall and seasonal temperature across the region. Thus climatic changes are likely to have different degrees and patterns of impacts in different parts of this region. Vulnerability of the people is largely shaped by these impacts along with their adaptive capacities. Therefore an important aspect of the assessment of vulnerability and water insecurity, and adaptation planning for climate change lies in an assessment of the observed trends and variability in the climatic variables. This will help understand the impacts on the biophysical systems and their consequent socio-economic implications.

In this paper, we present climatic trend and variability at four selected peri-urban locations in South Asia.

Figure 1.1: Peri-urban locations in South Asia selected for the study

These locations are in Khulna (Bangladesh), Kathmandu (Nepal), Gurgaon (India) and Hyderabad (India) (Figure 1.1). These four locations represent the wide variation in physiographic features and climate across South Asia while they also represent similarities in seasonal patterns and vulnerabilities to urbanization and climate change. Khulna is a coastal location vulnerable to sea level rise and salinity intrusion, and has a tropical monsoon climate. The annual average temperature in Khulna is 26.3 ^{0}C while the monthly average varies between 12.4 ^{0}C in January and 34.3 ^{0}C in May. Annual average rainfall in Khulna is about 1809 mm, 87% of which occurs between May and October. Kathmandu Valley has a mix of warm temperate, cool temperate, mild humid subtropical, and subtropical highland climatic zones at different elevations ranging from 1200 to 2700 m. In general, the summer temperature varies from 19 - 27 ^{0}C while the average winter temperature varies from 2 - 20 ^{0}C. Approximately 80% of the total annual rainfall of 1400 mm occurs during the monsoon season (June to September). The climate of Gurgaon is characterized by low humidity, hot summer and cold winter. Mean daily maximum temperature in the hottest months of May and June is about 41 ^{0}C. Mean daily maximum and minimum temperatures in the coldest month of January are 21 ^{0}C and 7 ^{0}C, respectively. Average annual rainfall is 773 mm, 82% of which occurs during the monsoon months of July to September. Hyderabad is characterized by predominantly a tropical wet and dry climate, with mixed features of a hot semi-arid climate. Average monthly temperatures in the hottest month of May and the coldest month of January vary from 26 to 38.8 ^{0}C and 14.7 to 28.6 ^{0}C, respectively. Most of the annual rainfall of 828 mm occurs in the southwest monsoon months.

Long-term climatic data are collected from the weather stations located nearest to these peri-urban locations. Trends and variability in two major climatic variables, temperature and rainfall, are mainly analyzed. Other variables such as evapotranspiration, sunshine and humidity are also analyzed with limited datasets. Standard statistical techniques are followed in these analyses. Based on the results of these analyses, we infer probable biophysical impacts of the long-term trends and short-term variability in the climatic variables that may have significant socio-economic implications. We also triangulate these climatic changes and the inferred impacts with the perception of peri-urban residents.

About the Report

This report is divided into six chapters focusing on climate trends and variability issues in four peri-urban research locations in three south Asian countries. Four chapters following the introduction dwell on the climate related issues and concerns in Khulna (Bangladesh) , Kathmandu (Nepal), Gurgaon and Hyderabad (India). Chapter six summarises the main issues and challenges of climate variability and its impact on the peri-urban population.

2

KHULNA

2. KHULNA

2.1 Climatic and Physiographic Settings

Khulna is the third largest city in Bangladesh, having a population of about 1.5 million. It is located in the south-west coastal region, which is hardly 1 m above the mean sea level and is under tidal excursions. The city has been identified as one of the 15 most climate change vulnerable cities of the world. It has a tropical monsoon climate. The peri-urban areas of Khulna are susceptible to cyclone, storm surge induced flooding, water logging and salinity intrusion. Sea level is projected to rise between the present (1980-1999) and the end of this century (2090-2099) by 23 to 47 cm in the A1B scenario of IPCC (2007). The spatial coverage and temporal duration of salinity could increase due to this sea level rise. The 5 ppt isohaline could move about 9 km farther inland during the dry season due to a sea level rise of 32 cm. The inundated area could also increase by about 11% due to the rise of sea level by 88 cm. Thus, any change in climate induced by global warming and dimming could further aggravate the threats to the life and livelihood of the people and worsen the poverty situation. The cyclone 'Sidr' in 2007 and 'Aila' in 2009 caused widespread damage to property and havoc with people's livelihoods. The rural population started migrating to the peri-urban and urban areas of Khulna as the opportunities for livelihood in rural areas have decreased due to climatic and hydrologic hazards.

This section presents the long-term trends in temperature, rainfall, sunshine, humidity and evapo-transpiration in Khulna based on secondary data and information. A questionnaire survey was also conducted among the peri-urban residents to understand their perceptions of climatic trends and variability. Probable implications of such changes on peri-urban communities were also evaluated from people's perceptions and secondary information.

2.2 Methodology and Data

In this study, the linear, monotonic trend in a variable was investigated mostly at annual, seasonal and monthly time scales. IPCC (2007) used this technique for investigating the long- and short-term trends in observed climatic and hydrologic variables. The method is based on fitting a straight line to a set of data so that the sum of squared errors becomes the least. This is the most common and widely used technique in trend analysis and is most robust in case of normally distributed data and in the absence of too many outliers. The statistical significance levels of the trends were studied by employing the t-test with the SPSS software.

The data were carefully examined before being used in trend analysis. Daily data on temperature, rainfall, sunshine and humidity were collected from the Bangladesh Meteorological Department (BMD) for its weather station in Khulna. Coordinates of this station located in the fringe of the city are 22° 46.8' north latitude and 89° 31.8' east longitude. Surroundings of the station are characterized by agricultural lands, water bodies and some settlements. The peri-urban study sites are located within 5 km of this station. The temperature, rainfall, sunshine duration and humidity data were available for 1948-2010, 1948-2010, 1984-

2010 and 1948-2010, respectively.

A baseline household survey, covering a wide range of issues including demography, socio-economic condition, water related vulnerabilities, urbanization impacts and climate change implications, was conducted in March 2012 in three peri-urban sites of Khulna. Qualitative information collected by employing PRA tools served as the initial step in identifying the relevant issues needing further consideration and devising the preliminary questionnaire. This questionnaire was then pre-tested in the study sites and the final questionnaire was adopted after incorporating the necessary modifications. Of the total 125 households surveyed, 36, 40 and 49 households were from Chhoto Boyra, Alutola and Labonchara, respectively. In order to explore the difference in responses between male and female respondents, a gender segregated household survey was administered through surveying a male and a female from the same household constituting 250 respondents from 125 households.

In addition, a number of participatory research techniques and tools were used to explore local people's perceptions of climate change and its probable implications for their livelihood assets and well being. A series of consultation meetings were held with the local service providers, NGOs and civil society groups to understand the existing water related problems in the peri-urban areas and to contextualize those with the climate change issues. These were followed by a series of focus group discussions with the peri-urban communities. A number of interviews were held with different key informants including sluice gate operator, boatman and ship-crew. The age or working experience of the informant in the Khulna area was a key factor in the selection. A few case studies were also conducted with the climate migrants in the urban and peri-urban Khulna areas.

2.3 Trends in Temperature

The daily maximum and minimum temperatures at Khulna were available for 63 years (1948-2010). From the daily values, monthly and seasonal time series were created. Graphical plots of these time series indicate that the temperature at Khulna has started rising faster since 1980. So, in addition to the long-term trends, the trends for the period of 1980-2010 were estimated. The results (Table 2.1) indicate that the average

Table 2.1: Trend (^{0}C/year) in seasonal temperatures at Khulna.

Season	Trend in maximum temperature for the period		Trend in minimum temperature for the period	
	1948-2010	1980-2010	1948-2010	1980-2010
Winter	-0.018***	0.022	-0.018***	0.047***
Pre-monsoon	0	0.034**	-0.001	0.045***
Monsoon	0.019***	0.037***	0.003	0.013*
Post-monsoon	0.021***	0.027**	0.006	0.042***

Note: ***, ** and * indicate that the trends are significant at 99%, 95% and 90% level of confidence, respectively.

maximum temperatures in the pre-monsoon (March-May) and monsoon (June-September) seasons, and the average minimum temperatures in the pre-monsoon, post-monsoon (October-November) and winter (December-February) seasons are increasing at faster rates in recent times than anticipated either from long-term observed trends or climate model projections.

The mean monthly maximum temperature has an increasing trend in all months except for December-March, which is the winter season in Bangladesh (Table 2.2). The monthly trends also have become stronger in recent years for all the months except for October. The trend in January is negative even in recent years. The trends in mean monthly minimum temperatures also have become stronger in recent years (Table 2.2). The trends are found to be positive for all the months in recent years. Furthermore, their statistical significance has also increased. The mean minimum temperature in different months of the dry season (November-May) is found to be increasing at a relatively high rate.

Table 2.2: Trend (^{0}C/year) in monthly temperatures at Khulna.

Month	Trend in maximum temperature for the period		Trend in minimum temperature for the period	
	1948-2010	1980-2010	1948-2010	1980-2010
Jan	-0.028***	-0.013	-0.032***	0.025
Feb	-0.016	0.046*	-0.013	0.067***
Mar	-0.013	0.014	-0.003	0.048*
Apr	0.001	0.028	0.008	0.051**
May	0.010	0.059***	-0.008	0.037**
Jun	0.020***	0.039**	0.001	0.013
Jul	0.022***	0.033***	0.007**	0.018*
Aug	0.023***	0.043***	0.005	0.012
Sep	0.013**	0.035***	-0.001	0.010
Oct	0.023***	0.021	0.002	0.020
Nov	0.018***	0.034**	0.008	0.064***
Dec	-0.006	0.024	-0.009	0.066***

Note: ***, ** and * indicate that the trends are significant at 99%, 95% and 90% level of confidence, respectively.

The annual minimum temperature time series indicated that there is no overall trend in the long-term series. However, there is a strong increasing trend (0.05 oC per year) in the recent data series. The annual maximum temperature has no significant trend in both long-term and recent time series. The number of extremely cold nights was found to be decreasing. However, the number of extremely hot days was found not to be changing significantly. The longest durations of consecutive hot days and cold nights exhibited trends more or less similar to the above trends.

The long-term temperature data indicated an increasing trend (significant at 99% level of confidence) in the diurnal temperature range during the months of May to October. However, such trends have become non-significant and decreasing in recent years. The mean monthly diurnal temperature range has non-significant decreasing trend in long-term data and significant (99% level) decreasing trend in recent data during the months of December-April.

The analysis of heat index, which is a measure of perceived temperature in human body, indicates that the probabilities of occurrences of heat stress in a day with apparent temperature greater than or equal to 27 ^{0}C are 66, 95, 97, 97, 98, 98, 97 and 87 percent in the months of March-October, respectively. The heat index was found to be increasing in all these months. The increasing trends also have become higher in recent years. The trends for August-September are significant at 99% level of confidence and that for May, July and October at 95% level of confidence. The trend in June is significant at 80% level of confidence.

2.4 Trends in Sunshine and Humidity

The bright sunshine duration data were available for 27 years (1984-2010). The average durations of sunshine in the winter, pre-monsoon, monsoon and post-monsoon seasons were found to be about 7.7, 8.0, 4.9 and 7.4 hours a day, respectively. There is a decreasing trend in seasonal sunshine durations, except for the monsoon season. The decreasing trend in the winter season is about 0.6 hours a day per decade, which is equivalent to a decrease of 7.8% in average sunshine duration in a decade. The post-monsoon season has a decreasing trend of 0.4 hours a day per decade, which is equivalent to a decrease of 4.9% in average sunshine duration in a decade. The winter and post-monsoon trends are statistically significant at 99% and 95% level of confidence, respectively. The pre-monsoon season has a non-significant decreasing trend of 0.2 hours a day per decade (1.6% a decade). The monsoon season, in contrast, has a non-significant increasing trend of 0.2 hours a day per decade (4.0% a decade). In a monthly scale, the sunshine duration has a decreasing trend for all months, except for June, July and August. The trends in December and January of the winter season are statistically significant at 99% and 95% level of confidence, respectively. The trend in October of the post-monsoon season is significant at 95% level of confidence. The trends in other months are not significant at 90% level of confidence.

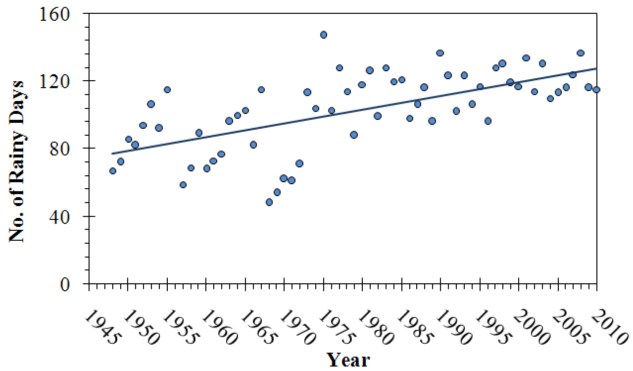
The data on relative humidity were available for 63 years (1948-2010). The relative humidity at Khulna has increasing trends of 2.3%, 1.3% and 0.3% per decade in the winter, post-monsoon and pre-monsoon seasons, respectively. In contrast, the monsoon season has a decreasing trend of 0.4% per decade. The trends in the winter and post-monsoon seasons are significant at a level of confidence of 99%. The decreasing trend at the monsoon season is significant at a lower level of confidence (90%). The trend of the pre-monsoon season is not significant. At a monthly scale, the highest rate of increase is found in the month of January in the middle of winter and then the rate gradually falls till the month of June, the beginning of the monsoon and thereafter the rate increases gradually till January. The months of May-August show decreasing trends in humidity. The increasing humidity trends of the winter, post-monsoon and pre-monsoon seasons are consistent with the decreasing sunshine trends in these seasons. Furthermore, the decreasing humidity trend of the monsoon season is consistent with the increasing sunshine duration trend in this season.

2.5 Trend in Rainfall

The analysis of rainfall data for 63 years (1948-2010) indicates that the rainfalls have increasing trends of 8 mm, 31 mm, 9 mm and 6 mm per decade during the winter, monsoon, post-monsoon and pre-monsoon seasons, respectively. The trend in the winter season is significant at 95% level of confidence and that in the monsoon season is significant at 80% level of confidence. However, the trends in the pre- and post-monsoon seasons are not significant at 80% level of confidence. Among the monsoon months, June has a non-significant negative trend of 6 mm a decade, July has a non-significant positive trend of 5 mm a decade, August has a positive trend of 14 mm a decade being significant at 80% level of confidence, and September has a positive trend of 7 mm a decade being significant at 90% level of confidence. Thus, the monsoon is found to be strengthening towards the end of the season. The annual total rainfall is found to be increasing at 53 mm a decade which is significant at 95% level of confidence.

The number of rainy days is found to be increasing at 0.8 days per annum, which is significant at 99% level of confidence (Figure 2.1). The numbers of rainy days during the wet (June-October) and dry (November-May) seasons show increasing trends of 0.6 days and 0.2 days a year, respectively. Both these trends are significant at 99% level of confidence. The maximum number of consecutive rainy days in a year is found to be increasing at 99% level of confidence. The maximum number of consecutive non-rainy days in a year is found to be decreasing at 99% level of confidence.

Figure 2.1: Trend in number of rainy days per year in Khulna.



The maximum rainfalls in one day, in consecutive 3 days, and in consecutive 7 days, though increasing, are not statistically significant. Also, the numbers of days with rainfall of more than 50 mm and 100 mm, though show increasing trends, are not statistically significant.

It thus appears that there are some evidences of increase in rainfall in the southwest coastal Bangladesh. The increasing trend in rainfall results primarily from the increasing number of rainy days. The trend in rainfall intensity, though increasing, is not statistically significant. Nevertheless, climate model results indicate an increase in the frequency of extreme rainfall events of shorter duration (6 hours) at Khulna in future. The rainfall trend is found to be consistent in general with the sunshine and humidity trends at Khulna.

2.6 Trends in Evaporation and Evapotranspiration

The trend in evaporation could not be investigated in this study as the BMD evaporation data at Khulna was not available for this study and the quality of the BWDB evaporation data is suspected due to the presence of frequent missing and absurd values in the data set. However, secondary information on changes in average 10-day evaporation at 11 locations in Bangladesh is available in Climate Change Cell based on BWDB data. Though such information for Khulna is not available, the information for Jessore is available. The evaporation at Jessore has decreased in all the 10-day periods in a year during the post-1980 period compared to the pre-1980 period. Also, information on long-term trend in reference crop evapotranspiration (ETo) at four locations in Bangladesh is available at IWFM. There is an average decreasing trend of 0.02 mm/day per year in the dry season ET_o at Jessore. The decreasing sunshine and increasing humidity are attributed to be the reasons for the decreasing trend in ET_o, although temperature is increasing.

2.7 People's Perception of Climatic Trend and Variability

The baseline survey revealed that there is variation in the perception of climate change among the peri-urban households. Temperature related manifestations (i.e. warmer and frequent hot days, warm spell, etc.) are perceived more by the female respondents than the male. Other manifestations, such as drought, cyclone, flood and salinity intrusion, are perceived more by the male respondents. Such differences in perception may be due to the fact that male respondents are more exposed to external environment than the female. Such perceptions are also linked to the perceived urbanization rate. The people perceiving higher urbanization rate in their localities tend to perceive climate change manifestations higher.

Stakeholder discussions, interviews and participatory mapping revealed that the peri-urban residents do not experience long winters now. They now wear warm clothes only for a few days during the winter and experience hot and humid weather throughout the rest of the year. They perceive that the weather is becoming warmer day by day. In the past, the weather was not as hot as today. The gentle breeze hardly blows now in summer. The local people also perceive that the heavy rainfall events are increasing and the frequency and intensity of natural disasters are increasing.

The perception of changes in river water level varied among different livelihood groups. The fisherman group and the wood traders found the level to be increasing, while the operator of the Alutala regulator, a local shopkeeper and a ferry driver found the same to be increasing. The former people mentioned that the river depth and water level were reducing after the construction of the Rupsha Bridge and due to the reduction of floodplain areas, which caused huge siltation in the river bed. The water pressure from the sea was increasing, and the natural disasters, like flood, drought and cyclonic storm surge, were increasing in Khulna region. The tidal influence was less in the Rupsha-Bhairab river system before the Farakka Barrage due to heavy water pressure from the upstream. But after the construction of the barrage, due to reduced water pressure, saline water started to come upward from the Bay of Bengal which increased the salinity in Khulna and its peripheral areas. The latter people mentioned that the water level is now higher than it was before. During the Cyclone Aila, water level was very high in the river and it was unprecedented. A ferry driver of age 75 years said that the water level is now higher during both the high and low tides. The floodplains are now mostly closed which result in increased water level in the river. According to the Port and Traffic Officer of Bangladesh Inland Water Transport Authority (BIWTA), the water level of the Rupsha is increasing. The present BIWTA yard becomes flooded during high tide in most years, especially during the monsoon. In July, the water level becomes very high and often inundates the main road at the BIWTA landing station.

The analysis of different climatic variables, such as temperature, sunshine, humidity and rainfall, indicate that the temperature of Khulna is rising very fast since 1980. The rate of rise is much higher than that reported elsewhere based on long-term observed data or climate model projection. The number of extremely cold nights and the number of consecutive such nights also show decreasing trend. The diurnal temperature range shows decreasing trend for the months of December to April. The baseline survey revealed similar information as most of the people mentioned that the frequency of hot days has increased and the frequency of cold nights has decreased. The sunny days have now become much hotter than those of 20-30 years back as revealed from the individual interviews with the local farmers. The people also mentioned that the frequency of heat waves has increased.

The analysis of secondary data on rainfall indicated that the rainfall in the southwest coastal Bangladesh has in general an increasing trend. However, the trend is not statistically significant in many cases. The number of rainy days and the maximum number of consecutive rainy days are increasing at statistically significant rates. In conformity, the maximum number of consecutive non-rainy days is decreasing at a statistically significant rate. The trends in different extreme rainfalls are increasing; however, they are not statistically significant. The baseline survey also indicated that the heavy rainfall events in and around Khulna have increased. However, the people's perception on the increase of the drought events could not be supported by the secondary data analysis.

The bright sunshine duration has a general trend of decrease except for the monsoon season and the relative humidity has in general an increasing trend except for the monsoon season. The heat index, which is the joint effect on human body of humidity and temperature, was found to be increasing in the months of March-October. The people's experience about hot days, cold nights and heat waves, as revealed from the baseline survey, also corroborates these findings.

2.8 Probable Impacts and Implications

A large portion of the peri-urban population is engaged in occupations of crop farming, local labor, private service and small business. These people are economically poor, have small asset base, low education level and little access to political/social leadership. They are likely to be more vulnerable to climate change induced hazards and disasters. The heat stress during the pre-monsoon summer season is likely to bring discomfort to the lives of these people, particularly to the aged and physical laborers. The local farmers mentioned that earlier they did not face as much stress as now while working in their fields during hot humid days. Also, now they cannot work as long as before due to increased humidity and higher temperature. Thus, the rising temperature, coupled with a rising humidity, is causing serious discomfort to the people of Khulna.

The domestic water demand for drinking, bathing, etc., is most likely to increase due to the rising temperature and humidity, particularly during the pre-monsoon season. This may add to the stress of the women, who usually take on the burden of household water collection.

The trend in the net irrigation requirement for the boro rice was found to be decreasing at 0.01 mm/day per year. Thus, due to climate change, the overall irrigation demand may not increase. This is contrary to the general belief that, due to global warming induced climate change, irrigation demand would increase.

Due to the rising temperature, the growth and yield of winter crops, such as wheat, may decrease. Since the night-time temperature has an increasing trend, the yield of rice, which is the major staple crop, may also decrease. However, the positive effect of increasing CO2 is likely to offset the negative effect of increasing temperature. The increasing trend of rainfall is likely to be beneficial for reducing on-farm soil salinity and irrigation water demand. The increasing trend in rainfall towards the end of the monsoon season is likely to be beneficial for the aman rice which is the dominant and rainfed crop in the coastal region. However, such rainfall may delay land and soil drainage and hamper the cultivation of rabi (winter) crops. Furthermore, the standing rice plant near maturity may not withstand with the rainfall accompanied by wind during this time and may wilt on the land surface resulting in huge yield losses as happened in 2012 due to the rainfall in early November. The decreasing trend in sunshine duration is likely to affect the crop growth and yield. The decreasing sunshine duration is usually associated with an increasing foggy environment. Such weather is conducive to the prevalence of some insects and root rotting disease in rabi crops. Increased incidences of fungi attacks may also occur in the event of fogs. Foggy environment may also cause the late blight diseases to potato and turn the boro rice leaves into yellow. The occurrence of fogs may result in twisting of chili leaves. A damped weather may affect the yields of mango, oil-seed and onion seed in particular.

Since the magnitude of rainfall has an increasing trend and the rainfall intensity is more or less stationary, it is expected that the groundwater recharge would increase in future. However, the local rainfall will increase recharge primarily to the upper aquifer, which is saline. Moreover, with time, the peri-urban areas will experience more urbanization and hence less recharge due to an increase in paved areas. The combined effect would very likely be a significant lower recharge in future than the present. As a result, water stress in peri-urban areas could increase.

The Mayur River is thought to be one of the potential sources of water supply for both urban and peri-urban Khulna areas. With an increase in paved areas, decrease in depression and increase in rainfall, the surface runoff and hence the fresh water flow to the Mayur is likely to increase. However, the river is currently the recipient of urban and peri-urban effluents and solid wastes of Khulna. If it continues to do so without adequate treatment of effluent, the situation will worsen and the peri-urban communities, particularly the poor, aged, women and children, will suffer a lot due to water pollution, odor, loss of aquatic resources, etc.

The increasing temperature and humidity would create a more favorable condition for the formation of cyclone in the Bay of Bengal. Very recently, there have been two devastating cyclones - the Sidr in May 2007 and the Aila in November 2009. These cyclones, accompanied by storm surges, caused widespread damage to properties and loss of human and animal lives. The increase in soil salinity due to the long standing of saline water on farm lands from the inundation caused by the surges has affected the crop cultivation. In some of the affected areas, such as Koyra Upazila of Khulna district, crops cannot be grown even today. The lives and livelihoods of the general people living there have been adversely affected by the Aila. Many people from those areas have migrated to the urban and peri-urban areas of Khulna in search of their livelihoods. Since Alutola is under tidal influence, and the Mayur, which is the main drainage channel of the area, has been silted up, the malfunctioning of the Alutola regulator and/or any breach in or overtopping of the polder in the event of such a storm surge may create water logging, increase soil salinity, reduce farm productivity and affect the peri-urban community.

The increasing water level, accompanied by a higher rainfall, may exacerbate the flooding problem in Chhoto Boyra and the water logging problem in Labonchara. More agricultural lands in Alutola may come under tidal influence, the soil salinity of those lands may increase, the cropping pattern may change and some of those lands may become under shrimp aquaculture. Thus, some of the current cropped lands may become shrimp ghers in future and the share-croppers, small farmers and agricultural laborers may be adversely affected by such changes in land use.

The anticipated change in future climate is likely to have an impact on human health. There is already a prevalence of water-borne diseases, such as diarrhea, cholera, typhoid, dysentery and jaundice, and skin and eye diseases among the peri-urban communities in Khulna. The summer season is the peak time for the outbreak of such diseases. Incidences of such diseases may increase in future due to an increase in flood and water logging from increased rainfall and river water level. Water logging, particularly in Labonchara and Chhoto Boyra, which are already facing such problems, may increase. The prevalence of mosquitoes may increase in such water logged areas. Moreover, outbreaks of cholera, typhoid and diarrheal diseases may occur after flooding as floodwaters in peri-urban areas become contaminated with human and animal wastes. Informal interviews with some local people indicated that the rainfall pattern in the area has changed and the people are now suffering frequently from fever, diarrheal diseases, headache, allergy and nausea. The combined increases in temperature and rainfall in summer may cause the spread of many infectious diseases. Increasing extreme temperature and heat wave in summer months may increase diarrheal diseases, particularly in children. Increasing coastal water temperature may exacerbate the abundance and/or toxicity of cholera. Vector-borne diseases, such as dengue, malaria and kala-azar, may increase in the summer-rainy season. Cardio-vascular diseases, such as heart attack and stroke, dehydration, heat stroke, and respiratory illness may increase under a warmer and more humid climate. However, among the positive effects of anticipated climate change could be a fewer deaths associated with cold weather.

The baseline survey also revealed that about half of the peri-urban people were not aware of the possible impacts of climate change. However, almost all the respondents who were aware of the impacts mentioned that the crop yield had decreased and the pest attacks, physical stress in work and incidence of human diseases had increased. Most of the people mentioned that the extent of saline water areas was increasing. These perceptions of the local people are more or less congruent with the results of the secondary data analysis, and indicate that, those who responded to the questions were generally aware of the possible changes in climate and their impacts rightly. However, the people's perception on lowering of groundwater table (GWT) due to low rainfall, and water logging due to intense rainfall within a short period could not be supported by secondary data analysis. The lowering of GWT could be due to increased water demand and decreased recharge as a result of urbanization, rather than due to climate change directly. Besides this, there was a heavy rainfall event in June 2011 which was not covered by the secondary rainfall data and the fresh memory of the people about this event during the survey could have led to the water logging perception from intense rainfall.

Nearly 50% of the households mentioned that there was no initiative taken in their localities to address climate change vulnerabilities. The remaining respondents did not even know about any such possible initiative. These findings indicate that the climate change initiatives, including awareness raising, capacity building, risk reduction and adaption measures, of government, non-government and inter-governmental agencies have not reached the grass-root communities living in peri-urban Khulna, though they are among the most vulnerable to climate change.

3

KATHMANDU

3.1 Climatic and Physiographic Settings

Climate change is one of the major phenomena that have received special attention in the last decades. During the past few decades the world has been experiencing significant increase in global temperature resulting into climate change. Chaulagain (2006) states the climate change in Nepal is going even faster than the global average. According to the Thematic Assessment Report on Climate Change (2008) prepared under the National Capacity Self Assessment (NCSA) project, ongoing records of national temperatures since 1962 and recent analyses of these records show high inter-annual variability, and that maximum temperatures in Nepal are progressively increasing in line with global and regional records. Between 1977 and 1994, the mean annual temperature is estimated to have increased by 0.06 ^{0}C, and is projected to increase by another 1.2 ^{0}C by 2030, 1.7 ^{0}C by 2050, and 3.0 ^{0}C by 2100 (as cited in ADB, 2009). A study made by Practical Action Nepal (2009) on the temporal and spatial variability of temperature and rainfall, based on the observed meteorological data for the period 1976- 2005, shows increasing trend in temperature over Nepal. The maximum temperature was found to be increasing at a greater rate (0.05^{0}C/year) than the minimum temperature (0.03^{0}C/year). The trend analysis of maximum temperature in Nepal carried out by Shrestha et al. (1999) found that the average annual warming between 1971 and 1994 was 0.06 ^{0}C/year. The warming in the maximum temperature is found to be more pronounced in the high altitude regions.

Most of the climatic data analysis in Nepal has been concentrated at the national level and generalized to represent the entire country. With extensive variations in topography and microclimate there is a need for site specific climatic data analysis to understand the climatic variation at local contexts.

Climate change vulnerability mapping for Nepal prepared as a supplementary effort to National Adaptation Programme of Action- Nepal has ranked Kathmandu, Bhaktapur and Lalitpur districts in very high to high in the most of risk specific and combined vulnerability maps (MoEST, 2010). However, there has been very limited study to understand the climatic variation focusing particularly on Kathmandu valley. Considering the context, this study has analyzed the hydro-meteorological data from seven different hydro-meteorological stations of Kathmandu valley for the observed trend of change, persistence and anomalies.

Besides, meteorological information from the scientific analysis is rarely available at the community levels in developing countries and farmers rely on their own observations and subjective interpretations (LI-BIRD undated; Gbetibouo 2009). These interpretations are based on a longstanding experience and familiarity with seasonal patterns of rainfall and a set of local climate indicators that constitute the climatic perceptions (Dahal 2005; Thomas et al. 2007; Mertz et al. 2009; Green and Raygorodetsky 2010; Piya 2012). It is important to be aware of these perceptions since people frequently act on their perceptions, change their behavior, and develop strategies to cope with the changes in the short run and to adapt to the long term changes based on their dynamic and evolving knowledge, whether or not they are consistent with meteorological data (Vedwan and Rhoades 2000; Gearheard et al. 2010; Speranza et al. 2010).

It is expected that a better understanding of the changing climate in the Kathmandu Valley can be achieved through the findings of hydro-meteorological data analysis, local peoples' perception on the changing climate and implication for their livelihoods and natural resources.

3.2 Materials and Methods

3.2.1 Study Area

Kathmandu Valley lies at latitudes 27° 32'13" and 27° 49'10" north, and longitudes 85° 11'31" and 85° 31'38" east at an average altitude of 1,300 m above the mean sea level. The valley is bowl shaped and surrounded by the Mahabharat range of mountains on all sides. Administratively, the valley encloses three districts- Kathmandu, Lalitpur, and Bhaktapur that together cover an area of 899 km2, whereas the area of the valley as a whole is 665 km2. The three districts of the valley consist of five municipalities and 114 Village Development Committees (VDCs). As per the rural and urban classification criteria set by Local Self Governance Act 1999, there are three municipalities (Bhaktapur, Madhyapur-Thimi, and Kirtipur), one sub-metropolitan city (Lalitpur) and one metropolitan city (Kathmandu) in Kathmandu valley. Among these, the study was focused around the four peri-urban VDCs of Kathmandu valley namely Lubhu, Matatirtha, Jhaukhel and Dadhikot.

Kathmandu Valley has a predominantly sub-tropical cool temperate climate with four distinct seasons viz., winter from December to February, spring from March to May, summer from June to August and autumn from September to November. In general, the temperature ranges from 19 ^{0}C to 27^{0}C in summer and 2^{0}C to 20^{0}C in winter with 75% annual average humidity. The annual average rainfall is 1,400 mm, most of which falls during June to August (Pant and Dongol, 2009).

3.2.2 Methodology and Data

Hydro-meteorological data were collected on a daily, weekly and monthly basis for analysis from seven different weather stations in the Kathmandu Valley (Table 3.1). The stations Tribhuwan International Airport (TIA) and Panipokhari are situated within the urban core of Kathmandu City. Khumaltar lies in the newly built urban area of Lalitpur. The stations Godawari, Changunarayan and Sankhu

Table 3.1: Details on weather stations and collected data.

Index No.	Station	Period of Meteorological Records	
		Rainfall	Temp.
1029	Khumaltar	1967 - 2009	1967 – 2009
1030	TIA	1968 - 2009	1968 – 2009
1022	Godawari	1953 - 2009	1972 – 2009
1039	Panipokhari	1971 - 2009	1971 – 2009
1059	Changunarayan	1971 - 2009	
1035	Sankhu	1971 - 2009	
1076	Naikap	1997- 2009	

are situated the furthest from the urban center. Collected data were analyzed by using an open source software R to understand the trends in temperature and rainfall.

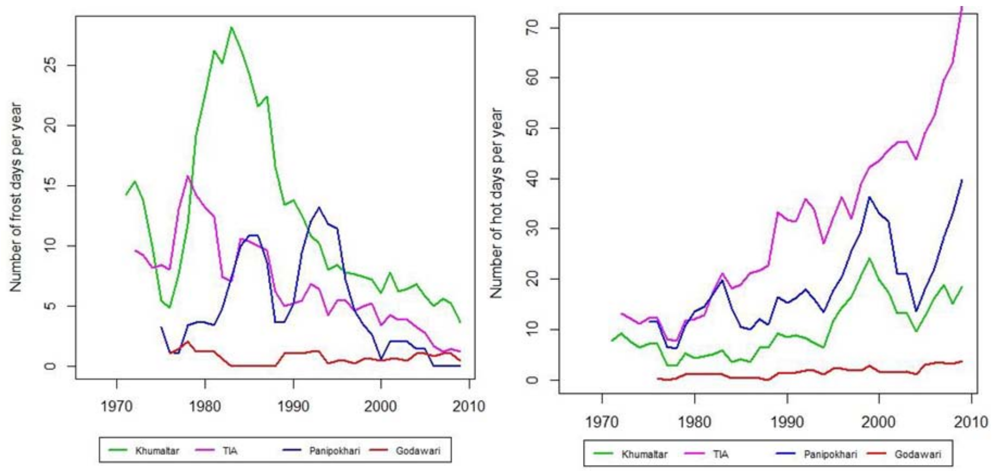
This study also used participatory tools to collect qualitative and quantitative information about climate change and its implications. A series of focus group discussions were organized with local people to capture the perception of climate change and its implications. A time frame was developed based on the major events so that the local people could easily recall the retrospective experiences on climate. During focus group discussion, participants were requested to recollect their memory on decadal change in the climate through a time frame of over past 40 years (prior to 1980s, 1980s, 1990s and 2000s). Besides this, a household survey was also conducted among 582 households to understand the individual perception of the changes in different attributes of climate and their social implications.

3.3 Trends and Variability in Important Climatic Variables

3.3.1 Temperature

Temperature is one of the most important variables of climate. The three different indices were used to see the trend and variability in temperature. While the number of days with temperature below 0°C decreased in all the stations, the number of hot days with temperature more than 30°C had increased in all the stations. The five-year moving averages for both the indices are shown in Figure 3.1. It is evident that the strong downward pattern of temperature < 0°C in Khumaltar and TIA and strong signal of increasing days with > 0°C in TIA with an annual increase of 1.52 hot days. The weakest signal was in Godawari for both the cases. This is striking; TIA and Khumaltar are two stations situated in urban areas, whereas Godawari is the station furthest away from the urban core. This gave the idea that there might be an urban heat island effect. This effect is more pronounced in minimum temperature (Mitchell, 1961), and might therefore very well be visible in the number of < 0°C-days.

Figure 3.1: Five-year moving average for the number of days with temperature < 0°C and > 30°C per year.



The most extreme temperature measurements per station per year were considered based on daily data. It was found that both the maximum and minimum Tmax of the year had increased. The same counts for the maximum Tmin of the year and the minimum Tmin of the year, which might imply that the warmest day of the year had become warmer, and the coldest day of the year too. Increase in temperature was the lowest in summer season and the strongest in fall and winter season for both Tmin and Tmax. Based on Sen's Slope applied to the complete data series, Tmin showed an average increase of 0.04^{0}C per year and Tmax showed on average an increase of 0.05 ^{0}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.

3.3.2 Precipitation

For every station for every year, the number of days with rainfall was counted for monsoon and non-monsoon period. Although this is not very convincing (also with low R^2 values), the pattern generally indicates a negative direction (decrease in number of rainy days), which has a stronger signal than the positive directions (Table 3.2). For monsoon period, only three out of seven stations have a decrease in number of rainy days. Again it is recognizable that the negative numbers are in general stronger than the positive numbers. 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.

Table 3.2: Slope of trend line for number of rainy days per year.

Station	Slope for Non-Monsoon Events	R^2	Slope for Monsoon Events	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

The number of rainy days that exceeded 50 mm per day was counted for all seven stations within the monsoon period. Most of the stations find an increase in the number of days with precipitation more than 50 mm in a day in monsoon period (averaged without taking into account Naikap, an increasing slope of

0.02). The low R^2 values show that there is large variation in the yearly number of > 50 mm precipitation events (Table 3.3).

Table 3.3: Slope of trend line for number of extreme events per year

Station	Slope for Events > 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

Baidya et al. (2008) did a comparable study for data series throughout the whole country of Nepal and applied this to the whole year, not only monsoon period. An average increase of 0.001 was found for the number of days with more than 50 mm rainfall. The slopes found in Table 3.3 imply a larger increase in events with more than 50 mm precipitation than found by Baidya et al. (2008), but this is only for monsoon period and only for Kathmandu valley. However, these numbers are based on daily precipitation sums only. This leaves out the possibility to identify heavy rainfall which for example started a few hours before measurement time and lasted some hours after measurement time.

Linear trend analysis per month for the precipitation while averaging the trends over all months and all stations (except Naikap) showed an increasing trend of 0.06, implying the increase in precipitation. However, seasonal and ordinary Mann-Kendall test showed that there was no significant increasing or decreasing trend in total precipitation.

Similarly, the number of days without rainfall in monsoon period was counted for every year for every station. It was found that the slope of the trend line through the number of individual dry days in monsoon is the opposite of the slope of the trend line through the number of rainy days in monsoon. The length of the dry spells was also studied but had not shown a clear pattern.

3.4 People's Perception on Climate Change

3.4.1 Perceived Changes in Temperature

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

Traditionally the respondents related the seasonal cycle of summer and winter to the rituals. Shree Panchami celebrated during the month of February/March was symbolized as the day for the onset of summer while winter was believed to start since Naag Panchami celebrated in the month of July/August. There was an unequivocal opinion across all the sites concerning the increasing duration of summer season and decrease in the duration of winter season. They perceived that if the summer season duration continued to expand in the perceived rate, winter season would be vanished over the next few decades. They felt that the spring season that used to be distinct starting around Falgu Poornima (full moon day in the month of March) and autumn season bringing festive weather during Dashain and Tihar (festivals celebrated during the month of October and November) were no more distinct. In spring, they felt that the days were much hotter giving feeling of summer. Similarly, they felt autumn started very late and though the mornings were colder, the days were as hot as in summer. Prior to 1980s, people felt that winter used to begin by Kartik (October/November) and the peak winter season months used to extend from November second week to mid February (Mangsir to Magh). In 2000s, they felt winter began much later and ended earlier. Even during the months considered as peak winter, they noticed that though the days were cold during the morning, temperature gained higher peak by the afternoon giving no more feeling of winter. The analysis of the recorded data also showed a similar pattern. The deviation plots of 5-year moving average for temperature for all the stations showed that the minimum as well as the maximum temperatures in monsoon and non-monsoon seasons seem to have increased in the recent years.

People also perceived that despite the temporal increasing trend of temperature within the village, the rise was not as extensive as they felt during their travels to city cores. The expression indicated experiences of the urban heat island effect which was also showed by the analysis of hydro-meteorological data collected from different stations.

The respondents across the sites felt that extreme hot days were getting more frequent whereas the extremely cold winter days were gradually declining. Analysis of temperature data also found that there was a decrease in number of days with temperature < 0°C and an increase in the number of hot days (>30°C). The respondents remembered that the practice of setting up fire called as Maghe Mudo during the month of February used to be common till the 1980s. However, this practice had almost disappeared across all the sites. They also perceived that a small decline in the number of frost days started in the 1990s which became more intense in 2000s. People recalled that the occurrence of Thanto (icy film formed on the water surface), was more common prior to 1980s. This gradually declined during 1990s and stopped occurring in 2000s. They considered that the general trend of occurrence of frost was from the November second week to February second week and then Kalo Tusaro (invisible black frost), used to occur by third week of February. This was believed to be responsible for morning chills though the afternoon temperature was much higher by this time of the year. The invisible black frost used to extend till first week of March but after mid 2000s, they experienced decrease in usual frost while the period of invisible black frost was extending up to March last week. Similarly, people memorized the occurrence of fog started by second week of September linking the occurrence of light fog in the days prior to Dashain and used to extend till February. They felt the occurrence of fog started much later around the second week of October in 2000s and was much lighter by the mid of February. In addition, they also felt the decline in the fog density and decline in foggy duration within a day.

3.4.2 Perceived Changes in Rainfall

The changes in the rainfall pattern perceived by the local people across the study sites were captured based on the perceived changes in the total amount of rainfall, number of rainy days, onset and cessation of monsoon and amount of winter rainfall as these direct the decisions made by the local farmers for selecting cropping pattern. The respondents were asked to base their perception of change on rainfall attributes over time period of past four decades- prior to 1980s, 1980s, 1990s and 2000s.

All the respondents across the sites except in Jhaukhel, perceived a continued decrease in total amount of rainfall starting since 1990s which further declined in 2000s. However, 2010 onwards they perceived the situation has been better and some even considered that the climate was taking its original trend. Unlike this, people of Jhaukhel perceived consistent increase in the total amount of rainfall after 2000s. Similarly, the respondents perceived that the decrease in number of rainy days started since 1990s which further got disturbed in 2000s (Table 3.4).

Table 3.4: Perceived change in the total amount of rainfall over time

Rainfall Indicator	Site	Sex	2000s	1990s	1980s	Prior to 1980s
Total Rainfall	Lubhu	Male	-2	-1	0	0
		Female	-2	0	0	0
	Matatirtha	Male	-2	-1	0	0
		Female	-2	-1	0	0
	Jhaukhel	Male	2	0	0	-1
		Female	0	0	0	0
	Dadhikot	Mix	-2	-1	0	0
Number of rainy days	Lubhu	Male	-1	-1	0	0
		Female	-2	-1	0	0
	Matatirtha	Male	-2	-1	0	0
		Female	-1	-1	0	0
	Jhaukhel	Male	1	0	-1	-1
		Female	-1	-1	0	0
	Dadhikot	Mix	-2	-1	0	0

Note: Large increase (2), Small increase (1), No change (0), Small decrease (-1), Large decrease (-2)

People relate the monsoon rainfall with the timely completion of paddy transplantation in the area, availability of water in irrigation canals and standing water in paddy fields at the time of weeding and soil moisture retention at the time of harvesting of crops. Most of the respondents across all the sites except Jhaukhel perceived the decline of amount of monsoon rainfall since the 1990s and perceived further reduction since the 2000s, whereas respondents in Jhaukhel perceived monsoon rainfall to be very less till the 1990s. Rice transplantation was mostly started only in the second week of July (Shrawan). Since the decade of 2000, they felt that the monsoon rainfall started to be abundant. They perceived the monsoon onset to be delayed by about 15 days but once the monsoon got started, it has been more dependable since 1990s while no change in the off-set of monsoon was perceived.

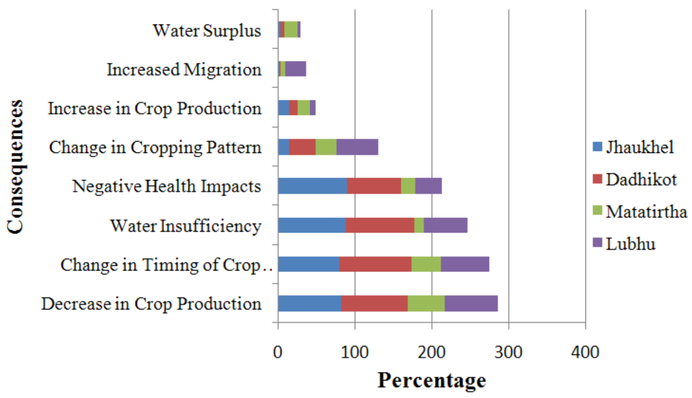
Farmers recalled the occurrences of persistent rainfall lasting over days and nights prior to 1980s in such a way that they could not leave "Ghum" (folded mat made from bamboo strips and leaves and used by farmers as an umbrella) for a long time and remembered the incidences of occurrence of Lice in Ghum which they locally called “Ghum ma LikhaParthyo”. This was a regular event during monsoon and termed as "sat din sat rat jhari" (rainfall lasting for days and nights for seven days) which as per the respondents has remained only in their memory. Shaunejahriduring July/August, ShoraShraddhaJhariduring September, NaurathaJhari during September/October, Maghejhari during January/February were recalled as common incidences prior to 1980s. However, in Jhaukhel, the persistence in the monsoon rainfall was perceived to have improved and better compared to the 1980s and 1990s. They considered dry spells as regular event but has been less stressful to them as compared to 1980s.

3.5 Probable Impacts and Implications

Responding to the impacts of climate change, most of the respondents perceived the decrease in agricultural crop production followed by change in timing of crop planting and harvesting; water scarcity; negative health impacts and change in cropping pattern. A few respondents also perceived increase in crop production, increase in migration and water surplus (Figure 3.2).

IPCC (1996) also mentioned that the change in climate will affect agriculture through effects on crops, soils, insects, weeds and diseases. Other changes in agriculture, such as loss of local species of both crops and domestic animals, changes in cropping

Figure 3.2: Peoples' perception on social consequences of climatic variability. Multiples choices have been allowed from the respondents.



sequences, scarcity of water due to drying up of wells, and increasing incidences of disease and pest have also been noticed (Regmi et al., 2008). According to WECS (2011), Nepal was self sufficient in food grain production until 1990 and due to drought condition in 2005-06, production fell short by 21,553 metric tonnes and by 179,910 metric tonnes in 2006-07 due to drought and natural calamities. The rising maximum temperature had a negative impact on the rice yield and increase in minimum temperature can also lead to yield decline due to early maturity of the crop (Rai et al., 2011 and Lal, 2011). If the increase in minimum temperature is less strong than the increase in maximum temperature, the daily variability of temperature increases which can decline crop yields (Wheeler et al., 2000).

According to the focus group discussion, natural spring sources have been adversely affected by rainfall variability. Either the yield of spring sources has been declining or the whole system got vanished. However, they observed that these changes in spring sources were not solely by climatic variability but these were the compounded implication of climate change and urbanization which is rightly pointed by Manandhar (2010) stating that Climate change is not always the main reason behind these changes but may act as a catalyst in many cases.

Similarly, the local people perceived that the crop damage due to increase in pest attacks has increased. The farmers also reported on the emergence of new pest in crops and felt this to be an impact of increasing temperature along with the disturbance in the natural pest predator system as consequences of soil degradation resulted from unbalanced use of chemical fertilizers and pesticides. Consequently, the cost of production has been increasing and the crop production is declining. Literature also showed that an increase in maximum temperature can enhance invasive weeds to enter the area (Dukes and Mooney, 2000) and also it increases the risk of vector borne and rodent borne diseases (Patz et al., 2000). A decrease in the number of days with < 0^0C also can cause an increase in insects and pests because of less winter kill (Ziska et al., 2011). People perceived that the occurrence of weeds increased in 2000s which has increased the need of weeding practice more. While Sama (Echinochloa colona), Ketu, Kasauti, Phuke, Dubo (Cynodon dactylon) were indigenous weeds, new weeds like Maobadi Jhar, Navo, Madila, Tantane, Pire (Polygonum barbatum), Mothe (Cyperus difformis), Baspate, Pani ghans appeared in rice field and progressively increased in 2000s. Similarly, the diseases called Sete (the tip of the leaves turning white as a result of inundation for longer period) and Rate were increasing in rice plants. The farmers recalled the occurrence of green aphids that started in 1990s while black aphids appeared only in 2000s, and considered the latter to be more destructive. Though the occurrences of the insect pests were lower during winter season compared to the summer season, it was observed that the pest population was gradually increasing with winter being milder.

4

GURGAON

4.1 Climatic and Physiographic Settings

Gurgaon district is situated in NCR of New Delhi, the National Capital of India. It is about 32 km away from New Delhi and the southern-most district of Haryana. The district lies between $27^0$39' and $28^0$32' 25" north latitudes, and 76^0 39' 30" and $77^0$20' 45" east longitudes. Over the past 25 years the city has undergone rapid development and construction.

The normal annual rainfall in the district is 553.0 mm. The rainfall in the district increases from the west towards the east. About 77% of the annual rainfall in the district is received during the south-west monsoon months. From about the beginning of March, temperatures begin to increase rapidly. May and June are the hottest months when the mean daily maximum temperature is about 41 ^{0}C. While days are little hotter in May than in June, nights are warmer in June than in May. From April onwards, hot dust-laden winds locally known as 'loo' blow and weather is unpleasant. The mean daily maximum temperature in January is about 21^{0}C and the mean daily minimum temperature is about 7 ^{0}C. The air is generally dry during the greater part of the year. Humidity is high in the south-west monsoon season. April and May are the driest months when the relative humidity in the morning is about 30 percent and in the afternoon less than 20 percent. In the south-west, during the monsoon season and for brief spells of a day or two in winters in association with passing western disturbances, heavily clouded or overcast skies generally prevail. The skies are mostly clear or lightly clouded during rest of the year. Winds are generally light but gain force in the summer and monsoon seasons.

4.2 Methodology and Data

In the analyses, a linear monotonic trend in a variable was considered at annual, seasonal and monthly scales. In this method, a linear trend line is fitted to a set of data such that the sum of squared errors becomes the least. This is the most convenient method used to analyze the long-term and short-term trends observed in the climatic variables. This method would also enable to predict and forecast the future trends in the absence of the influence of external factors.

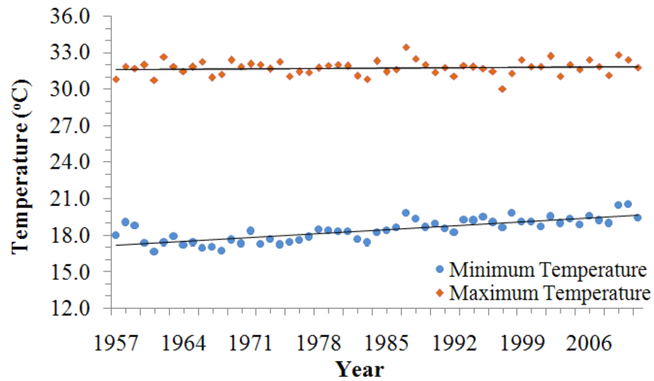
The meteorological data for the Gurgaon region is procured from the New Delhi, Palam Station of Indian Meteorological Department (IMD). This station is situated approximately 25 km away from the peri-urban locations. Monthly mean rainfall and maximum and minimum temperature data for a period of about 50 years (1957-2011) were collected from the official website of IMD. Daily data for the last decade (2001-2010) were collected directly from IMD office. Seasonal values were derived from the monthly data using standard statistical methods. Apart from this, people's perception of a changing climate was captured through semi-structured interviews, focus group discussions and PRA exercises such as time and trend lines and seasonality analyses. These were conducted across four villages, namely, Sultanpur, Jhanjhrola Khera, Budheda and Sadhraana, about 15 kms from Gurgaon city.

4.3 Trends and Variability in Temperature

4.3.1 Annual Temperature

Analysis of data indicates that the means of both the minimum and maximum temperatures are increasing (Figure 4.1). The annual mean minimum temperature is increasing at 0.046°C per year, which is statistically significant at 99% level of confidence. Since 1968, the mean minimum temperature is rising very fast (0.061°C per year). Though the annual mean maximum temperature is increasing at 0.007°C per year, the trend is not statistically significant.

Figure 4.1: Trends in mean maximum and minimum temperature at Gurgaon for the period 1957-2010.



Apart from the long-term trends, the trends in temperatures for the period 1980-2011 were estimated separately, which indicated that there is not much difference in the trends in the recent years compared to the long-term observed trends.

4.3.2 Seasonal Temperature

Trends in both maximum and minimum temperatures are positive in the pre-monsoon season (March-May) (Table 4.1). Also, the trends have become stronger in recent years. For monsoon season (June-September), the minimum temperature is increasing. The trends in minimum temperatures in both the post-monsoon (October-November) and winter (December-February) seasons are increasing. Pre-monsoon season exhibits the highest trend of temperatures among all the four seasons.

Table 4.1: Trend (°C/year) in seasonal temperatures at Gurgaon

Season	Trend in Maximum Temperature for the Period		Trend in Minimum Temperature for the Period	
	1957-2011	1980-2011	1957-2011	1980-2011
Pre-Monsoon	0.013	0.055**	0.060***	0.075***
Monsoon	0.010	-0.023	0.027***	0.040***
Post-Monsoon	0.010	-0.000	0.059***	0.047**
Winter	-0.004	-0.010	0.049***	0.026*

Note: ***, ** and * indicate that the trends are significant at 99%, 95% and 90% level of confidence, respectively.

4.3.3 Monthly Temperature

Like seasonal trend, the monthly mean minimum temperature shows increasing trend both in long-term and recent data (Table 4.2). The increasing trends in the pre-monsoon months of March and April are really alarming. The monthly mean maximum temperatures of these two months also exhibit strong increasing trends in recent years. The seasonal and monthly variability is also evident in the trends. Though all the seasons (except the pre-monsoon) exhibit negative trends in maximum temperatures in the recent years (1980-2011), some of the monthly trends are positive. This indicates a relatively high month-to-month variability in temperature in the recent years.

Table 4.2: Trend (^{0}C/year) in monthly temperatures at Gurgaon

Month	Trend in Maximum Temperature for the Period		Trend in Minimum Temperature for the Period	
	1957-2011	1980-2011	1957-2011	1980-2011
January	-0.023**	-0.049**	0.036***	0.008
February	0.005	0.035	0.060***	0.057**
March	0.011	0.084**	0.060***	0.080***
April	0.025*	0.062*	0.059***	0.080***
May	0.005	0.018	0.063***	0.065**
June	-0.031**	-0.058	0.007	0.019
July	0.017	0.024	0.029***	0.066***
August	0.036***	0.007	0.031***	0.047***
September	0.017	-0.066**	0.042***	0.030*
October	0.010	-0.014	0.056***	0.063**
November	0.011	0.012	0.062***	0.032*
December	0.006	-0.008	0.051***	0.015

Note: ***, ** and * indicate that the trends are significant at 99%, 95% and 90% level of confidence, respectively

The variability in temperature was estimated by computing standard deviation of monthly mean maximum/minimum temperatures in a year. The minimum temperature shows a negative trend, which is significant at 95% level of confidence. This indicates that the variability in night-time temperature from one month to another is reducing. A relatively strong increasing trend in the winter months in long-term minimum data (Table 4.2) may be the reason for the decreasing variability. In contrast to the variability in minimum temperature, the maximum temperature shows an increasing variability which is not statistically significant. Thus the natural fluctuation in daytime temperature within a year is increasing due to global warming phenomenon. Another interpretation could be that the days are becoming more heterogeneous and the nights more homogeneous in terms of mean monthly maximum and minimum temperatures, respectively. The inter-year variability in both maximum and minimum temperatures at seasonal and annual scales has decreased (Figures 4.2 and 4.3).

Figure 4.2: Inter-year variability in seasonal and annual mean maximum temperature at Gurgaon

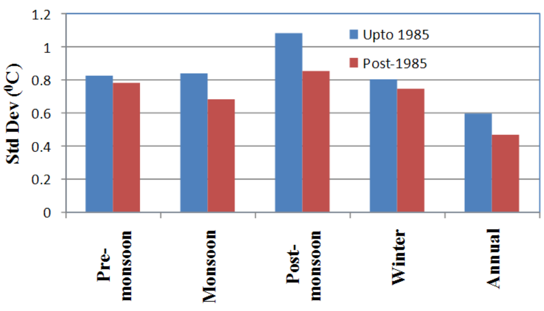
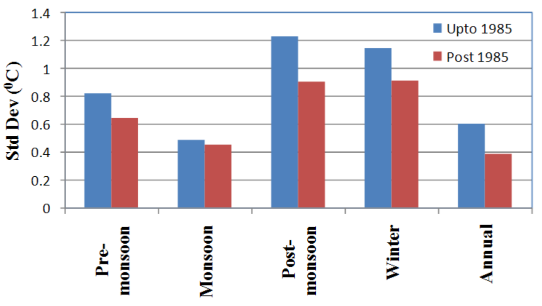


Figure 4.3: Inter-year variability in seasonal and annual mean minimum temperature at Gurgaon



4.4 Trends and Variability in Rainfall

The mean annual rainfall in Gurgaon is 773 mm. About 82% of the annual rainfall (633 mm) occurs in the monsoon season. The pre-monsoon, winter and post-monsoon seasons receive about 9%, 6% and 3% of the annual rainfall, respectively. Agriculturists in Gurgaon feel that the rainfall has reduced significantly over the years. Figure 4.4 supports this observation, which shows a generally decreasing trend (though not statistically significant) in annual rainfall of 3.9 mm per year. At a seasonal scale, the monsoon season has a decreasing trend of 4.1 mm per year, which is statistically significant at 90% level of confidence. The post-monsoon season has a non-significant decreasing trend of 0.3 mm per year, the pre-monsoon season has a non-significant increasing trend of 0.3 mm per year and the winter season has a non-significant increasing trend of 0.2 mm per year. The variability in rainfall during different seasons in a year is found to be decreasing at a confidence

Figure 4.4: Trend in annual rainfall at Gurgaon for the period 1957-2011

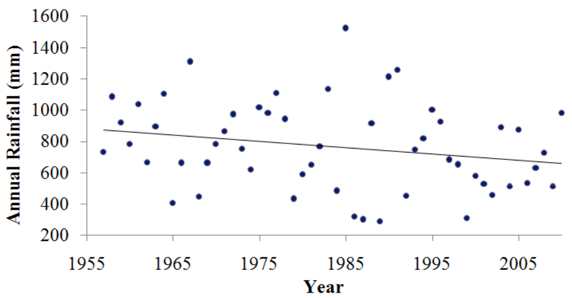
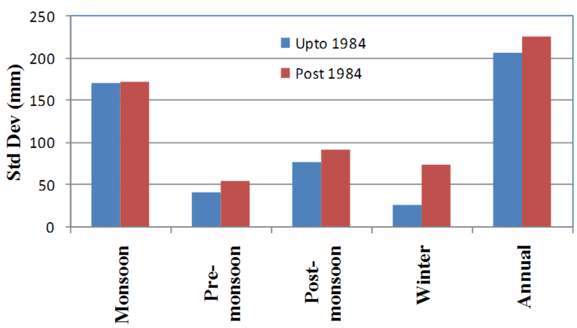
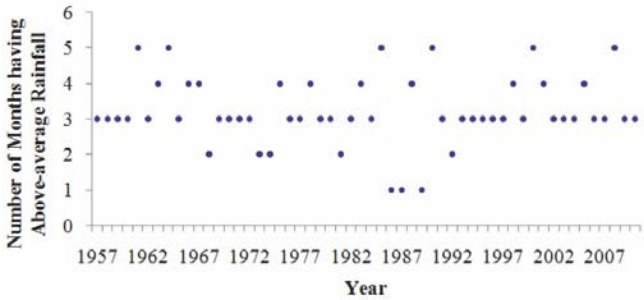


Figure 4.5: Inter-year variability in seasonal and annual rainfalls during two time periods at Gurgaon



level of 90%. This is understandable from the decreasing trend in the monsoonal rainfall. Thus, the natural seasonal distribution pattern of rainfall is gradually changing in Gurgaon. Furthermore, the inter-year variability in rainfall has increased in the latter half of the available period of data as compared with the earlier half at both seasonal and monthly scales and thus making rainfall availability more uncertain (Figure 4.5) at Gurgaon. During the analysis period, 1985 witnessed the highest rainfall of 1523.4 mm. On the other hand, 1986 and 1987 were drought years and 1989 had the least rainfall of 289.4 mm. From 1997 onwards, the recorded rainfall was below the trend line except in 2003, 2005, 2008 and 2010, which received a total rainfall of 888.5 mm, 874.5 mm, 725.61 mm and 981.6 mm, respectively.

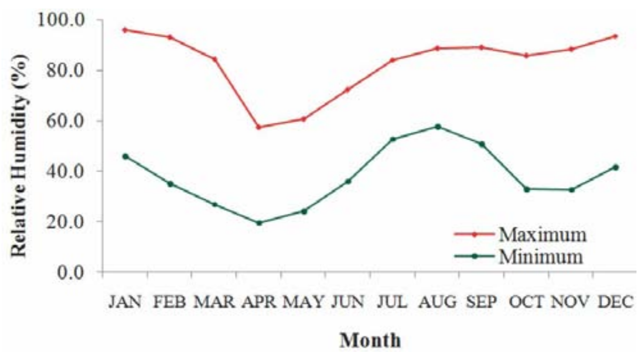
Figure 4.6: Trend in annual number of months having rainfall above long-term average (64.6 mm) at Gurgaon for the period 1957-2011



The monthly average rainfall for the analysis period is 64.6 mm. Figure 4.6 shows that this monthly average is exceeded in 3 months in most of the years. Only in 6 years of the analysis period this average value is exceeded in 5 months. It also appears that there is a decreasing trend in this number in the recent years.

4.5 Trends and Variability in Humidity

Figure 4.7: Monthly variation in maximum and minimum relative humidity at Gurgaon



The data for relative humidity at Gurgaon were available for the last decade (2001-2010) in the form of daily maximum and minimum values. From these values, monthly average maximum and minimum relative humidity was estimated. Figure 4.7 shows the monthly variation in the average humidity. The minimum values are in correlation with the maximum values and exhibit similar changes across the year. It is evident that the humidity levels decrease gradually from January to April and then rise again, indicating very low humidity in the dry season. Relatively high humidity levels result from the monsoon rainfall during July - October.

The relative humidity at Gurgaon exhibits negative trends in all seasons (Table 4.3). At a monthly scale, all months except July exhibit negative trends in average maximum relative humidity. The average minimum relative humidity also shows negative trends in most of the months.

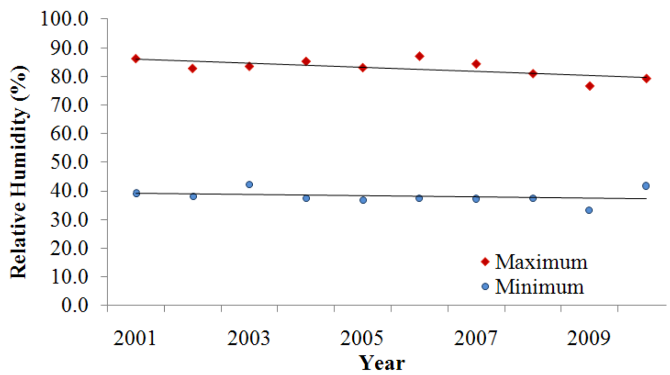
Table 4.3: Seasonal and monthly trends in relative humidity at Gurgaon.

Season	Trend in Maximum Humidity	Trend in Minimum Humidity	Month	Trend in Maximum Humidity	Trend in Minimum Humidity
Winter	-0.65**	-0.33	December	-0.783***	-0.301
			January	-0.522***	-0.247
			February	-0.464	-0.258
Pre-monsoon	-0.32	-0.53*	March	-0.287	-0.311
			April	-0.518	-0.773***
			May	-0.066	-0.258
Monsoon	-0.51	0.17	June	-0.436	-0.351
			July	0.074	0.095
			August	-0.515	0.232
			September	-0.174	0.471
Post-Monsoon	-0.54*	0.13	October	-0.641**	-0.178
			November	-0.319	0.504

Note: ***, ** and * indicate that the trends are significant at 99%, 95% and 90% level of confidence, respectively.

Figure 4.8 shows a decreasing trend in the annual average maximum relative humidity, whereas the trend in the minimum relative humidity is nearly static. In 2009, the least values of both the maximum and minimum relative humidity were recorded. The decreasing humidity trend at Gurgaon is consistent with the decreasing rainfall trend.

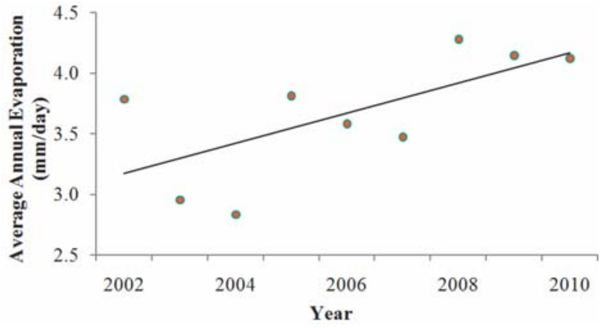
Figure 4.8: Trends in the annual mean maximum and minimum relative humidity at Gurgaon for the period 2001-2010



4.6 Trends and Variability in Evaporation

The data for evaporation rates at Gurgaon were available for the last decade (2002-2010). Figure 4.9 shows that the annual average evaporation rate has been increasing in the last decade. There is approximately 0.8 mm/day per year increase in the annual average evaporation rate over the past 9 years (2002-2010). In 2002, the evaporation rate was 3.8 mm/day. The rates dropped to 3.0 mm/day in 2003 and further to 2.8 mm/day in 2004. There was a slight decrease in the evaporation rates to 3.6 and 3.5 mm/day in 2006 and 2007, respectively. The increasing evaporation trend is consistent with the decreasing rainfall and humidity trends and increasing temperature trend at Gurgaon.

Figure 4.9: Trend in evaporation rates at Gurgaon for the period 2002-2010



At a seasonal scale, the trends in evaporation rates are positive in all the seasons. The trend in the winter season shows the maximum positive trend among all the seasons. The trends are also positive at the monthly scale showing values from 0.295 to 0.797 mm/day. Only the month of May shows a negative trend in the evaporation rates (Table 4.4).

Table 4.4: Seasonal evaporation trends (mm/day per year) at Gurgaon for the period 2002-2010

Season	Trend in Evaporation	Month	Trend in Evaporation
Winter	0.78***	December	0.600*
		January	0.631*
		February	0.780***
Pre-monsoon	0.42	March	0.797***
		April	0.512
		May	-0.157
Monsoon	0.54	June	0.446
		July	0.411
		August	0.524
		September	0.295
Post-Monsoon	0.63*	October	0.618*
		November	0.427

Note: ***, ** and * indicate that the trends are significant at 99%, 95% and 90% level of confidence, respectively.

4.7 People's Perception of Climatic Trend and Variability

Local residents perceive climate change in terms of changes in duration and intensity of seasons and rainfall, especially with regard to their cropping practices and festivals. They use festivals as benchmarks for the on-set of seasons. For instance, the festival of Deepawali (in November) marks the onset of winter. Many people interviewed felt that unlike previous years, they continue to wear warm clothes even at the time of Deepawali celebrations. Through our seasonality analyses we could confirm that they experience winters of a shorter duration. Winter now is only about a month or two long, against 3-4 months about 3-4 decades ago. However, the winters are more intense. The rainfall months have also reduced in their duration. Summers are prolonged and more intense.

Time line analyses for rainfall carried out as part of the PRA tools and exercises suggested 1977 to be a year of peak rainfall. In semi-structured interviews and group discussions, residents pointed out 2010 as a year of high rainfall as well. 2010 witnessed rainfall flooding, causing damage to the paddy crop. Farmers also lost the sowing season for wheat as the fields remained submerged under water well into the latter part of the year. However, a graphical depiction of this on the rainfall trend line (as part of the PRA exercises) suggested that the rainfall of 2010 was only about a third of the 1977 level.

The interviewees perceive decline in rainfall after the 1980s, with a strong recall of flooding in the 1977 rains. Thus, 1977 stands out as a watershed in the memory of the peri-urban residents in as far as rainfall is concerned. The 1980s stand out as the time after which they notice a shift in the duration and intensity of seasons. They also perceive an increase in aridity and less moisture in the soil. Winters that are less moist are seen as less conducive to the rabi (winter) crop. Seasonality analyses indicate that the demand for irrigation water is at its peak during November to January when water is required for wheat cultivation. It is interesting to note that the perception of a changing climate was higher among the poorer social groups, perhaps because they have less opportunities or resources to protect themselves from the impacts of these changes. Many respondents also said that warmer climates reduced opportunities for social interaction; in the older days, when the weather was more pleasant, long hours were spent under the shade of a tree playing cards and socializing.

Most people interviewed attribute the fall in the water table to the decline in rainfall over the years. They have adapted by digging deeper into the aquifers through more expensive water extraction technologies. Those who cannot do so are forced to leave their land fallow or take only one crop in a year. Others adapt by irrigating only part of their fields and taking one rainfed crop. However, the erratic rainfall means that their rainfed crop is no longer certain. The cultivation of fruits, flowers and vegetables has declined. Farmers now stay confined mainly to wheat and mustard in the rabi (winter) season and pearl-millet and some fodder crops in the kharif (monsoon) season. The exception is the farmers who have access to wastewater, that allows them to take a paddy crop in the kharif season.

4.8 Probable Impacts and Implications

Increase in maximum temperatures, decrease in the minimum temperatures during the winter season would severely affect the day to day activities by causing discomfort and health disorders.

Hydro-meteorological trends also suggest that there would be a decrease in the soil moisture due to increase in mean temperatures as well as the evaporation rates. This would have a direct effect on the crop yield. Changes in the climate could result in severe reduction in food production particularly in these project locations that are at present vulnerable to climate variability.

Also, changes in temperature may lead to increased input costs thus over burdening the already poor farmer. The severity of the extreme weather results in increased risks to farmers. Reduced rainfall over the years is probably the greatest risk to agriculture. High temperatures require high water use efficiency for crop sustenance. Temperature increases of even 0.5^0C probably would reduce wheat yields due to heat stress, by about 10% if rainfall did not increase. Decrease in crop yield could aggravate food insecurity.

Increased evaporation rates may result in the dry summer seasons. There is a possibility of droughts due to high rates of evaporation and also due to combined effects of reduced rainfall. Changes in the intensity of the drought symbolize the most serious impact of the climate change on agriculture.

Increase in temperatures also increases the risk of pest attacks on the crops, thus reducing the crop productivity. Increase in population levels of disease vectors may lead to increased epidemics of the diseases they carry. Livestock diseases too become more in number causing significant decline in the productivity.

Heat waves would worsen the quality of life and level of comfort and well-being. There would be increase in respiratory diseases due to air pollution. This would also result in increased risk of heat mortality and morbidity.

Climate change would also have severe affect on the water resources. With reduction in rainfall, there is burden on the scarce availability of the water resources. In some situation, this scenario might lead to conflicts over shared resources. The existence of inequities in the water supply leads to a more vulnerable and helpless situation among the deprived section of people. People in the low-income groups are more likely vulnerable to the climate change. On account of their economic status, it is hard for them to cope up with adverse effects arising due to climate change.

Climate change has serious health impacts both for children and adults. Rapid metabolism may cause immature growth in organs and nervous disorders. Children are also at risk when they face challenges while coping with the natural disasters as a result of climate change. Psychologically, children might take a long time to recover from such shocks.

5

HYDERABAD

5.1 Climatic and Physiographic Settings

The climate of Hyderabad is characterized by a hot pre-monsoon and is generally dry except during the south-west monsoon season. Typically, a year constitutes of four seasons. Mid February to May is the pre-monsoon season, June to September constitutes the south-west monsoon season, October and November form the post-monsoon or retreating monsoon season and December to mid- February is the winter season.

Rainfall records at Hyderabad are available for a period of 60 years (1951-2010). The average annual rainfall is 828 mm. The rainfall during the south-west monsoon months, i.e. from June to September, constitutes about 74 % of the annual rainfall. August is generally the rainiest month. There is some rainfall during the latter part of the pre-monsoon and the early part of the post-monsoon seasons, mainly in the form of thunder-showers.

Records from the meteorological observatory at Begumpet are collected. From about mid-February temperatures begin to rise. May is the hottest month with a mean maximum temperature of 39.5^{0}C. During the pre-monsoon season and in June, before the onset of the south-west monsoon, the day temperatures often go above 40^{0}C. The days in pre-monsoon are intensely hot. With the onset of south-west monsoon in early June, there is appreciable drop in temperatures and the weather becomes more pleasant. After September, when the south-west monsoon season withdraws, there is slight increase in the day temperatures. But, there is steady decrease in the night temperatures. By the beginning of November, the decrease in both the day and night temperatures is rapid. December is the coldest month with a mean daily maximum temperature of 28.7^{0}C and a mean daily minimum temperature of 14.6^{0}C. In this month, the night temperatures sometimes drop down to about 12^{0}C.

During the south-west monsoon season, the relative humidity is generally high, ranging from 70 to 80 percent on an average. Humidity decreases from the post-monsoon season onwards. The driest part of the year is the pre-monsoon season when the humidity is generally in the range of 30-35 percent in the afternoons.

5.2 Methodology and Data

In the analyses, a linear monotonic trend in a variable was considered at annual, seasonal and monthly scales. In this method, a linear trend is fitted to a set of data such that the sum of squared errors becomes the least. This is the most convenient method used to analyze the long-term and short-term trends observed in the climatic variables. This method would also enable to predict and forecast the future trends in the absence of external factors influence.

The meteorological data for the Hyderabad region is procured from the Indian Meteorological Department (IMD) which is located at Begumpet, Hyderabad. This weather station is situated approximately 45 km away from the peri-urban locations. The official website of IMD provides with the monthly mean values for the maximum and minimum temperatures along with the monthly rainfall for a period of 50 years (1951-2010).

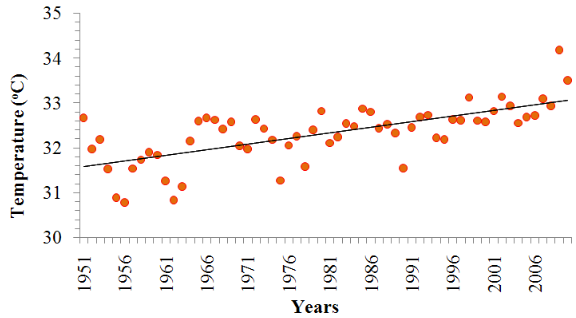
Detailed data for the last decade (2001-2010) were collected directly from the IMD office.

5.3 Trends and Variability in Temperature

5.3.1 Annual Temperature

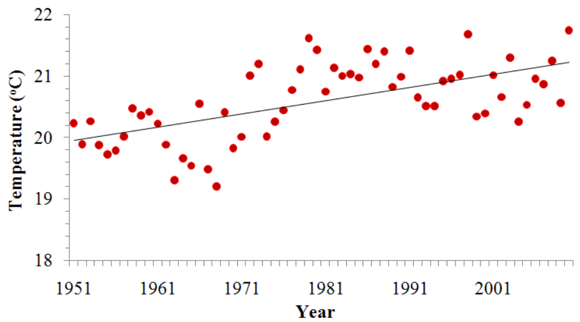
The annual mean maximum temperatures at Hyderabad have gradually increased since 1951 at 0.025 0C per year being significant at 99% level of confidence. The lowest mean maximum temperature of 30.7^{0}C was recorded in 1956. In the 1960s, the temperatures were relatively low till 1962, after which the temperatures slowly increased. However, the period of 1975-2005 showed a static trend in temperature. In this period, mean temperatures varied from 31^{0}C to 33^{0}C. The highest mean maximum temperature of 34.1^{0}C was recorded in 2009. The trend line in Figure 5.1 shows that the temperatures have been gradually increasing over the years. There is an overall increase of 1.5^{0}C in the mean maximum temperatures in the last six decades.

Figure 5.1: Trend in the mean maximum temperature at Hyderabad for the period 1951-2010



The annual mean minimum temperature of Hyderabad falls in the range of 19-22^{0}C. The decade of 1960-70 witnessed a period of low mean minimum temperatures (Figure 5.2). After 1971, there has been a gradual increase in the mean minimum temperatures compared to the previous decade. However, the temperatures dropped during the early nineties. From 2009, the temperatures have gradually increased, where the highest mean minimum temperature of 21.75^{0}C was recorded in 2010. Overall, the mean minimum temperatures over the years have been slowly increasing at a rate of 0.022^{0}C per year being significant at 99% level of confidence.

Figure 5.2: Trend in the mean minimum temperature at Hyderabad for the period 1951-2010



5.3.2 Seasonal Temperature

In Hyderabad, the pre-monsoon season exhibits the highest temperatures among all the seasons. The mean maximum temperatures in the monsoon, post-monsoon and winter seasons are almost the same.

For the mean minimum temperatures, the pre-monsoon and monsoon seasons have a close difference whereas the winter season exhibits the least minimum temperature. The seasonal mean maximum temperature shows rising trend in all seasons (Table 5.1). The trend in the recent years is very high in the winter season. The long-term seasonal mean minimum temperature shows increasing trend. However, the trend in minimum temperature has weakened in recent years.

Table 5.1: Trends (°C/year) in seasonal temperatures at Hyderabad

Season	Trend in Maximum Temperature for the Period		Trend in Minimum Temperature for the Period	
	1951-2010	1980-2010	1951-2010	1980-2010
Pre-Monsoon	0.022***	0.009	0.017***	-0.026*
Monsoon	0.026***	0.030**	0.010***	0.007
Post-Monsoon	0.029***	0.037**	0.032***	0.012
Winter	0.022***	0.044***	0.033***	-0.026

Note: ***, ** and * indicate that the trends are significant at 99%, 95% and 90% level of confidence, respectively.

5.3.4 Monthly Temperature

At a monthly scale, the mean maximum temperatures in both periods (1951-2010 and 1980-2010) show positive trends (Table 5.2). The trends in recent years are higher for the months of November-January. The changes are irregular for the mean minimum temperatures. In the long-term (1951-2010), all the months show positive trends in the mean minimum temperatures, whereas seven months show negative trends in the mean minimum temperatures in the recent years (1980-2010). None of the data trends of the mean minimum temperature in the recent years shows statistical significance at 90% level of confidence, indicating a relatively high variability.

Table 5.2: Trend (°C/year) in monthly temperatures at Hyderabad

Month	Trend in Maximum Temperature for the Period		Trend in Minimum Temperature for the Period	
	1951-2010	1980-2010	1951-2010	1980-2010
January	0.025***	0.048**	0.030***	-0.034
February	0.016**	0.015	0.044***	-0.009
March	0.022**	0.014	0.033***	-0.023
April	0.025***	0.010	0.012*	-0.020
May	0.021*	0.004	0.005	-0.034
June	0.017	0.037	0.011*	0.021
July	0.031***	0.033*	0.011***	0.010

August	0.023***	0.033**	0.007*	0.008
September	0.033***	0.015	0.013***	-0.010
October	0.028***	0.026	0.017***	0.005
November	0.029***	0.049***	0.047***	0.018
December	0.031***	0.065***	0.028**	-0.027

Note: ***, ** and * indicate that the trends are significant at 99%, 95% and 90% level of confidence, respectively.

May is the hottest month in Hyderabad. The temperatures in the month vary from 36°C to 41°C. The trend in the mean maximum temperatures of this month appears to be increasing (Figure 5.3). In a year, the least mean minimum temperature is recorded in the month of December. The temperatures in December vary from 10.1°C to 19.2°C during 1951-2010 (Figure 5.4). The average mean minimum temperature in this period is 14.6°C. The mean minimum temperature also shows an increasing trend in this month.

The intra-year variability in minimum temperature is found to be decreasing in long-term data set. Such decreasing trend is statistically significant at 99% level of confidence. However, the variability is increasing since 1978, although it is not statistically significant. The long-term maximum data set also shows a decreasing trend in intra-year variability although the trend is not statistically significant. The recent data since 1991 also shows a decreasing trend in variability being significant at 90% level of confidence. Thus, unlike Gurgaon, the days within a year in Hyderabad are becoming more homogeneous and the nights are more heterogeneous in terms of their temperature variation. The over-year variabilities in mean seasonal and annual maximum and minimum temperatures have decreased in post-1980s compared with those of pre-1980s (Figures 5.5 and 5.6)

Figure 5.3: Trend in mean maximum temperature in May at Hyderabad

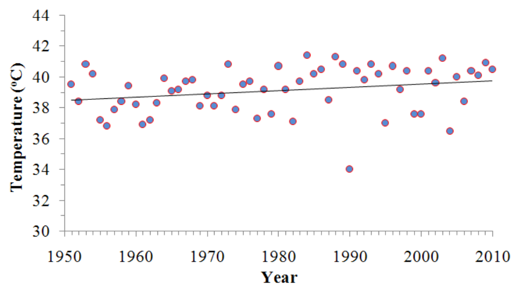


Figure 5.4: Trend in mean minimum temperature in December at Hyderabad

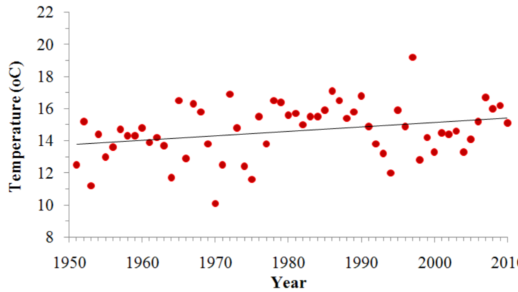


Figure 5.5: Inter-year variability in seasonal and annual mean maximum temperatures at Hyderabad

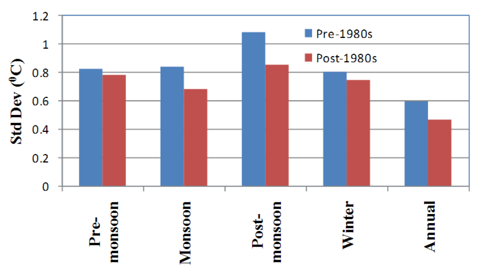
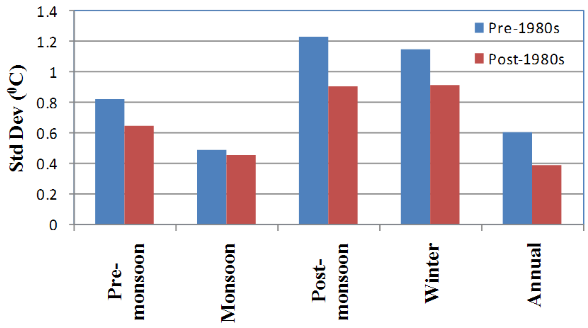
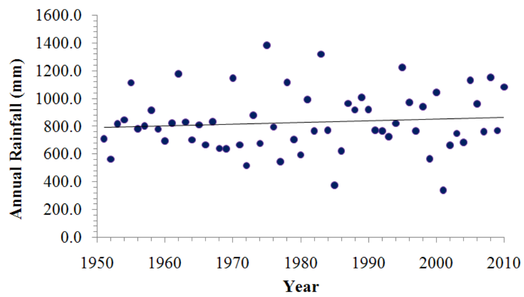


Figure 5.6: Inter-year variability in seasonal and annual mean minimum temperatures at Hyderabad



5.4 Trends and Variability in Rainfall

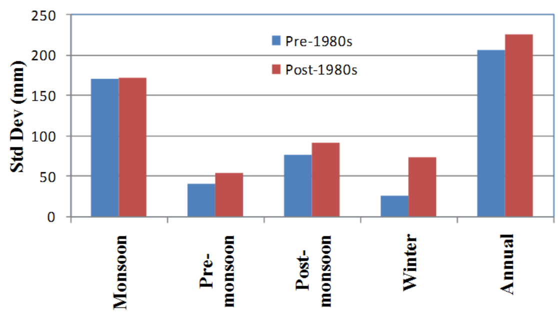
Figure 5.7: Trend in annual rainfall at Hyderabad for the period 1951-2010



The data for the annual rainfall at Hyderabad was available for a period of 60 years (1950-2010). The average annual rainfall at Hyderabad is about 828 mm. The monsoon season receives about 74% of the annual rainfall. The post-monsoon, pre-monsoon and winter seasons receive about 14%, 9% and 3%, respectively, of the annual rainfall. The least annual rainfall of 373.4 mm and 337.9 mm was recorded in 1985 and 2001, respectively. These years showed extreme drought conditions. The highest annual rainfall witnessed till date was in 1975. The latter half of 2000 decade saw good rainfall varying from 600-1000 mm. In this period, 25 years witnessed rainfall above this average value. There is an increasing trend of 1.2 mm per year in the annual rainfall (Figure 5.7). This trend, however, is not statistically significant. In a seasonal scale, the monsoon, post-monsoon, pre-monsoon and winter seasons have non-significant increasing trends of 0.2, 0.3, 0.3 and 0.4 mm per year, respectively.

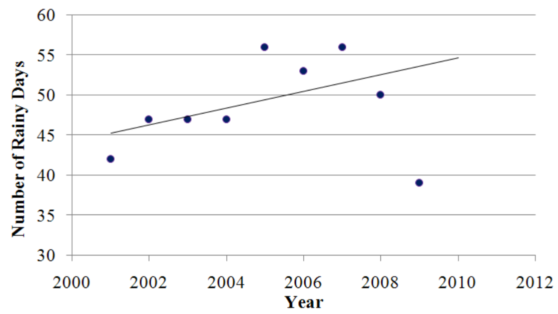
The rainfall in a given month is not consistent over the years. The month of January, which does not fall under the monsoon season, had a rainfall of 400 mm in 1983. July and August receive the maximum rainfall in a year whereas December and February record the least amount of rainfall. Monsoon rainfall starts in late June in Hyderabad. The month of September recorded considerable amount of rainfall till 1980, but the amount of rainfall has slowly reduced afterwards where the least had been recorded in 2001. September received a good amount of rainfall in the year 2005. The average rainfall in October over the years is 94.45 mm with a maximum occurrence of 315 mm in 1975. November had a rainfall ranging from 0-50 mm, with a few exceptional years such as 1987 and 1992 where the rainfall was 239 and 113 mm, respectively. There is a non-significant increasing trend in within-year rainfall variability. Also, the inter-year variability in rainfall has increased in post-1980s as compared with pre-1980s (Figure 5.8)

Figure 5.8: Inter-year variability in seasonal and annual rainfalls during two time periods at Hyderabad



The number of rainy days (rainfall > 10 mm) in a year varied from 39-63 in the last decade (Figure 5.9). Year 2001 had 42 rainy days whereas years 2002, 2003 and 2004 recorded 47 days of rainfall. There were 56 days of rainfall in 2005, where the number came down to 53 in 2006 and again rose to 56 in 2007. Further, the number of rainy days reduced after 2007 where the least of the decade (39 days) was recorded in 2009. Year 2010 received a good amount of rainfall spread over 63 days. Only four years recorded rainfall above 50 days, the average number of rainy days in the decade.

Figure 5.9: Number of rainy days at Hyderabad for the period 2001-2010



5.5 People's Perception on Climatic Trend and Variability

Scanty rainfall over the last decade (and which has progressively been decreasing year after year) has added to the woes of these farmers. “There have been no heavy rains over the last few years, only slight drizzles”, they said, attributing this to the reduced green cover around. People feel that the process of urbanization led to rapid destruction of the forests. The reduction in the forest cover led to climate change resulting in lesser amount of rainfall. An empty tank means lower levels of groundwater, reduced rainfall only intensifying the problems, in terms of water availability for domestic and agricultural purposes.

From the structured questions and focus group discussions, a trend in the rainfall pattern was recorded based on inputs given by the people. Hydro-meteorological trends showed that the year 1970 witnessed heavy rainfall with an annual rainfall of 1146.8 mm, which was also indicated as the heaviest rainfall year by the respondents in the project locations. It was reported that the years 1995-96 received good rains. It was also stated that the year 1999 received dry, scanty rainfall. People recollected that year 2001 faced severe drought conditions. Among the last 6 decades, year 2001 witnessed extreme drought conditions with an annual rainfall of 337.9 mm. Again, in the year 2002 the village received heavy rains. It was affirmed that the rainfall was low in 2010.

Among the various communities, it is believed that the climate change led to decrease in water available for irrigation, decrease in groundwater levels and has severely affected water sources in ponds and tanks.

5.6 Probable Impacts and Implications

In Hyderabad, for farmers engaged in agriculture, climate change could play havoc in their lives. Apart from the financial crisis, there could be growing migration pressure. It is already evident in two of the project locations where the farming practices have taken a back seat. People are now forced to become industrial labourers or migrate to the city for other small jobs. Even in a situation where the farmers are managing to cultivate the crops using the water from the private tubewells, there is a drastic reduction in the agricultural productivity. A few years back, the farmers were blessed with such good agricultural output that they made huge profits while selling it. However, now with a decrease in agricultural productivity, the yield is only sufficient to meet their consumption requirements.

Rise in temperature and increased variability may influence interspecies interactions between pests and their predators. Hot temperatures would lead to pests' invasion, causing greater damage to crops. Increases in temperature, even the relatively small increases of about 1.5^{0}C would increase rates of evapo-transpiration by 5-15%. If there were not compensated increases in rainfall, there would be decrease in the yields.

Rise in temperatures cause irreversible damage to growing children. Heat stress for young children is dangerous for their metabolic rates. Children are prone to respiratory disorders which might lead to long term implications. Heat waves take a severe toll on adults who have no choice but to work in harsh summers like the migratory labourers who work in brick industries.

Even if rainfall seems constant, water availability can decrease by 10% or more due to a temperature increase of 1.5^{0}C. Shortage in water would result in drought conditions. As a result, the prices of basic commodities may shoot up, causing inconvenience to many people who cannot afford such soaring prices. The indirect effects of this would be malnutrition.

Reduced rainfall over the years has forced farmers to cultivate vegetables like tomatoes, brinjals, green chillies and leafy vegetables alongside rice which is their traditional crop in both the Kharif and Rabi seasons. However, due to decreased levels of annual rainfall, farmers are forced to cultivate rice in only one season. The demand for water is met through the bore wells which support extensive cultivation of rice for a few months in a year. In the summer season, most of these dug up bores go dry. Hence, the decision to grow vegetables to sustain their incomes during summer is inevitable.

In some extreme cases, intense precipitation may lead to floods which spread the risk of water-borne diseases. Apart from health implications, economic conditions would be severely affected due to loss of crops and livestock, destruction of houses and properties.

6 SUMMARY

Climatic trends and variability are analyzed in four peri-urban locations in South Asia. These locations represent a diversity in physiographic and climatic patterns as well as similarities in peri-urban issues and processes across South Asia. Long-term climatic data on temperature, rainfall, humidity and evaporation observed at the weather stations near these locations are analyzed using standard statistical techniques mostly involving assessment of linear, monotonic trend in a variable at annual, seasonal and monthly time scales. Statistical tools such as t-test and Mann-Kendall test were also employed to assess the significance of the trends. Results of these analyses are interpreted to understand the impacts and implications of these long-term trends and short-term variability in climatic variables.

Khulna, a coastal tide-influenced area, is susceptible to sea level rise, cyclone, storm surge, rainfall flooding, water logging and salinity intrusion, and has a tropical monsoon climate. The annual average temperatures in Khulna range from 12.4^{0}C in winter to 34.3^{0}C in summer. Approximately 80% of the average annual rainfall of 1809 mm occurs during the monsoon months of June-October. Secondary data analysis results indicate that average maximum temperatures in the pre-monsoon and monsoon seasons, and the average minimum temperatures in the pre-monsoon, post-monsoon and winter seasons are increasing at faster rates in recent times (1980-2010) than other projections or model predictions. The monthly data also have similar trends. Heat Index, representing the combined effect of humidity and temperature on human body, is increasing in March-October. Rainfalls in all seasons, and annual number of rainy days and number of consecutive rainy days have generally increasing trends while the monsoon appears to be strengthening towards the end of the season.

Kathmandu Valley has a predominant sub-tropical cool temperate climate where summer and winter temperatures vary from 19 - 27^{0}C and 2 - 20^{0}C, respectively. The relatively large range in altitude in this orographic setting makes the climatic variables more erratic. Approximately 80% of the average annual rainfall of 1400 mm occurs during the monsoon months of June-September. Three different indices were used to analyze the trend and variability in temperature data from seven weather stations at different time scales. Analysis results indicate that both the annual maximum and minimum values of the temperatures have increasing trends. Both the warmest and the coldest days of the year are becoming warmer. There is a decrease in annual number of days with temperature < 0^{0}C and an increase in the number of hot days (> 30^{0}C). Analysis results also indicate an urban heat island effect in the peri-urban locations. Trend in total annual rainfall is almost static while there is a non-significant increase in the annual number of rainy days during monsoon.

The semi-arid climate of Gurgaon is characterized by low humidity, hot summer and cold winter. The average temperatures vary from 41^{0}C in summer to 7^{0}C in winter. Approximately 82% of the annual rainfall of 773 mm occurs during the monsoon months of July-September. Analysis results of secondary data indicate that monthly averages of both the minimum and maximum temperatures are increasing although there is a relatively high month-to-month variability in temperature in the recent years (1980-2011). In this recent period, maximum and minimum temperatures are increasing at relatively higher rates. The mean monthly minimum temperature in January also has a slightly positive trend. However, this temperature has a negative trend in the recent years, which implies that the winters are getting colder in the recent years. The month-to-month variability in night-time temperature is found to be reducing while the maximum temperature shows an increasing variability. This implies that the natural fluctuation in daytime temperatures within a year is increasing, most likely due to global warming. The variability in both maximum and minimum temperatures at seasonal and annual scales is decreasing. The variability in rainfall during different seasons is found to be decreasing, indicating that the natural seasonal distribution of rainfall in Gurgaon is gradually changing. The variability in annual rainfall has increased in the post-1980 period at both seasonal and monthly scales.

Hyderabad, situated in the semi-arid Deccan plateau, has a predominantly tropical wet and dry climate. Temperatures in the hottest and coldest months of May and January vary from 26-38.8^{0}C and 14.7-28.6^{0}C, respectively. The average annual rainfall in Hyderabad is 828 mm, 74% of which occurs in the monsoon months of June-September. Analysis results of secondary data indicate an increasing trend in temperature. The monthly mean maximum temperature is increasing in both the overall analysis period (1951-2010 and the recent years (1980-2010). At seasonal scale, pre-monsoon season exhibits the highest temperatures among all the seasons. The intra-year variability in minimum temperature is found to be decreasing at Hyderabad. Long-term maximum data also indicate a decreasing trend in intra-year variability which is supported by the data since 1991. This means that unlike Gurgaon, the day temperatures in Hyderabad are becoming similar whereas the ranges in night-time temperatures are increasing. It is also evident that variability in mean seasonal and annual maximum and minimum temperatures has decreased in the post-1980 period. The inter-year variability in rainfall has increased in the post-1980 period although the annual rainfall has slightly increasing trend.

It is evident that temperature is rising in all four locations. Rising trends in temperature are observed in general at annual, seasonal and monthly scales, while year-to-year or seasonal variability is also increasing in some locations. May and January are approximately the hottest and coldest months, respectively. Trends in annual rainfall vary widely across the region. Khulna is experiencing increasing rainfall whereas rainfall in Gurgaon has a decreasing trend. Annual rainfall trends in Kathmandu and Hyderabad are almost static. There is, however, an increasing trend in annual number of rainy days in all four locations. For Gurgaon, Hyderabad and Kathmandu, where the annual rainfall is either decreasing or static, this means less rainfall intensity distributed over the year. Variability in short-term rainfall will directly affect water availability and balance in the hydrologic cycle.

These climatic changes in the four peri-urban locations of South Asia may have significant impacts on the biophysical systems that have considerable socio-economic implications, which are also perceived by the peri-urban residents. Rising temperature will increase soil evaporation and result in a decrease in the growth and yield of winter crops. Increasing extreme temperatures will cause heat waves, discomfort, reduction in working hours, and increase in pests. Rising temperatures also have direct impacts on human health and well being. Higher temperatures in the monsoon will create an environment favorable to spread of infectious diseases. Decreasing annual and seasonal rainfalls will have direct impact on surface and groundwater availability, soil moisture and groundwater recharge, affecting agricultural production, domestic water supply and irrigation. Increasing rainfalls will be beneficial for aman crop and flushing of soil salinity, but may have adverse impact on soil drainage and rainfall flooding.

Peri-urban residents perceive climatic trends and variability in timeline and seasonality. Most people can relate these changes with the onset and offset of monsoon, water bodies and springs, groundwater level, crop yield, fog and frost, pest attacks, heat waves, and work stress. These perceptions are in general agreement with the impacts and implications inferred from the secondary data analysis.

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