Characterizing Long-term Changes of Bangladesh Climate in Context of Agriculture and Irrigation

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Climate Change Cell
Department of Environment

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Foreword

The impacts of global warming and climate change are worldwide. For Bangladesh they are most critical because of its geographical location, high population density, high levels of poverty, and the reliance of many livelihoods on climate-sensitive sectors, such as agriculture, fisheries.

To address current impacts and manage future risks of climate change and variability towards development of a climate resilient Bangladesh, the government has established the Climate Change Cell (CCC) in the Department of Environment (DoE) under the Comprehensive Disaster Management Programme (CDMP). Climate change research, covering modeling and adaptation is one of the major activities of the Cell.

CCC in association with its Technical Advisory Group (TAG) and other stakeholders identified a set of research activities related to climate change in Bangladesh through a number of consultations. The activities have been prioritized and a number of projects have been commissioned in last few years.

Systematic observations of meteorological and hydrological information are a precondition to estimate and forecast hazard risks and vulnerabilities. For Bangladesh, this is critical, as both climate variability and change are strongly evidenced. Weather patterns, seasonal variations are becoming increasingly erratic, hence uncertainty becoming the order of the day. The agricultural sector of Bangladesh is under a great threat due to the changes in the climatic parameters. To understand the current situation and predictions of future scenarios to assess the impacts of climate change on agriculture, analysis of previous trends of different climatic parameters is essential.

The study attempted to characterize the spatial and temporal changes in long-term climate of Bangladesh using the measured data available with the Bangladesh Meteorological Department (BMD) at different locations of Bangladesh (8 out of 34 BMD stations) as well as to evaluate how the changes in climate might affect local irrigated and rain-fed agriculture.

The report revealed that trend of rainfall is increasing during summer and winter for the entire country, while is decreasing during monsoon. The trend of temperature in general, both maximum and minimum is increasing except in the winter season. The average sunshine duration in Bangladesh is declining at an alarming rate which results in decreasing crop evapotranspiration although temperatures have rising trends.

The study is the first step in long-term trend analysis of climatic parameters, and is expected to create opportunity for the researchers, practitioners and other stakeholders to share the results. This report may serve as a base document for updating of future projections in light of the existing trends. However, as this study used data from some selected stations, analysis of data of other stations should be carried out. Such analysis will facilitate policy makers and planners to formulate viable adaptation policies, strategies and action plan to combat climate change at national level.

Zafar Ahmed Khan, PhD
Director General
Department of Environment

Acronyms and Abbreviations

BMD	Bangladesh Meteorological Department
BWDB	Bangladesh Water Development Board
CEGIS	Center for Environmental and Geographic Information Services
ET	Evapotranspiration
FAO	Food and Agricultural Organization (of the United Nations)
GCM	General Circulation Models
IPCC	Intergovernmental Panel on Climate Change
IWFM	Institute of Water and Flood Management
NIR	Net Irrigation Requirement
SPSS	Statistical Package for Social Sciences
TAG	Technical Advisory Group

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Executive Summary

Long-term changes and trends in climatic variables, such as rainfall, temperature, sunshine duration and evaporation, have been investigated in this report. The data used for the study are from the BMD (Bangladesh Meteorological Department) except for evaporation for which BWDB (Bangladesh Water Development Board) data were used. BMD data were available for 34 stations of Bangladesh. Daily maximum and minimum temperature (1948-2007) and sunshine duration (1961-2007) data available at all these stations were analyzed. However, rainfall data (1960-2001) could be analyzed only for eight stations, namely Faridpur, Jessore, Bogra, Dhaka, Mymensingh, Sylhet, Chandpur and Chittagong, due to the limited time available for completion of the study after the receipt of the recent data from the Climate Change Cell of the Department of Environment. Evaporation data were analyzed for 11 BWDB stations (Faridpur, Jessore, Bogra, Sirajganj, Dhaka, Mymensingh, Sylhet, Srimangal, Comilla, Noakhali and Chittagong). The data for this study were available from Climate Change Cell, Center for Environmental and Geographic Information Services, Institute of Water and Flood Management, and also some data directly from BMD.

The rainfalls during the summer (March-May) and critical period (11 March-10 May) were found to have increased at all the eight stations. The rainfall during the winter (November-February) has also increased except at Sylhet. The statistics about the monsoon (June-October) rainfall are mixed – rainfalls have decreased at 5 stations and increased at 3 stations. For entire Bangladesh, the trends in seasonal rainfall totals are about 9 mm, 38 mm, -10 mm and 18 mm per decade (10 years) in the winter, summer, monsoon and critical period, respectively. It thus appears that the seasonal rainfalls have in general increasing trends except at monsoon. These findings are consistent with the findings of Mondal and Wasimi (2004) who have analyzed the seasonal rainfall data of the Ganges basin within Bangladesh and Rahman et al. (1997) who have analyzed the monsoon rainfall data at 12 stations of Bangladesh and found no conclusive evidence of any changing pattern of monsoon rainfall. The findings are also consistent with the findings of Singh and Sontakke (2002) who found a decreasing trend (statistically insignificant) in monsoon rainfall over central and eastern Indo-Gangetic plain. However, the findings are not consistent with the IPCC (2007) projections for winter and monsoon rainfalls. The IPCC has projected a decrease in winter rainfall and an increase in monsoon rainfall which is the reverse of the current trend. It is to be noted that the IPCC projection is for entire South Asia and not for Bangladesh alone. From the analysis of monthly and 10-day data, it is found that the monsoon may have weakened at the earlier months (June-July) of the season and strengthened during the later months (September). Analysis of annual maximum and 7-day moving average maximum rainfalls indicate mixed trends. The increasing trends in annual maximum rainfalls are identified at Chittagong, Sylhet, Mymensingh and Bogra stations which are eventually the path of traverse of the south-westerly monsoon wind. This indicates that the intensity of heavy rainfall may have increased along the main route of the monsoon wind; this needs however further study including recent data and more stations.

Annual and seasonal mean temperatures are found to have in general increasing trends in Bangladesh. The magnitudes of the trends are dependent on the period of analysis of the available data. The overall trend in mean annual temperature is found to be +0.10 and +0.21 ^{0}C per decade (equivalent to +1.03 and +2.14 ^{0}C per century) for data periods of 1948-2007 and 1980-2007, respectively. It thus appears that the warming has been more rapid in the recent decades. At seasonal time scales, the warming has strengthened in both summer and monsoon seasons and weakened in winter season over last three decades or so. The rise in mean annual temperature projected by IPCC (2007) for South Asia is 3.3 ^{0}C with a range of 2.0-4.7 ^{0}C. Thus, the current trend is at the lower end of the IPCC projection. However, it is clear that the use of the recent data, rather than the long-term data, provide results which are closer to the IPCC projection. Also, the IPCC projection is not unrealistic in that the recent trends are higher than the past and it may further strengthen in the future.

Other than the mean temperature, the maximum and minimum temperatures were also analyzed and the results are reported in the main text. Both maximum and minimum temperature, and hence the mean temperature, have decreasing trends in the month of January, which is the peak winter month. This indicates that the peak winter is becoming cooler day by day.

Season	Trend of mean temperature (^{0}C per century) in Bangladesh	
	for data period of 1948-2007	for data period of 1980-2007
Winter (Nov-Feb)	+1.67	+1.33
Summer (Mar-May)	+0.26	+2.15
Monsoon (Jun-Oct)	+1.05	+2.44
Annual (Jan-Dec)	+1.03	+2.14

The analysis of sunshine duration data reveals that the winter, dry season, summer and monsoon sunshines are declining at a rate of 5.7%, 5.0%, 3.9% and 3.8% respectively in every 10 years for the entire Bangladesh. The overall annual decrease for the entire Bangladesh is about 0.36 hours a day in every 10 years. This rate of decline in annual sunshine hour is equal to 4.7% a decade. There are some spatial patterns in the declining rates – the rates increased from south to north and east to west. The mean sunshine durations in the first 10-day period of January, for example, were 8.9, 9.2 and 9.0 hours a day during the period of 1961-1975 and these came down to 5.9, 6.2 and 5.8 hours a day during the period of 1991-2006 in Dhaka, Jessore and Bogra, respectively. This declining rate is very high and is really a matter of great concern for agriculture and health sectors in particular. The dimming trend is in general opposite to the rainfall trend.

Season	Decrease in mean sunshine duration per decade in Bangladesh
Winter (Nov-Feb)	5.7%
Summer (Mar-May)	3.9%
Dry Season (Nov-May)	5.0%
Monsoon (Jun-Oct)	3.8%
Annual (Jan-Dec)	4.7%

Crop evapotranspiration (ET_c) depends on temperature, sunshine, humidity and wind condition. In this study, ET_c was estimated using all these factors and the FAO recommended Penman-Monteith method. The crop evapotranspiration during the dry season is found to be decreasing. This is mainly due to the decreasing sunshine duration, though temperatures have rising trends. The net irrigation requirement during the dry season is also decreasing due to decreasing ET_c and increasing rainfall trends. The crop yield may be decreasing due to the reduced photosynthesis and this needs further study.

1 Introduction

The overall objective of this study is to characterize the spatial and temporal changes in long-term climate of Bangladesh using the measured data available with Bangladesh Meteorological Department (BMD) at different locations of Bangladesh. How the changes in climatic variables might affect irrigation requirement and agricultural production are also investigated in the study. This would allow the development of appropriate adaptation and climate risk management strategies. The specific objectives of the study are:

- Evaluation of long-term changes in rainfalls at different stations of the BMD. Annual, seasonal (monsoon, pre-monsoon, post-monsoon, winter, dry season and critical period), monthly and 10-day trends are assessed. Trends in annual maximum and 7-day cumulative maximum rainfalls are also evaluated.
- Evaluation of long-term changes in air temperature (maximum, minimum and average) at different stations of the BMD. Annual, seasonal (monsoon, pre-monsoon, post-monsoon, winter, dry season and critical period), monthly and 10-day trends have been assessed.
- Evaluation of long-term changes in solar radiation at different stations of the BMD. Annual, seasonal (monsoon, pre-monsoon, post-monsoon, winter, dry season and critical period), monthly and 10-day changes have been assessed.
- Evaluation of long-term changes in evaporation at different stations of the Bangladesh Water Development Board (BWDB). Annual, seasonal (monsoon, pre-monsoon, post-monsoon, winter, dry season and critical period), monthly and 10-day trends have been assessed.
- Characterization of regional and all-Bangladesh changes in rainfall patterns at different temporal resolution.
- Characterization of regional and all-Bangladesh changes in air temperature patterns at different temporal resolution.
- Characterization of regional and all-Bangladesh changes in incoming solar radiation patterns at different temporal resolution.
- Characterization of regional and all-Bangladesh changes in evaporation patterns at different temporal resolution.
- Assessment of possible impacts of climate changes on irrigation water demand and agricultural production.

The data for the study were collected from the Climate Change Cell of the Department of Environment as well as from the Center for Environmental and Geographic Information Services. The data were initially available for a period of 42 years ranging from 1960 to 2001. The updated sunshine duration data (upto 2006) were collected from the Institute of Water and Flood Management (IWFM). These data are primarily recorded and maintained by BMD.

There are about 34 BMD hydro-meteorological stations in Bangladesh to collect rainfall, temperature, sunshine duration and evaporation data. To reduce the analysis volume, only some selected locations spread over Bangladesh have been considered for hydro-meteorological trend analysis. Bangladesh is divided into eight hydrological regions for planning purposes. One of the regions is the River-Estuary region, which is basically a running water region. One climatic station was selected for analysis from each of the remaining seven regions. The stations are Faridpur, Jessore, Bogra, Mymensingh, Sylhet, Chandpur and Chittagong from the southcentral, southwest, northwest, northcentral, northeast, southeast and eastern hilly regions, respectively. In addition, Dhaka station was selected. The locations of the stations are shown in Figure 1.

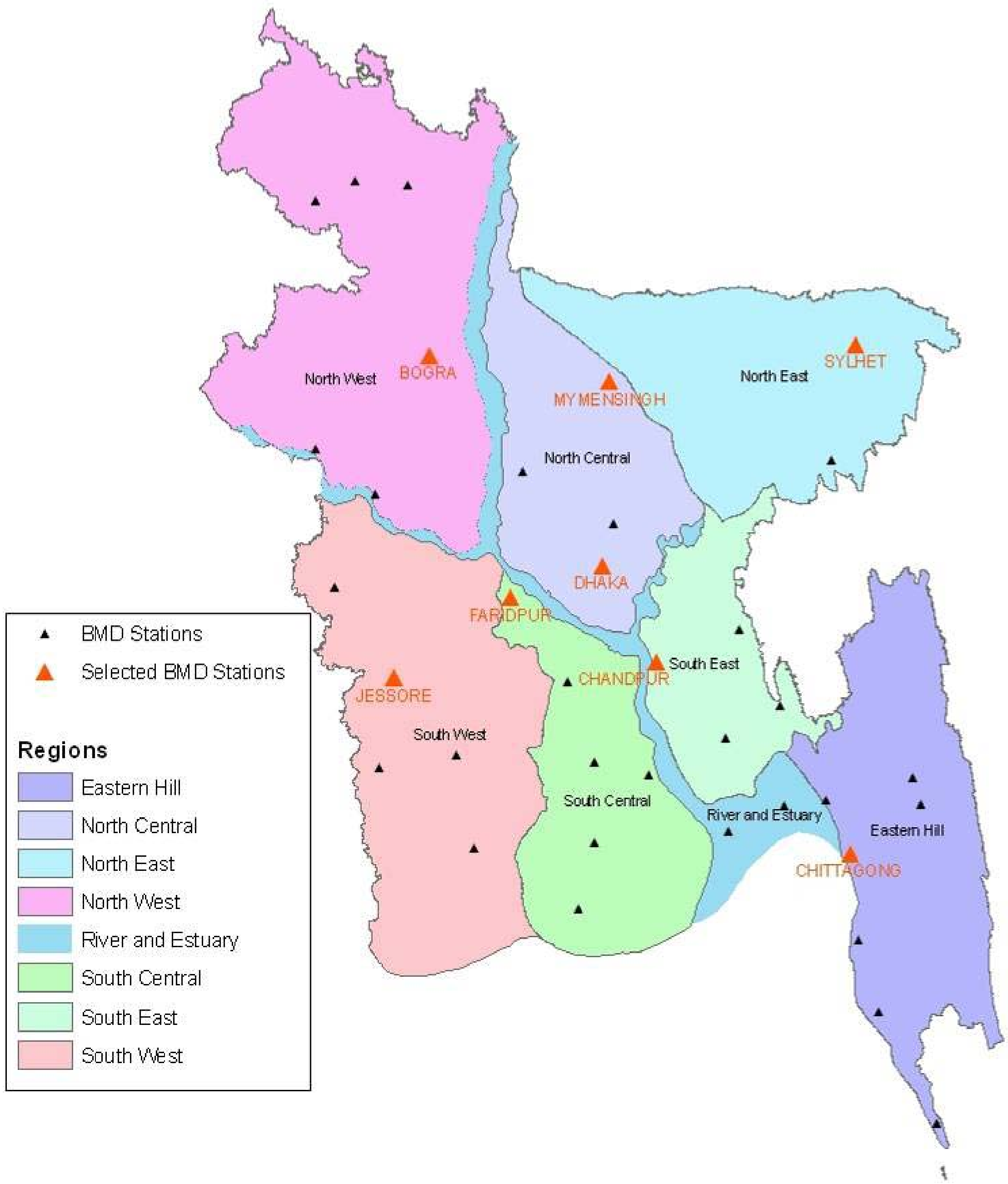

Figure 1: Locations of the BMD stations selected for rainfall analysis (temperature and sunshine duration were analyzed for all BMD stations).

A presentation based on the draft final report (submitted in March 2008) of the study was made at the TAG (Technical Advisory Group) workshop on 'Adaptation Research Activities to Climate Change' organized by the Climate Change Cell of DoE on 26 June, 2008. Based on the recommendations received from the workshop and also from the peer reviewer, the report has been updated with recent meteorological data supplied by Climate Change Cell. The analysis of temperature has been updated using data from 1948-2007 for all 34 stations. The analysis of sunshine duration has also been updated using data from 1961-2007 for all 34 stations. The analysis of rainfall could not be updated due to limited time availability.

The trend analyses of the variables were done using the Statistical Package for Social Sciences (SPSS) software. The results of rainfall, temperature, sunshine duration and evaporation analyses are reported in the next sections, and following that, the possible impacts of the changes in these variables on irrigation water demand and crop production are discussed.

2 Trends in Rainfalls

To analyze the long-term changes in rainfall at different stations of Bangladesh, the data were divided into two halves, each with 21 years of records. The first half is from 1960 to 1980 and the second half is from 1981 to 2001. The average rainfalls during these two halves are given in Figures 2, 3, 4 and 5 for the winter (November-February), summer (March-May), critical period (11 March-10 May) and monsoon (June-October) seasons, respectively. The average and standard deviation of measured rainfalls during these two halves are given in Tables 1, 2, 3 and 4 and Figures 6, 7, 8 and 9 for the winter, summer, critical period and monsoon seasons, respectively.

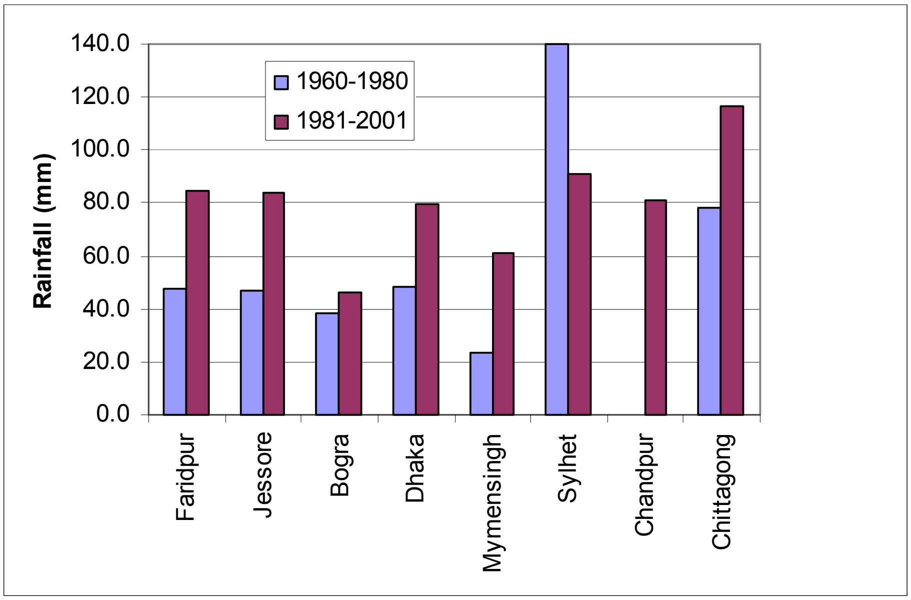

Figure 2: Mean winter rainfalls at different stations of Bangladesh during 1960-1980 and 1981-2001

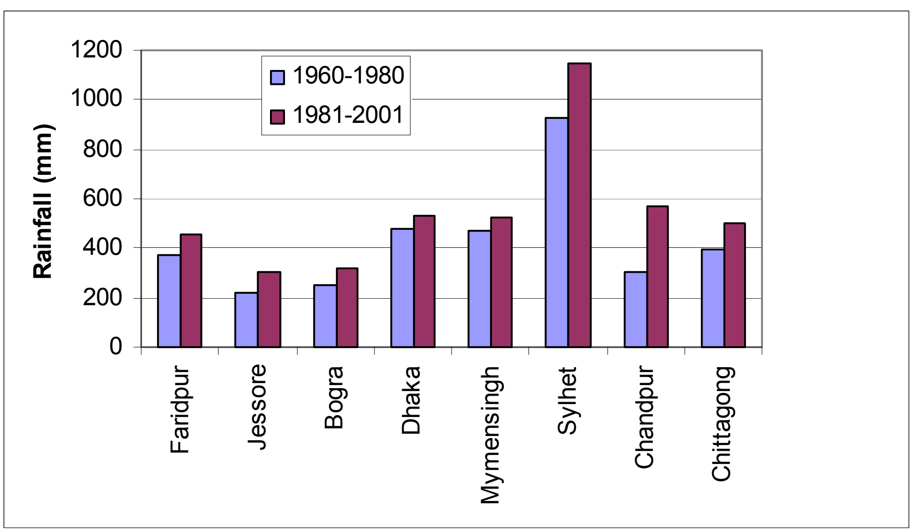

Figure 3: Mean summer rainfalls at different stations of Bangladesh during 1960-1980 and 1981-2001

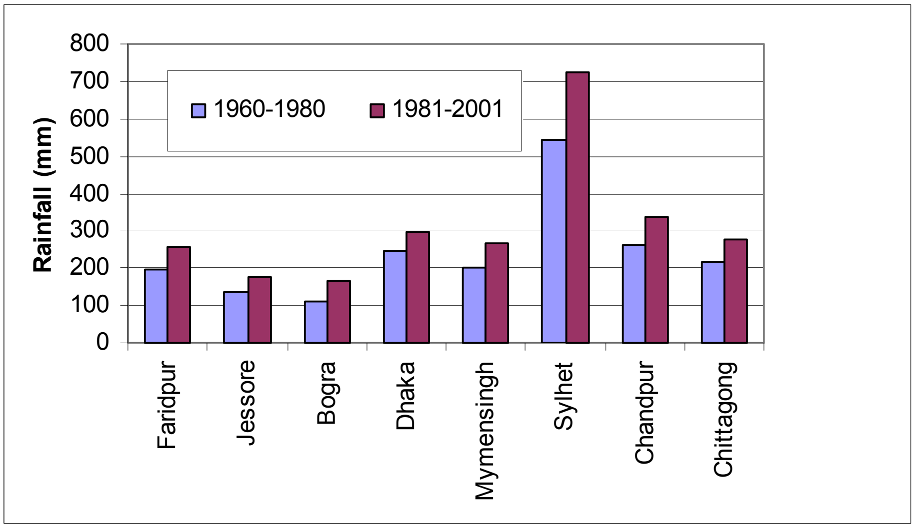

Figure 4: Mean critical period rainfalls at different stations of Bangladesh during 1960-1980 and 1981-2001

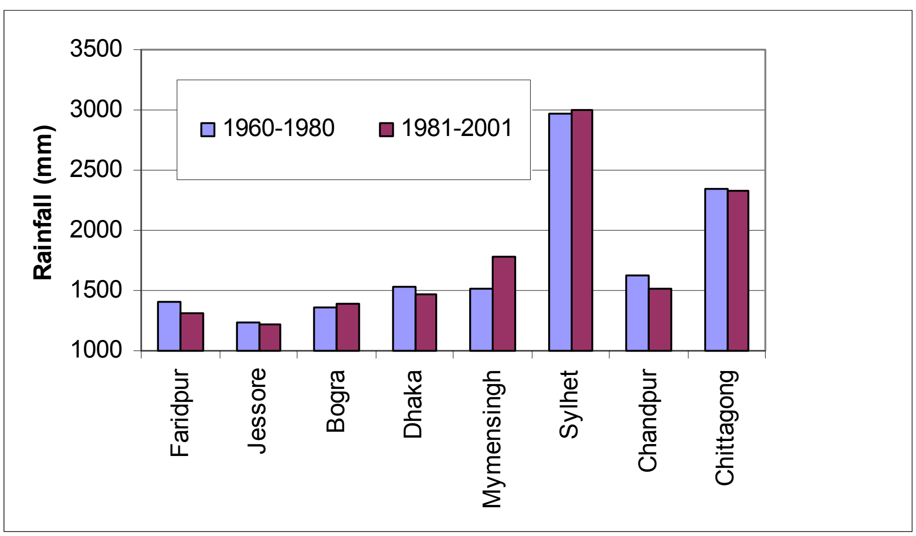

Figure 5: Mean monsoon rainfalls at different stations of Bangladesh during 1960-1980 and 1981-2001

Table 1: Mean and standard deviation of the winter rainfalls at different stations of Bangladesh

Station	**1960-1980**		**1981-2001**		**Difference**	
	Mean (mm)	**Standard Deviation (mm)**	**Mean (mm)**	**Standard Deviation (mm)**	**Change in Mean**	**Change in Std. Deviation**
Faridpur	47.6	44.3	84.7	58.2	78%	13.9%
Jessore	47.2	36.2	84.2	59.6	78%	23.4%
Bogra	38.1	23.3	46.1	36.5	21%	13.2%
Dhaka	48.2	38.4	79.6	51.9	65%	13.5%
Mymensingh	23.1	17.4	60.7	41.2	163%	23.8%
Sylhet	139.9	195.5	90.7	58.9	-35%	-136.6%
Chandpur	-	-	80.7	60.9		
Chittagong	77.9	83.7	116.7	114.9	50%	31.2%
Bangladesh	**60.3**	**62.7**	**80.4**	**60.3**	**33%**	**-2.4%**

Table 2: Mean and standard deviation of the summer rainfalls at different stations of Bangladesh

Station	**1960-1980**		**1981-2001**	
	Mean (mm)	**Standard Deviation (mm)**	**Mean (mm)**	**Standard Deviation (mm)**
Faridpur	371.3	163.0	453.0	152.6
Jessore	219.5	111.7	304.2	117.2
Bogra	251.6	136.7	321.6	139.8
Dhaka	478.6	177.8	529.3	189.7
Mymensingh	472.5	245.5	526.0	204.2
Sylhet	923.2	271.7	1148.6	344.2
Chandpur	305.0	143.9	566.0	364.8
Chittagong	398.3	173.4	503.0	236.9
Bangladesh	**427.5**	**178.0**	**544.0**	**218.7**

Table 3: Mean and standard deviation of the critical period rainfalls at different stations of Bangladesh

Station	1960-1980		1981-2001	
	Mean (mm)	Standard Deviation (mm)	Mean (mm)	Standard Deviation (mm)
Faridpur	196.2	99.3	257.4	126.0
Jessore	135.4	70.0	175.4	104.3
Bogra	108.2	92.0	165.4	98.4
Dhaka	244.9	127.2	298.7	149.2
Mymensingh	202.6	106.5	264.6	118.8
Sylhet	542.4	243.2	725.3	248.9
Chandpur	260.6	162.2	339.2	268.3
Chittagong	214.6	146.2	277.5	187.3
Bangladesh	**238.1**	**130.8**	**312.9**	**162.7**

Table 4: Mean and standard deviation of the monsoon rainfalls at different stations of Bangladesh

Station	1960-1980		1981-2001	
	Mean (mm)	Standard Deviation (mm)	Mean (mm)	Standard Deviation (mm)
Faridpur	1399	219	1310 (↓)	295
Jessore	1233	291	1213 (↓)	263
Bogra	1367	374	1389 (↑)	443
Dhaka	1526	168	1464 (↓)	336
Mymensingh	1517	417	1787 (↑)	401
Sylhet	2977	670	3006 (↑)	536
Chandpur	1625	129	1518 (↓)	471
Chittagong	2340	464	2323 (↓)	512
Bangladesh	**1748**	**342**	**1751**	**407**

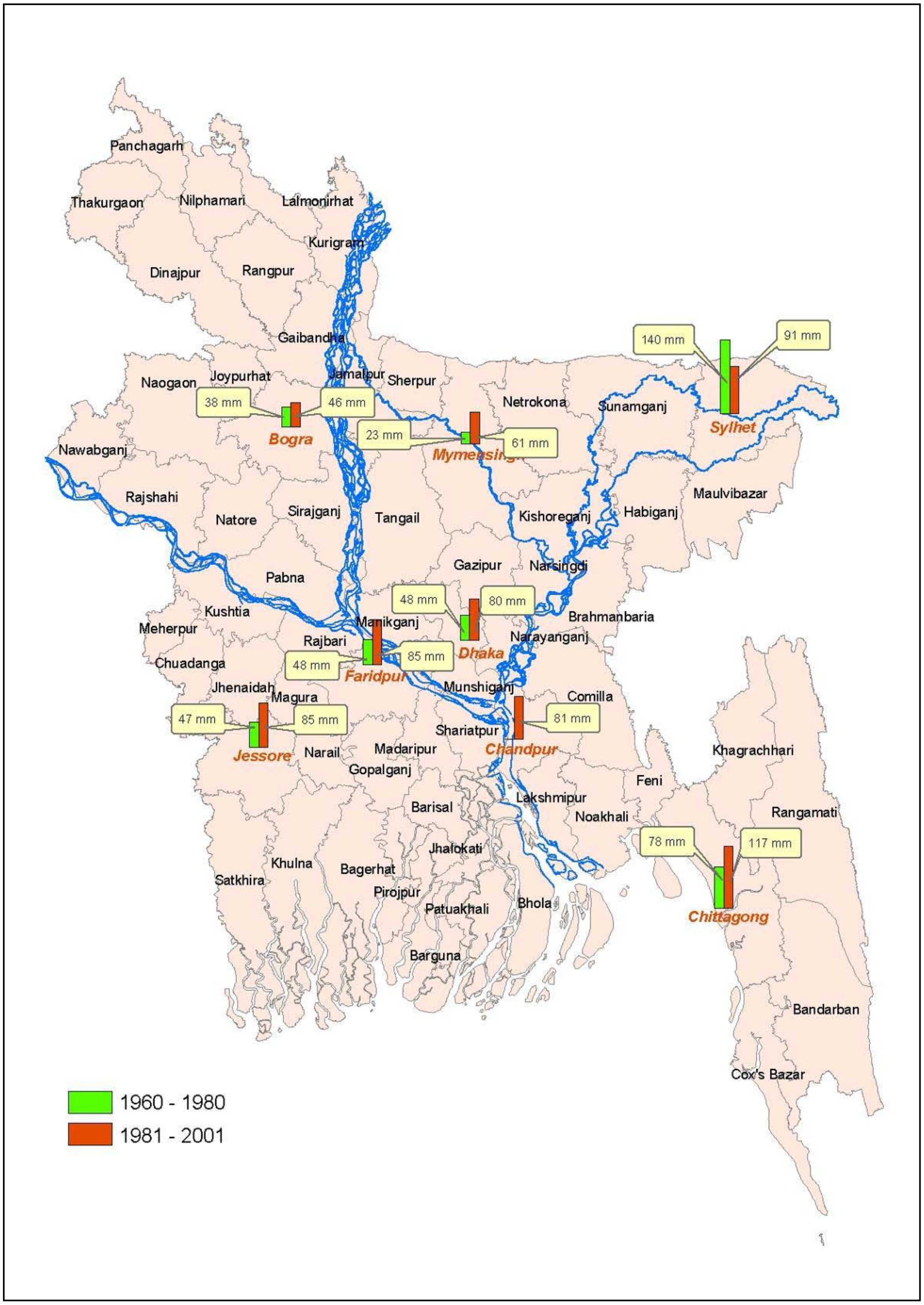

Figure 6: Mean winter rainfalls at different BMD stations of Bangladesh (Data from Table 1)

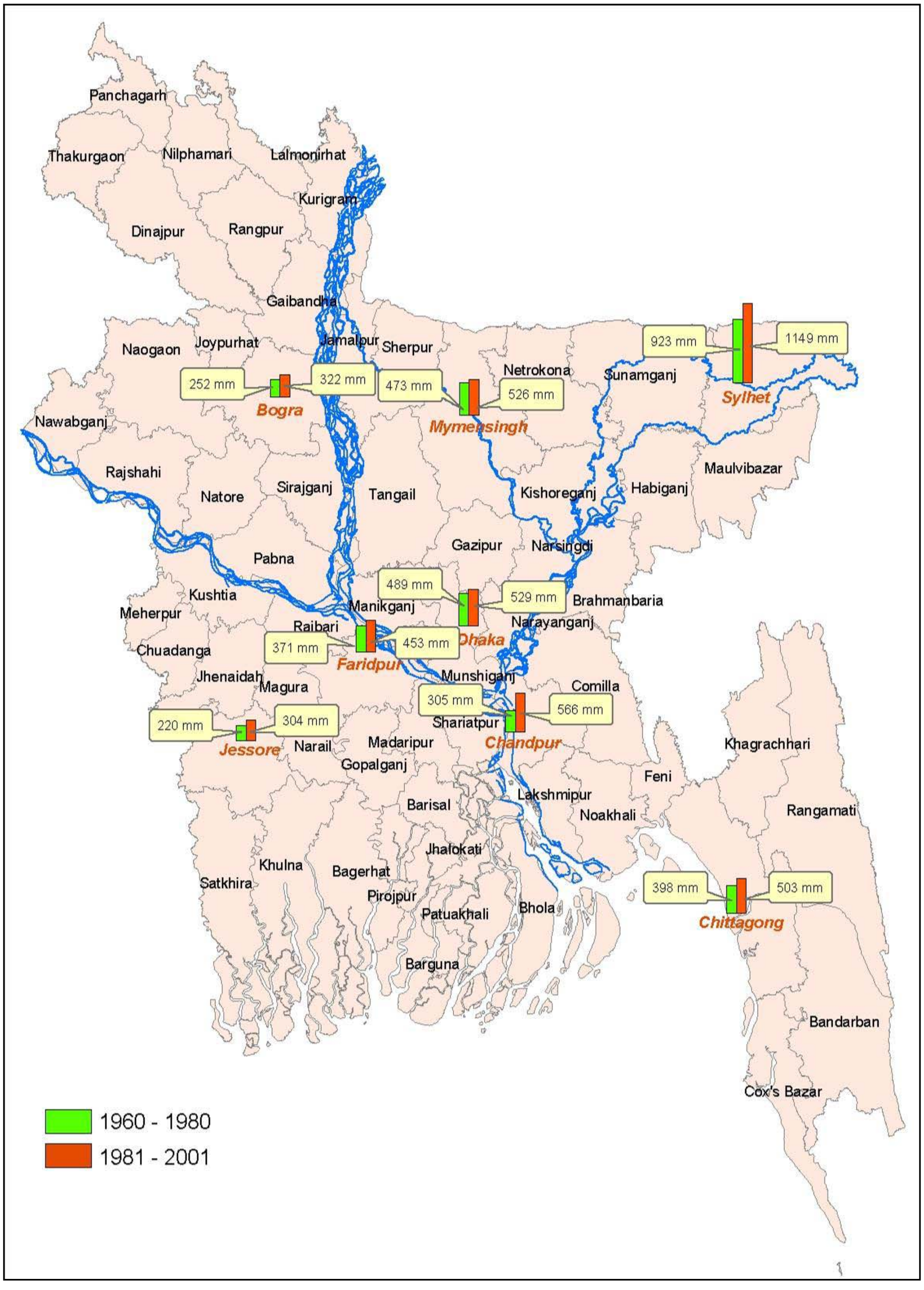

Figure 7: Mean rainfalls during the summer at different stations of Bangladesh (data from Table 2)

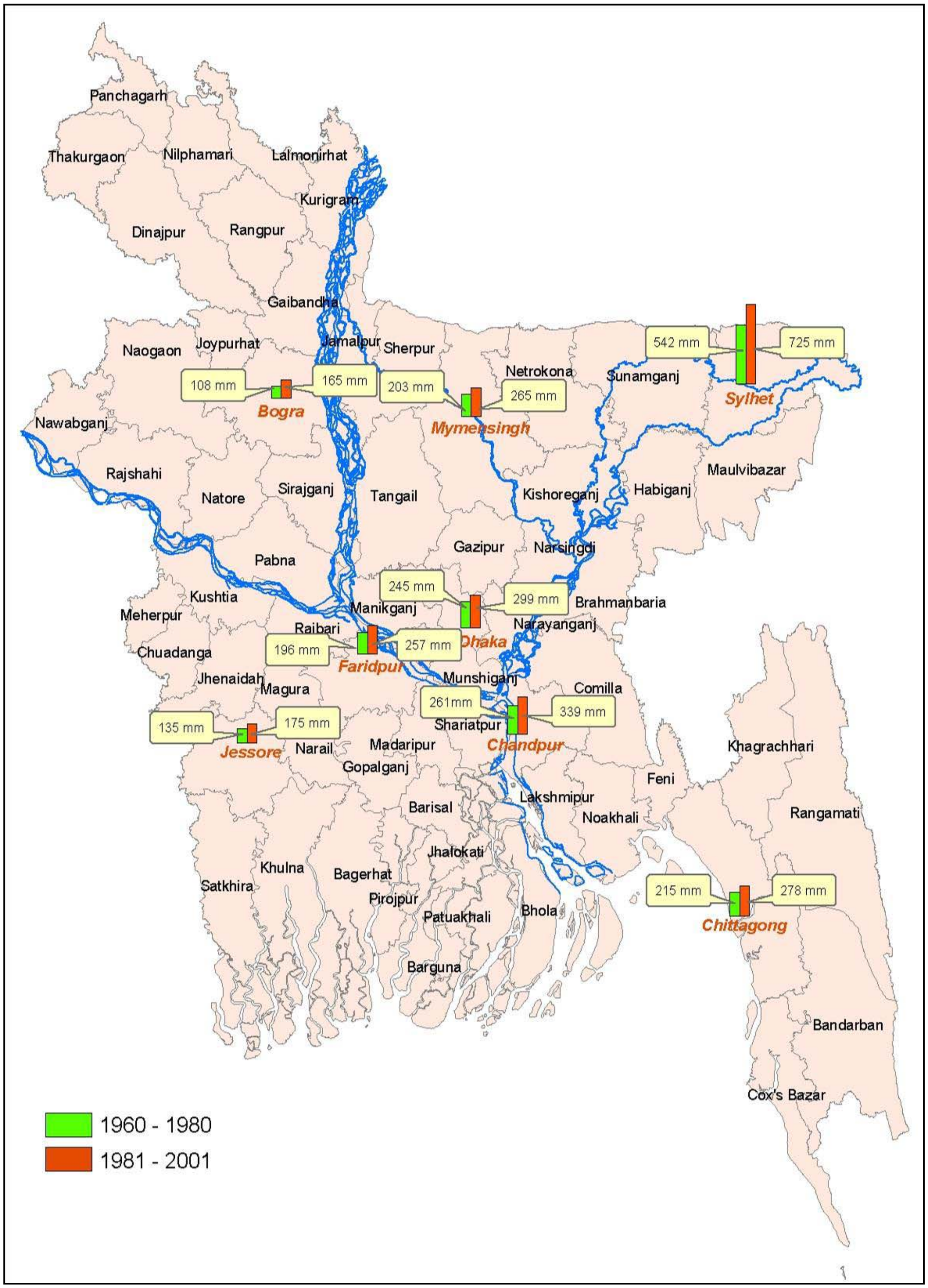

Figure 8: Critical period mean rainfalls at different BMD stations of Bangladesh (data from Table 3)

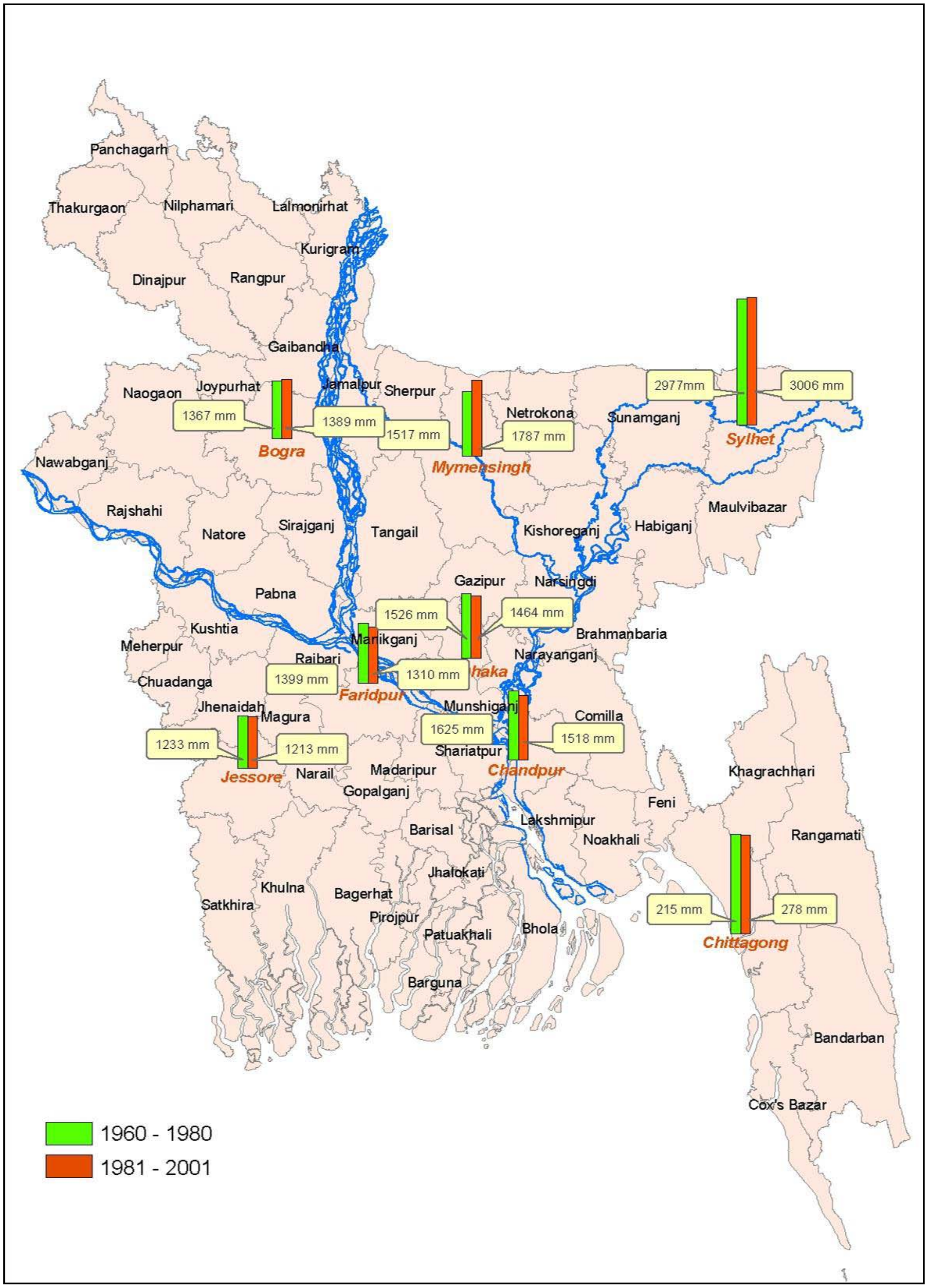

Figure 9: Mean of the monsoon rainfalls at different stations of Bangladesh (data from Table 4)

It is seen from Figures 2 and 6 and Table 1 that the winter rainfalls are higher during the second half of the available time series compared to the first half, the only exception is Sylhet where it reduces by 35%. The variability, measured in terms of the standard deviation, has also increased except Sylhet. For the summer, the rainfall has increased at all stations and there is no ambiguity about this increase (Figures 3 and 7, and Table 2). The critical period rainfall has also increased at all the stations and this increase is also unambiguous (Figures 4 and 8, and Table 3). The statistics about monsoon rainfalls are mixed – rainfalls have decreased at five stations and increased at 3 stations (Figures 5 and 9, and Table 4). The stations, which show increases, are Bogra, Mymensingh and Sylhet. It is to be noted that these stations are located to the north compared to the rest of the stations. Thus, it appears that the monsoon rainfalls have increased in the northern part of the country and decreased in the southern and central parts.

The linear trends in rainfalls per decade (10 years) at different seasons for the entire time series (1960-2001) are shown in Table 5 and Figure 10. The decadal trend was estimated simply by multiplying the annual trend with the number of years. It is seen from the table that the rainfalls have increasing trends at all stations during both summer and critical period. The winter rainfalls have also increasing trends except for Sylhet. The monsoon has in general decreasing trend, except at Bogra and Mymensingh.

Table 5: Trends in seasonal rainfalls (mm/decade) at different stations of Bangladesh

Season	Farid-pur	Jessore	Bogra	Dhaka	Mymen-singh	Sylhet	Chand-pur	Chitta-gong	Bangladesh
Winter	13.18	9.99	3.49	13.24	11.76	-20.33	23.38	19.89	**9.33**
Summer	28.48	19.86	31.51	27.90	32.64	82.45	15.43	63.89	**37.77**
Mon-soon	-15.13	-3.55	44.28	-26.90	37.16	-6.32	-84.00	-28.82	**-10.41**
Critical Period	10.87	1.28	28.88	15.75	28.61	68.26	-	16.10	**18.20**

Table 6: Trends in monthly rainfalls (mm/decade) at different stations of Bangladesh

Month	Farid-pur	Jessore	Bogra	Dhaka	Mymen-singh	Sylhet	Chand-pur	Chitta-gong	Bangladesh
Jan	1.65	0.59	0.19	1.71	0.64	-0.16	0.08	0.99	**0.71**
Feb	4.71	2.20	1.57	3.07	2.56	-8.27	10.70	8.54	**3.14**
Mar	4.97	-4.30	-1.02	9.23	2.67	34.09	-6.95	2.26	**5.12**
Apr	4.11	-0.33	18.96	0.41	21.47	13.83	-10.35	9.47	**7.20**
May	**23.57**	**25.92**	**21.60**	**26.55**	**16.32**	**24.60**	**34.20**	**54.94**	**28.46**
Jun	-23.70	10.86	10.40	-36.29	-17.13	-18.17	-27.66	-13.77	**-14.43**
Jul	**-28.61**	**-11.07**	**-10.86**	**-13.83**	3.54	**-2.34**	**-2.16**	**-35.04**	**-12.55**
Aug	11.95	-5.97	-4.65	-2.13	5.66	0.03	3.19	27.92	**4.50**
Sep	**9.77**	**14.57**	**35.93**	**10.81**	**15.48**	**39.61**	-9.57	**6.81**	**15.43**
Oct	9.83	-13.93	12.56	17.13	17.93	1.22	-9.80	5.22	**5.02**
Nov	4.23	5.52	-0.06	2.82	0.46	0.06	7.60	8.33	**3.62**
Dec	1.26	1.57	2.01	1.02	1.56	2.47	0.46	2.44	**1.60**

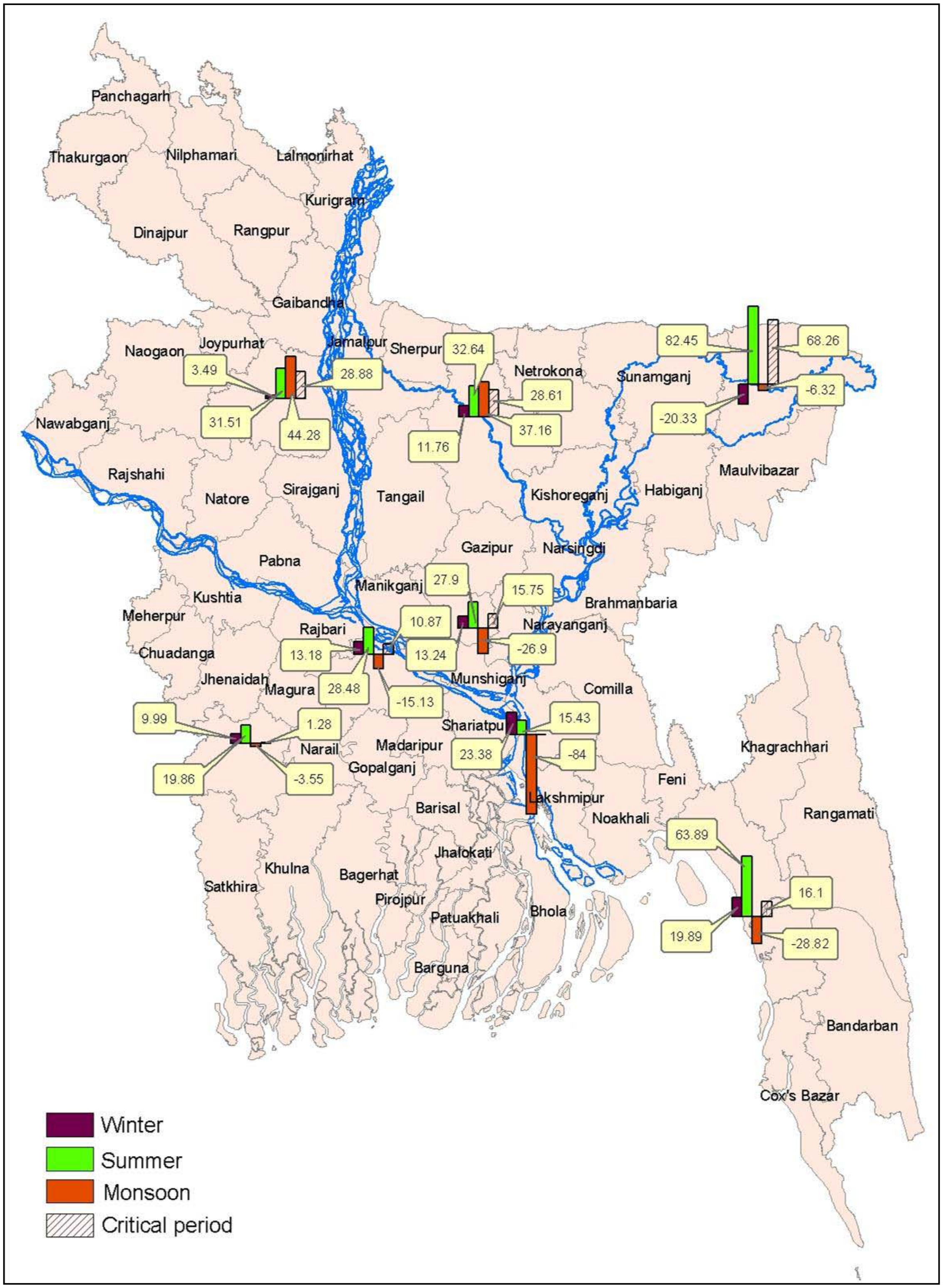

Figure 10: Trends in seasonal rainfalls (mm/decade) at different stations of Bangladesh (data from Table 5)

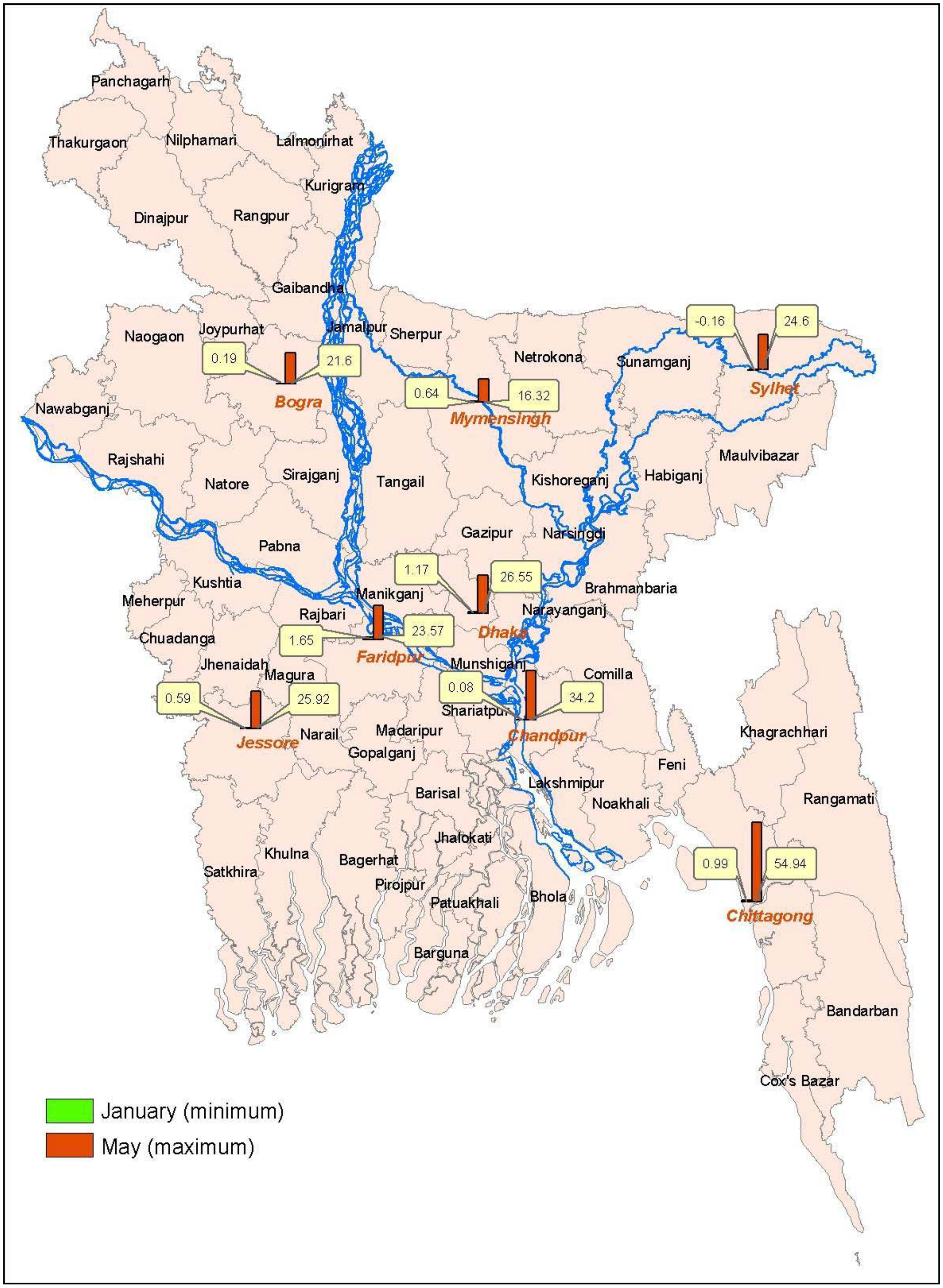

Figure 11: Trends in monthly rainfall (mm/decade) for two months (minimum and maximum) at different stations of Bangladesh (data from Table 6)

The trends in monthly rainfalls are shown in Table 6 and Figure 11. It is seen in the table that the rainfall in the month of May has an increasing trend at all stations. The month of July, which is the month of highest rainfall, has decreasing trend at seven stations, out of eight. The month of June has also decreasing trend at six stations. On the other hand, the month of September has increasing trends at seven stations. This intra-year variability in trends suggests that the monsoon may have weakened at the earlier months of the season and strengthened during the later months. The transplanting of the Aman rice during mid-July to mid-August could be delayed or negatively affected by this shift in rainfall pattern. This may put extra burden on the farmers as they may require more expenses on fuel and electricity for operation of tubewells for land preparation and transplanting purposes. The Aman rice production of the country could be negatively affected by this.

To gain further insights about the trend and shift in the rainfalls, 10-day rainfall trends were also investigated. The estimated trends are reported for the third 10-day of March (Mar III) to the third 10-day of October in Table 7 and Figure 12. The trends for Nov I to Mar II are not shown as there are lot of zero rainfalls during these 10-days, and as such, the trends are not reliable.

Table 7: Trends in 10-day rainfalls (mm/decade) at different stations of Bangladesh

10-day Period	**Farid-pur**	**Jessore**	**Bogra**	**Dhaka**	**Mymen-singh**	**Sylhet**	**Chand-pur**	**Chitta-gong**	**Bangladesh**
Mar III	5.45	6.23	-0.55	8.24	5.50	29.57	1.38	6.76	**7.82**
Apr I	3.25	-0.15	3.50	-3.09	1.81	9.88	0.95	3.90	**2.51**
Apr II	*-3.85*	*-5.02*	*-1.33*	*-3.49*	8.80	*-14.42*	*-20.45*	*-10.87*	**-6.33**
Apr III	**4.09**	**4.95**	**16.58**	**9.11**	**9.92**	**18.54**	**12.58**	**17.30**	**11.63**
May I	**2.32**	**5.39**	**12.61**	**6.97**	**8.37**	**14.36**	**3.04**	**11.95**	**8.13**
May II	**9.96**	**13.34**	**3.84**	**10.33**	-2.51	**1.75**	**7.15**	**17.59**	**7.68**
May III	**10.95**	**9.22**	**5.26**	**9.49**	**17.35**	**8.64**	**18.41**	**34.19**	**14.19**
Jun I	-16.77	3.89	-8.09	-14.93	-7.61	7.76	16.26	-16.06	**-4.44**
Jun II	-12.53	-1.40	6.93	-21.72	-10.94	-33.26	-20.31	-26.40	**-14.95**
Jun III	**7.54**	**8.55**	**13.81**	**0.04**	**3.78**	**9.04**	**8.25**	**32.78**	**10.47**
Jul I	-6.38	-8.30	11.43	-0.57	7.72	5.86	24.46	3.66	**4.74**
Jul II	**-19.81**	**-10.47**	**-5.28**	**-16.74**	**-13.56**	-7.08	**13.08**	**-6.04**	**-8.24**
Jul III	-0.76	7.57	-11.51	3.26	13.21	-1.13	8.55	-21.10	**-0.24**
Aug I	0.08	-0.07	-4.79	-2.00	3.93	7.64	0.92	10.31	**2.00**
Aug II	15.41	-5.09	0.84	-1.24	-1.05	15.13	-3.01	20.61	**5.20**
Aug III	-2.64	-0.88	-4.13	1.10	6.72	-22.74	4.77	-5.92	**-2.97**
Sep I	2.73	2.71	13.25	8.89	8.33	-1.93	-1.72	1.74	**4.25**
Sep II	-1.60	9.46	9.47	-4.53	11.06	15.72	-14.43	1.36	**3.31**
Sep III	8.63	4.28	12.63	9.85	-3.77	26.83	11.30	0.24	**8.75**
Oct I	0.65	-12.57	8.71	-1.70	-3.43	0.80	-14.26	11.45	**-1.29**
Oct II	12.72	3.33	5.34	13.40	22.10	5.96	-2.85	5.55	**8.19**
Oct III	-3.54	-5.52	-1.75	5.69	1.07	-2.15	11.43	-13.25	**-1.00**

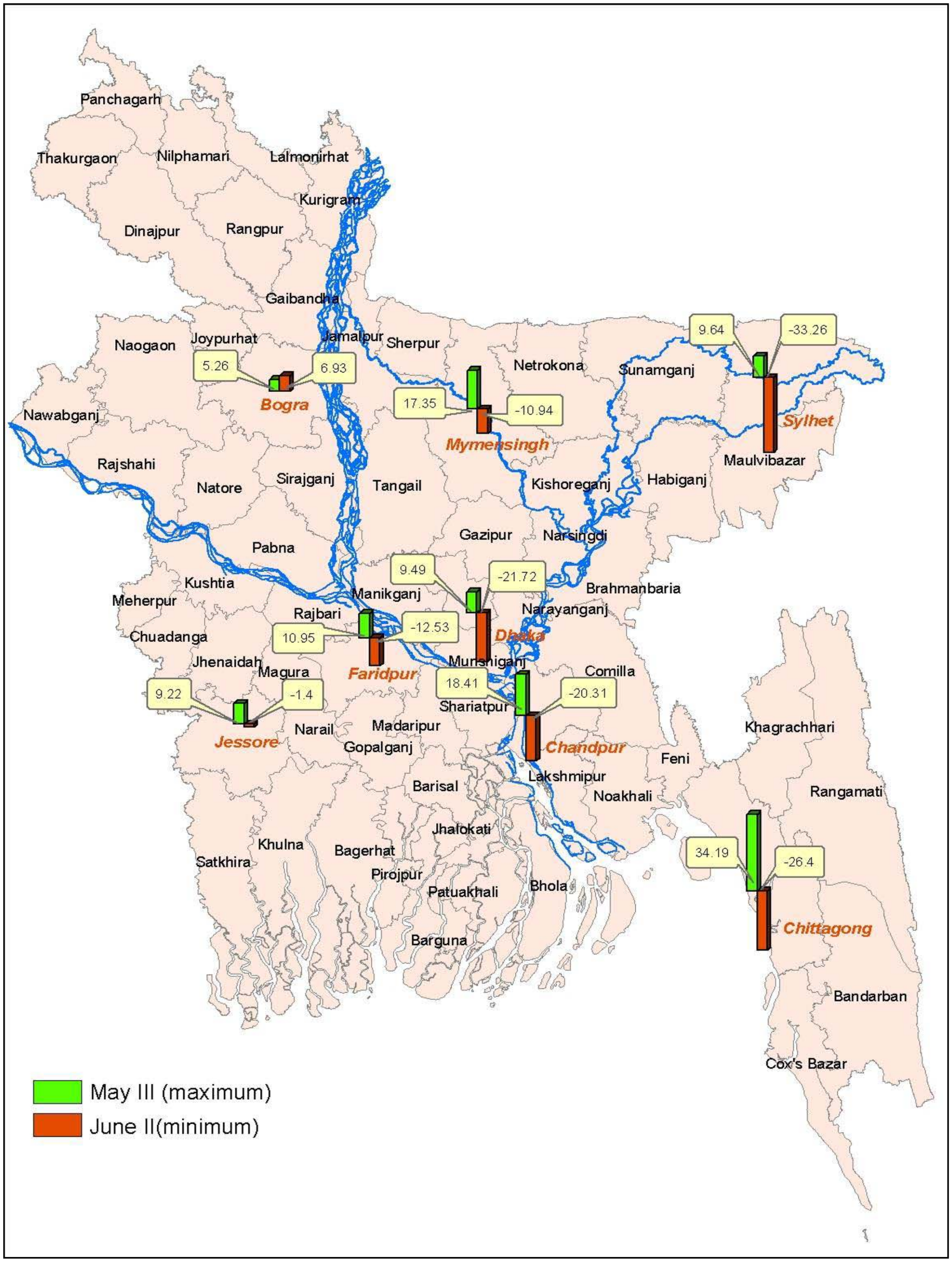

Figure 12: Trends in 10-day rainfall (mm/decade) for two months (minimum and maximum) at different stations of Bangladesh (data from Table 7)

It is seen in the Table 7 that the trends are positive at all stations during the four 10-days of Apr III to May III. This period is the harvesting time of Boro rice. The increase in rainfall during this period, though beneficial from irrigation point of view, could lead to a delay in harvest due to a slow drainage of crop lands as well as damage of standing crops in the farms and harvested crops at the homesteads. Another important result that the table reveals is that, the rainfall has a decreasing trend in the second 10-day period of April at seven stations out of eight. As this period eventually coincides with the typical highest water demand period of Bangladesh, and when the groundwater is at its lowest level, both irrigated and rainfed agriculture would be adversely affected by the decrease in Apr II rainfall.

The decrease in rainfall in July, as revealed from the monthly trend analysis in Table 6, is mainly due to the decreasing trend in the second 10-day period of July. This period has decreasing trends at seven stations. Though the month of June, as discussed earlier, has in general decreasing trends, the third 10-day period (Jun III) has increasing trends at all eight stations. The decrease in June rainfalls is mainly due to the decrease in Jun II rainfalls. Seven stations show decreasing trends during this period.

The trends in the annual maximum and 7-day moving average maximum rainfalls at different stations of Bangladesh are given in Table 8. It is seen from the table that, the trends are mixed. However, as we move from short duration (1-day) to long duration (7-day) rainfall maximums, the number of stations with decreasing trends increases. The increasing trends in annual maximum rainfalls eventually coincide with the path of traverse of the monsoon (Chittagong-Sylhet-Mymensingh-Bogra).

Table 8: Trends in annual maximum and 7-day moving average maximum rainfalls (mm/decade) at different stations of Bangladesh

Season	**Farid-pur**	**Jessore**	**Bogra**	**Dhaka**	**Mymen-singh**	**Sylhet**	**Chand-pur**	**Chitta-gong**	**Bangladesh**
Annual Maximum	-6.33	-10.23	1.94	-10.45	4.44	19.62	-24.37	0.16	**-3.15**
7-day Moving Average Maximum	-0.90	-0.54	1.09	-2.71	-0.81	2.20	-3.47	1.19	**-0.49**

Existing published literature based on predictions from different GCMs provide varying results not only in terms of magnitude but also in terms of direction about possible intra-year changes in rainfall over Bangladesh due to global warming. While 5-10% increase in both winter and summer rainfalls is predicted for the year 2030 in Warrick et al. (1996) and 8-15% in winter rainfall for 2050 in Brammer et al. (1996); in Alam et al. (1999) a decrease in winter rainfall of 3% and 37% for 2030 and 2050, respectively, is predicted. IPCC (2007) in its recent Fourth Assessment Report projected increases in rainfalls for South Asia except for winter. In none of these studies, available recorded rainfalls at different stations within Bangladesh were analyzed to compare with the GCM predictions. Mondal and Wasimi (2004) analyzed seasonal rainfalls at 73 BWDB stations of the Ganges basin within Bangladesh and found increasing trends in winter, summer and dry season of 2.1%, 0.4% and

1.6%, respectively, of the corresponding means per year. The changes and trends in seasonal, monthly and 10-day rainfalls found in this study and reported earlier in this section and the findings of Mondal and Wasimi (2004) indicate that there is no evidence so far to support any claim of decrease in rainfall during the dry season.

In Warrick et al. (1996), it is reported that monsoon rainfall may increase by 10-15% by the year 2030 and by 15-20% by the year 2050. 11% and 28% increases in monsoon rainfall over Bangladesh by the year 2030 and 2075, respectively, are reported in Alam et al. (1999). IPCC (2007) has projected 11-15% increase in monsoon rainfall over South Asia by the end of this century. In contrary to above increases, Divya and Mehrotra (1995) reported that there is no long-term trend in rainfall over India. Singh and Sontakke (2002) found a decreasing trend in summer monsoon (June-September) over central and eastern Indo-Gangetic plain. This trend is more or less similar to the trend found by Mondal and Wasimi (2004) for monsoon (June-October) rainfall over the Ganges basin within Bangladesh. Our analysis also provide no evidence in support of increased rainfall predicted from different GCMs, rather it supports the decreasing trend found by Singh and Sontakke (2002) and Mondal and Wasimi (2004) over the Ganges basin.

3 Trends in Temperature

3.1 Mean temperature

Daily maximum and minimum temperature were available at 34 locations for a period of 60 years (1948-2007). From these two temperature, mean temperature were calculated. In this study, the data available at all these stations were analyzed. The estimated trends in mean annual temperature for some selected stations are given in Table 9.

Table 9: Trends in mean annual temperature at some selected stations of Bangladesh

Station	Available period of data	Number of available years	Trend (^{0}C/century)	Significance
Cox's Bazar	1948-2007	60	2.6	**
Jessore	1948-2007	59	2.1	**
Chittagong	1949-2007	59	1.6	**
Srimangal	1948-2007	58	1.2	**
Satkhira	1948-2007	58	0.8	**
Faridpur	1948-2007	57	2.8	**
Khulna	1948-2007	57	-0.1	NS
Bogra	1948-2007	56	2.8	**
Comilla	1948-2007	56	0.2	NS
Dhaka	1953-2007	55	2.1	**
Barisal	1949-2007	55	-0.5	NS
Maijdee Court	1951-2007	54	1.9	**
Mymensingh	1948-2007	54	0.1	NS
Dinajpur	1948-2007	52	-0.4	NS
Sylhet	1956-2007	51	1.1	NS
Rangamati	1957-2007	51	-1.1	**
Ishwardi	1961-2007	46	0.3	NS
Rangpur	1957-2007	45	0.1	NS
Rajshahi	1964-2007	43	1.2	**
Bhola	1966-2007	41	2.2	**

Note: **Significant at the 95% level of confidence;
*Significant at the 90% level of confidence;
NS – Not significant at the 90% level of confidence

It is seen from Table 9 that most of the stations in Bangladesh exhibit increasing trends in mean annual temperature. In fact, our analysis including all the 34 stations suggests that the trend is 1.03 ^{0}C per 100 years (Figure 13). The corresponding winter, summer and monsoon trends are 1.67, 0.26 and 1.05 ^{0}C per century (Figures 14-16).

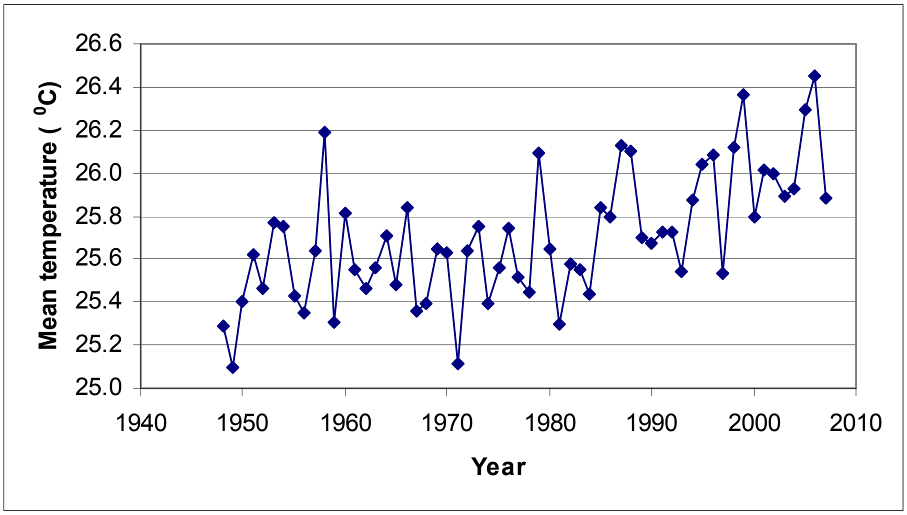

Figure 13: Time series of annual mean temperature of Bangladesh (Data period: 1948-2007)

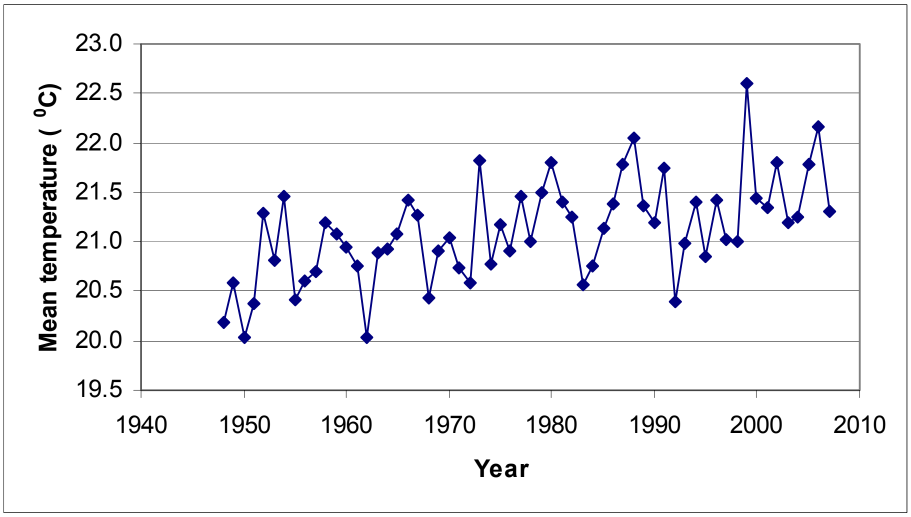

Figure 14: Time series of winter mean temperature of Bangladesh (Data period: 1948-2007)

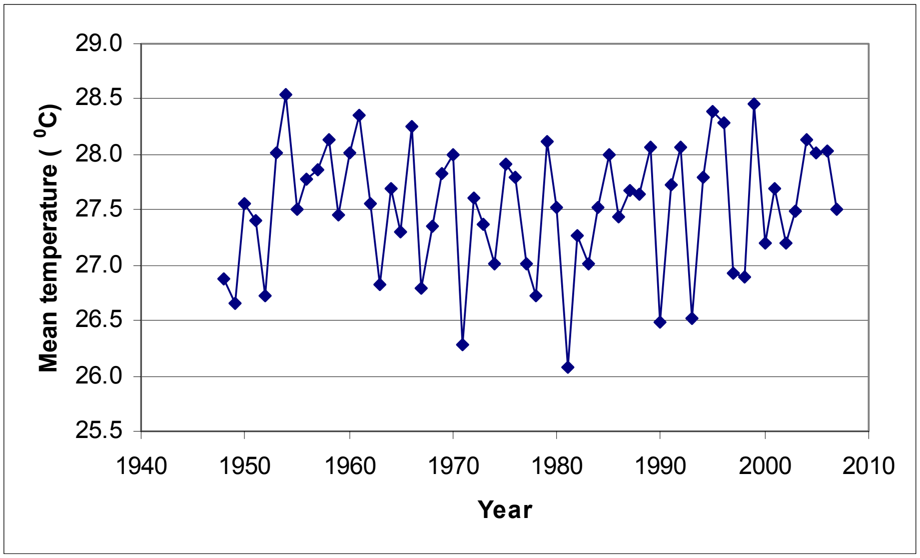

Figure 15: Time series of summer mean temperature of Bangladesh (Data period: 1948-2007)

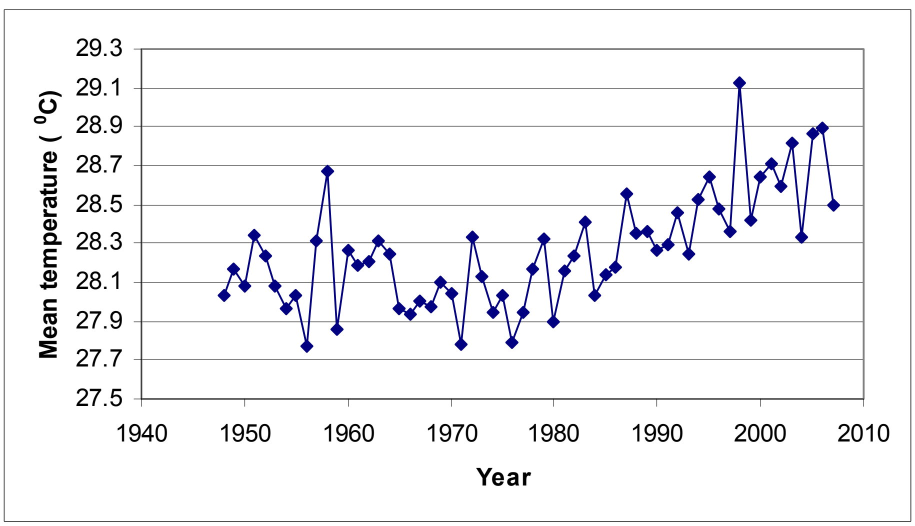

Figure 16: Time series of monsoon mean temperature of Bangladesh (Data period: 1948-2007)

It is seen from the figures that the trends would be quite different during the period of 1980-2007 than that in the entire time period (1948-2007). This is particularly evident in the summer and monsoon temperature. Therefore, the all-Bangladesh trends in seasonal and annual mean temperature are also calculated using the data since 1980 and are reported in Table 10.

Table 10: Trends in seasonal and annual mean temperature of Bangladesh (from 1980 to 2007 for all 34 stations]

Season	**Trend (^{0}C/century)**
Winter (Nov-Feb)	1.33
Summer (Mar-May)	2.15
Monsoon (Jun-Oct)	2.44
Annual (Jan-Dec)	2.14

It is seen from the table that the increasing trend in annual mean temperature during the 1980-2007 periods is about 2.1 ^{0}C per century. This value is about the double of the value computed using the data for the entire time period (1948-2007). The rise in mean annual temperature projected by IPCC (2007) for South Asia is 3.3 ^{0}C with a range of 2.0-4.7 ^{0}C. Thus, the current trend is at the lower end of the IPCC projection. However, it is clear that the use of the recent data, rather than the historical data, provide results which are closer to the IPCC projection. The monsoon and summer trends have become stronger and the winter trend has become weaker in the recent time period. The IPCC (2007) median projections for quarterly temperature are 3.6, 3.5, 2.7 and 3.1 ^{0}C increase in December-February, March-May, June-August, and September-November, respectively, by the end of the 21st century. The IPCC projections of seasonal temperature are also higher than the present seasonal trends. However, the projection is not unrealistic in that the recent trends are higher than the past and it may further strengthen in the future.

Trends in all-Bangladesh mean monthly temperature are given in Table 11. Two values are reported in the table – one using the data since 1948 and the other using the recent data since 1980. If we compare the values reported in Columns 2 and 4, we find that the recent trends are higher for all months except November. The trend in recent temperature in the month of January, which is the coldest month, is negative. This indicates that the peak winter is becoming cooler day by day. The recent increasing trend in the month of February is a staggering 4.6 ^{0}C per century.

Table 11: Trends (^{0}C/century) in monthly mean temperature of Bangladesh

Month	**Trend[1]**	**Significance[1]**	**Trend[2]**	**Significance[2]**
Jan	-0.2	NS	-2.4	NS
Feb	1.6	**	4.6	**
Mar	0.5	NS	1.3	NS
Apr	0	NS	1.2	NS
May	0.4	NS	4.0	**
Jun	1.2	**	2.3	*
Jul	1.0	**	3.0	**
Aug	1.3	**	2.9	**
Sep	0.5	*	1.8	**
Oct	1.2	**	2.0	*
Nov	2.8	**	2.5	*
Dec	2.1	**	2.4	NS

Note: [1]using data of all stations from 1948 to 2007; [2]using data of all stations from 1980 to 2007

3.2 Maximum temperature

The time series of annual mean maximum temperature of Bangladesh is shown in Figure 17. It is seen from the figure that the maximum temperature has started rising since 1970s or 1980s. The rising trend is 0.63 ^{0}C per century since 1948 and 2.58 ^{0}C per century since 1980. So the recent trend since 1980 is much higher than the historical trend since 1948. The seasonal trends are 0.74, -0.50 and 1.38 ^{0}C per century for winter, summer and monsoon seasons, respectively, since 1948. The corresponding trends from 1980 are 1.81, 2.63 and 3.13 ^{0}C per century. It is noted that even the sign of the trend for the summer season changes with the consideration of the recent data.

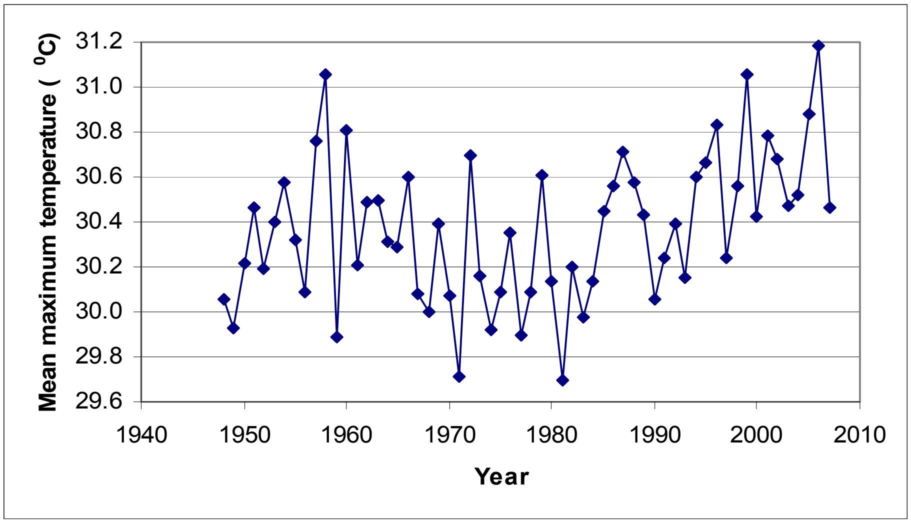

Figure 17: Time series of mean maximum temperature of Bangladesh (Data period: 1948-2007)

The monthly trends in mean maximum temperature provided in Table 12 show that the trends become steeper since 1980 for all months except November. During June-September, the trends are statistically significant for both periods (1948-2007 and 1980-2007).

Table 12: Trends (^{0}C/century) in monthly mean maximum temperature of Bangladesh

Month	Trend[1]	Significance[1]	Trend[2]	Significance[2]
Jan	-1.4	**	-2.2	NS
Feb	-0.1	NS	4.6	*
Mar	-1.2	NS	2.1	NS
Apr	-1.3	NS	1.2	NS
May	0.2	NS	4.5	**
Jun	1.4	**	3.3	**
Jul	1.2	**	3.7	**
Aug	1.9	**	4.1	**
Sep	0.7	*	2.8	**
Oct	1.8	**	1.9	NS
Nov	2.7	**	1.9	NS
Dec	1.5	**	3.0	*

Note: [1]using data of all stations from 1948 to 2007; [2]using data of all stations from 1980 to 2007

3.3 Minimum temperature

The time series of mean annual minimum temperature of Bangladesh is shown in Figure 18. It is seen from the figure that unlike the mean and maximum temperature, the minimum temperature shows an increasing trend from the very beginning. The trend is 1.44 ^{0}C per century since 1948 and 1.69 ^{0}C per century since 1980; the difference is not much. The trends in winter, summer and monsoon temperature are 2.62, 1.04 and 0.70 ^{0}C per century, respectively, since 1948 and 0.91, 1.37, 1.65 ^{0}C per century since 1980. It is noted from the values that the winter trend has substantially decreased and the monsoon trend has substantially increased in recent years.

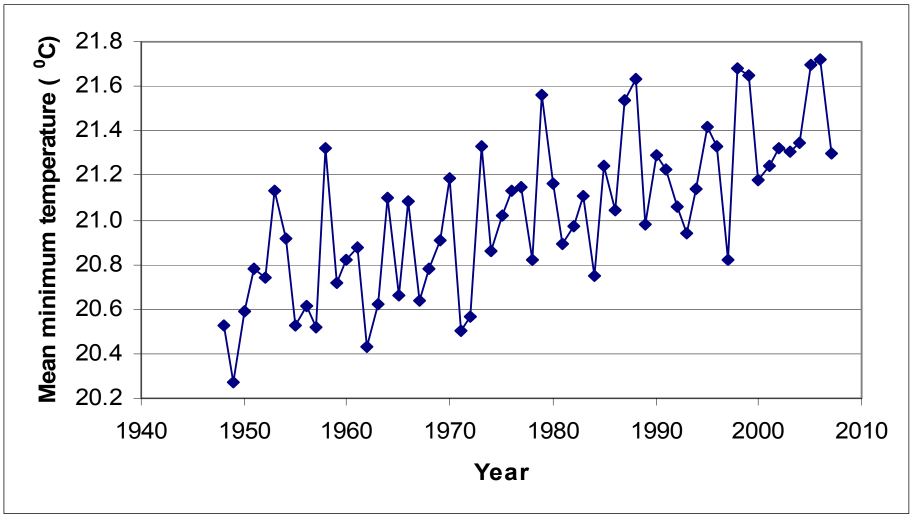

Figure 18: Time series of annual mean minimum temperature of Bangladesh (Data period: 1948-2007)

Trends in monthly mean minimum temperature for all-Bangladesh are given in Table 13. It is seen from the table that the trends have increased for February and May-November, and decreased for December-January and March in recent times. It is also apparent that, though the trends have in general increased the statistical significance has decreased; this implies that the variability has increased.

Table 13: Trends (^{0}C/century) in monthly mean minimum temperature of Bangladesh

Month	Trend[1]	Significance[1]	Trend[2]	Significance[2]
Jan	1.0	*	-2.7	NS
Feb	3.4	**	4.5	**
Mar	2.2	**	0.6	NS
Apr	1.2	*	1.1	NS
May	0.5	NS	3.5	**
Jun	1.0	**	1.4	NS
Jul	0.8	**	2.3	**
Aug	0.8	**	1.8	**
Sep	0.2	NS	0.7	NS
Oct	0.6	NS	2.1	NS
Nov	2.8	**	3.2	NS
Dec	2.7	**	1.8	NS

Note: 1using data of all stations from 1948 to 2007; 2using data of all stations from 1980 to 2007

4 Trends in Sunshine

The average bright sunshine duration in Bangladesh in the dry season is about 7.6 hours a day, and that in the monsoon season is about 4.7 hours. Although trends in solar radiation have been reported for many countries of the world, no study has so far been undertaken to investigate the long-term trends in solar radiation in Bangladesh. In this section, trends in measured bright sunshine duration at all the 34 stations in Bangladesh are analyzed for different seasons, including the 36 ten-day periods in a year. The data analyzed range from 1961 to 2007 (in some cases 2006).

The available records were first divided into three time spans: 1961-75, 1976-90 and 1990-06. The average sunshine duration during each of these time spans for each of 36 ten-day periods were calculated and shown in Figure 19 to 21, for Dhaka, Bogra and Jessore, respectively. The figures show that the average sunshine duration has declined over the three periods. The amount of decrease, particularly in the dry season, is quite significant. The time series of the winter and dry season sunshine duration for the entire Bangladesh are shown in Figures 22 and 23, respectively. The decadal (10 years) trends of winter and monsoon sunshine hours are shown in Figures 24 and 25, respectively.

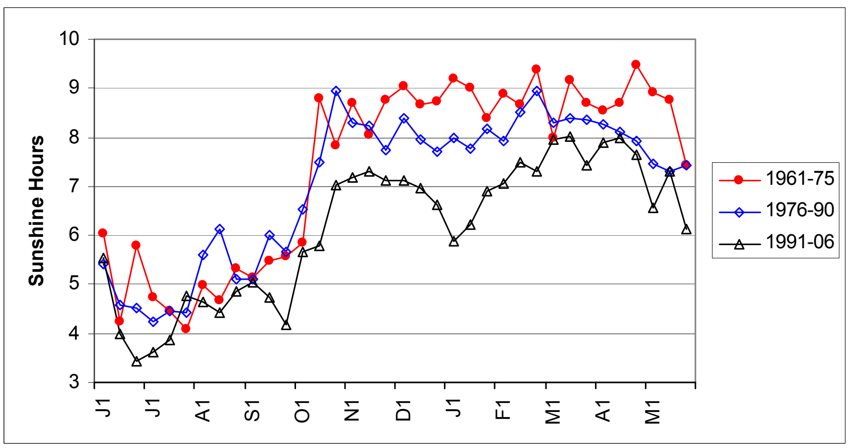

Figure 19: Average 10-day sunshine duration (in hours/day) in three different time spans in Dhaka city

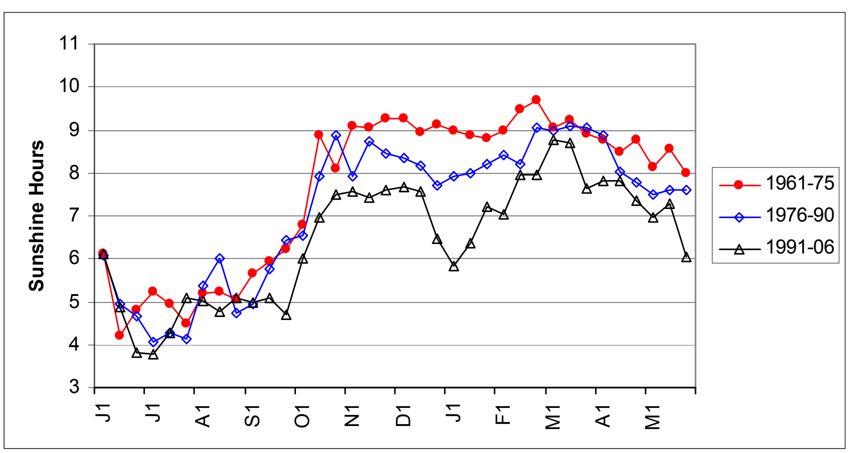

Figure 20: Average 10-day sunshine duration (in hours/day) in three different time spans in Bogra

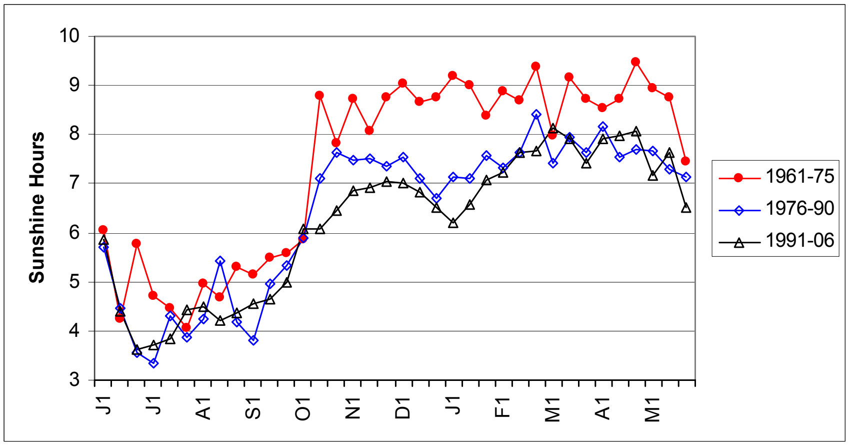

Figure 21: Average 10-day sunshine duration (in hours/day) in three different time spans in Jessore

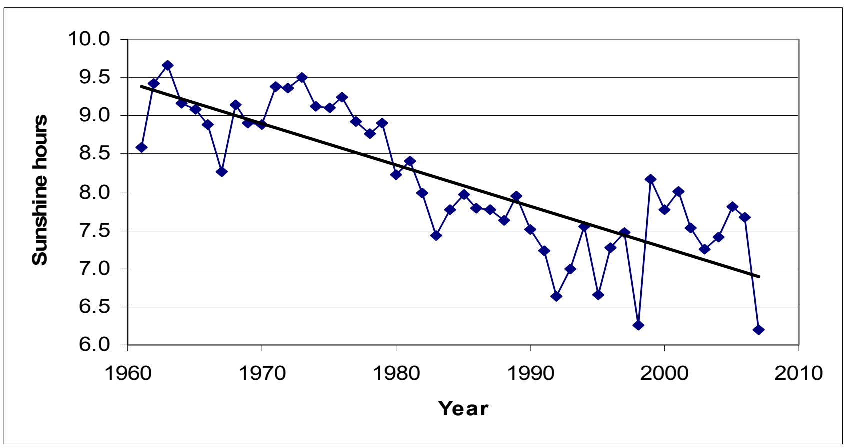

Figure 22: Time series of winter mean sunshine duration of Bangladesh (Data period: 1961-2007)

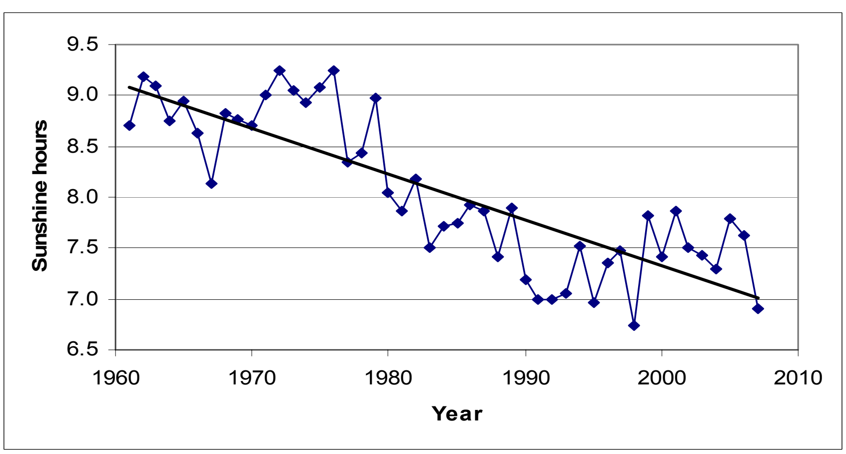

Figure 23: Time series of dry season mean sunshine duration of Bangladesh (Data period: 1961-2007)

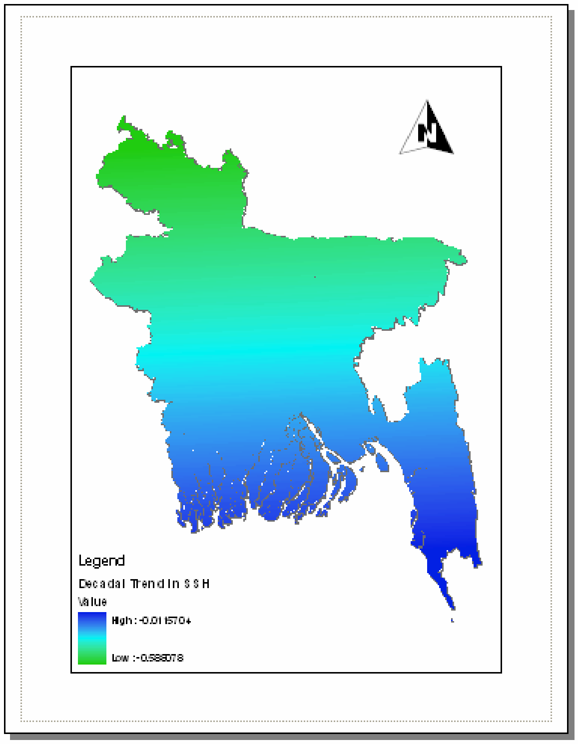

Figure 24: Trends (hours/day per decade) in winter (November-February) sunshine duration in Bangladesh (Data period: 1961-2007)

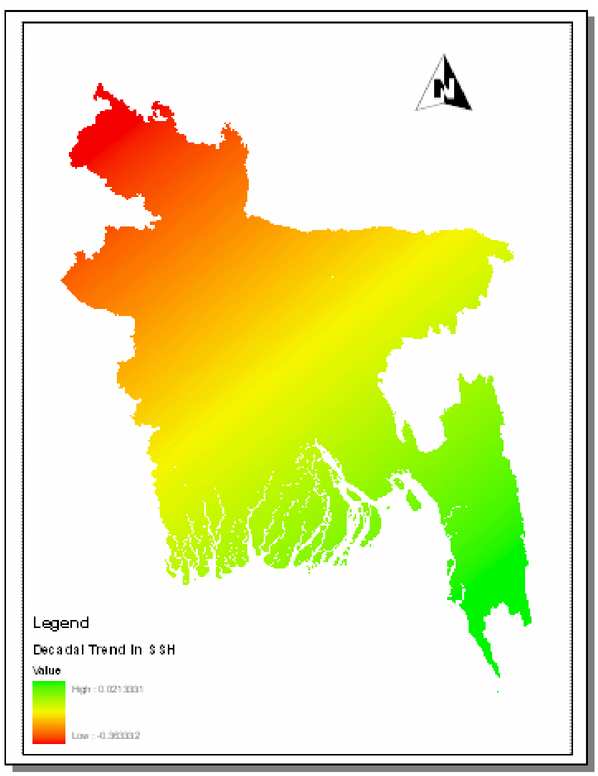

Figure 25: Trends (hours/day per decade) in monsoon (June-October) sunshine duration in Bangladesh (Data period: 1961-2007)

The results of the 10-day trend analysis are reported in Table 14 for some selected stations. To get a visual impression about the magnitude of the trend, trend lines superimposed on scatter plots for different 10-day periods in a year are shown in Annex III for Dhaka.

Table 14: Trends in 10-day average of bright sunshine duration (in hours/day per decade) at different stations of Bangladesh

10-day	Farid-pur	Jessore	Bogra	Dhaka	Mymen-singh	Sylhet	Chand-pur	Chitta-gong	Bangladesh
Jan I	-0.53	-0.78	-0.97	-0.89	-0.40	-0.52	-0.06	-0.30	**-0.74**
Jan II	-0.34	-0.55	-0.82	-0.81	-0.51	-0.80	-0.09	-0.36	**-0.73**
Jan III	-0.62	-0.42	-0.55	-0.55	-0.34	-0.58	-0.13	-0.41	**-0.61**
Feb I	-0.28	-0.31	-0.57	-0.52	0.00	-0.48	0.19	-0.40	**-0.52**
Feb II	-0.01	-0.31	-0.55	-0.58	-0.01	-0.65	-0.07	-0.45	**-0.51**
Feb III	0.04	-0.44	-0.51	-0.57	-0.04	-0.61	-0.15	-0.56	**-0.49**
Mar I	0.33	-0.01	-0.14	-0.18	0.01	-0.19	0.15	-0.06	**-0.24**
Mar II	0.28	-0.33	-0.15	-0.31	-0.15	-0.41	-0.08	-0.17	**-0.33**
Mar III	0.09	-0.35	-0.40	-0.43	-0.44	-0.62	-0.12	-0.50	**-0.36**
Apr I	-0.13	-0.23	-0.31	-0.28	-0.15	-0.36	0.09	-0.25	**-0.28**
Apr II	-0.31	-0.12	-0.26	-0.25	-0.09	-0.26	0.06	0.02	**-0.25**
Apr III	1.28	-0.22	-0.45	-0.41	-0.16	-0.54	-0.05	-0.51	**-0.43**
May I	-0.59	-0.42	-0.31	-0.47	0.14	-0.32	-0.05	-0.09	**-0.26**
May II	0.45	-0.20	-0.38	-0.50	-0.07	-0.20	-0.14	-0.77	**-0.46**
May III	-0.08	-0.40	-0.67	-0.64	-0.45	-0.64	-0.22	-0.61	**-0.40**
Jun I	-0.26	0.04	0.13	0.06	-0.34	-0.09	0.24	0.08	**0.06**
Jun II	-0.09	-0.07	0.14	-0.11	-0.28	0.09	0.21	0.35	**0.10**
Jun III	-0.62	-0.45	-0.31	-0.74	-0.46	-0.26	-0.47	-0.24	**-0.30**
Jul I	0.86	-0.27	-0.46	-0.60	-0.19	-0.58	-0.24	-0.46	**-0.41**
Jul II	-0.48	-0.18	-0.23	-0.51	-0.15	-0.32	-0.08	-0.24	**-0.26**
Jul III	0.52	0.07	0.03	-0.12	0.58	0.31	0.19	-0.17	**-0.06**
Aug I	0.70	-0.06	-0.03	-0.18	0.06	0.17	-0.05	-0.05	**0.07**
Aug II	0.09	-0.25	-0.09	-0.39	-0.23	-0.22	-0.02	-0.21	**-0.21**
Aug III	0.02	-0.17	-0.03	-0.29	0.19	-0.05	0.26	-0.16	**-0.15**
Sep I	0.41	-0.09	-0.32	-0.37	0.56	-0.35	-0.03	-0.06	**-0.33**
Sep II	-0.81	-0.33	-0.31	-0.33	0.17	-0.03	-0.40	-0.30	**-0.27**
Sep III	0.16	-0.22	-0.57	-0.63	-0.08	-0.61	-0.28	-0.12	**-0.43**
Oct I	-0.33	-0.01	-0.39	-0.41	-0.25	-0.24	0.16	-0.12	**-0.25**
Oct II	-0.78	-0.82	-0.57	-0.79	-0.13	-0.57	-0.45	-0.62	**-0.68**
Oct III	-1.24	-0.51	-0.19	-0.24	-0.47	-0.18	-0.61	-0.15	**-0.14**
Nov I	-0.35	-0.63	-0.50	-0.67	-0.26	-0.52	-0.26	-0.49	**-0.60**
Nov II	0.25	-0.32	-0.52	-0.40	-0.18	-0.12	-0.07	-0.15	**-0.42**
Nov III	-0.21	-0.40	-0.45	-0.54	-0.17	-0.19	0.18	-0.44	**-0.41**
Dec I	-0.23	-0.50	-0.44	-0.65	-0.23	-0.16	0.14	-0.40	**-0.49**
Dec II	-0.52	-0.55	-0.43	-0.63	-0.27	-0.18	0.07	-0.43	**-0.43**
Dec III	-0.51	-0.54	-0.79	-0.76	-0.33	-0.39	0.17	-0.46	**-0.64**
Average	**-0.28**	**-0.32**	**-0.39**	**-0.51**	**-0.27**	**-0.32**	**-0.13**	**-0.21**	**-0.36**

Both the tabulated and graphical results indicate that the sunshine duration in Bangladesh is in general decreasing at an alarming rate. The winter, dry season, summer and monsoon rates of decline are respectively 5.7%, 5.0%, 3.9% and 3.8% in every 10 years for the entire Bangladesh. The overall annual decrease for the entire Bangladesh is about 0.36 hours a day in every 10 years. This rate of decline in annual sunshine hour is equal to 4.7% a decade. There are some spatial patterns in the declining rates – the rates increase from south to north and east to west. This is evident from Figures 24 and 25 above. Of the 34 stations, 26 stations were found to have decreasing trends in annual sunshine, 6 with increasing trends, and 2 stations with insufficient data for analysis. The six stations which show positive trends are Patuakhali, Rangamati, Khepupara, Sitakunda, Srimangal and Madaripur. The highest decrease (0.5 hours a day per 10 years, the last row in Table 14) is found in Dhaka, the capital city with a population of about 15 million. The maximum decrease for entire Bangladesh is about 0.74 hours in the first 10-day period of January, which is the coldest month in the winter season. During this period, the average sunshine durations were 8.87, 9.19 and 8.99 hours a day during the period of 1961-1975 and this came down to 5.89, 6.19 and 5.84 hours a day during the period of 1991-2006 at Dhaka, Bogra and Jessore, respectively. This declining rate is very high and is really a matter of great concern for agriculture and health sectors in particular.

The statistical significance of the trends is also tested using a nonparametric technique at a 10% level of significance. The results for some stations are reported in Table 15. It was found that the trends are even statistically significant for 28, 23, 21, 18, 18, 16, 7, 4, and 3 ten-day periods, out of 36 ten-day periods in a year, for Dhaka, Jessore, Bogra, Sylhet, Barisal, Chittagong, Mymensingh, Faridpur and Chandpur stations, respectively. The urban areas show somewhat more dimming compared with nearby agricultural areas. We have already reported the rainfall trend of these stations. Rainfall trend is in general opposite to the dimming trend. The increase in cloud coverage due to the gradual increase in greenhouse gases and aerosols in the atmosphere resulting from deforestation, urbanization and land-use change, both at local and regional scales, may be the reasons for such dimming.

Table 15: Statistical significance of trends in 10-day average of daily sunshine

10-day	**Dhaka**		**Bogra**		**Jessore**		**Sylhet**	
	Correlation	**Significance**	**Correlation**	**Significance**	**Correlation**	**Significance**	**Correlation**	**Significance**
Jan I	**-0.449**	0.000	**-0.561**	0.000	**-0.500**	0.000	**-0.387**	0.000
Jan II	**-0.439**	0.000	**-0.532**	0.000	**-0.372**	0.001	**-0.498**	0.000
Jan III	**-0.444**	0.000	**-0.424**	0.000	**-0.332**	0.004	**-0.454**	0.000
Feb I	**-0.347**	0.001	**-0.451**	0.000	**-0.230**	0.045	**-0.299**	0.004
Feb II	**-0.398**	0.000	**-0.311**	0.004	**-0.303**	0.007	**-0.426**	0.000
Feb III	**-0.344**	0.001	**-0.339**	0.001	**-0.363**	0.001	**-0.362**	0.000
Mar I	-0.150	0.179	-0.121	0.244	-0.002	0.990	-0.129	0.217
Mar II	-0.172	0.113	-0.071	0.498	**-0.293**	0.011	**-0.239**	0.022
Mar III	**-0.299**	0.007	**-0.270**	0.010	**-0.331**	0.004	**-0.375**	0.000

Apr I	**-0.232**	0.037	-0.157	0.134	**-0.220**	0.056	**-0.278**	0.010
Apr II	**-0.214**	0.052	**-0.233**	0.026	-0.057	0.624	-0.162	0.142
Apr III	**-0.295**	0.007	**-0.342**	0.001	**-0.184**	0.114	**-0.314**	0.003
May I	**-0.246**	0.028	**-0.175**	0.098	**-0.272**	0.018	**-0.174**	0.104
May II	**-0.287**	0.009	**-0.244**	0.032	-0.090	0.433	-0.084	0.435
May III	**-0.312**	0.005	**-0.285**	0.007	**-0.200**	0.082	**-0.215**	0.045
Jun I	0.018	0.870	0.078	0.464	0.063	0.586	-0.028	0.784
Jun II	-0.064	0.572	0.067	0.537	-0.039	0.726	0.056	0.592
Jun III	**-0.338**	0.002	-0.112	0.298	**-0.206**	0.064	-0.132	0.206
Jul I	**-0.316**	0.005	**-0.233**	0.026	**-0.195**	0.085	**-0.257**	0.014
Jul II	**-0.267**	0.015	-0.110	0.303	**-0.171**	0.131	-0.114	0.275
Jul III	-0.021	0.852	0.066	0.525	0.081	0.474	**0.211**	0.047
Aug I	-0.129	0.234	-0.023	0.831	0.023	0.837	0.126	0.247
Aug II	**-0.178**	0.097	-0.031	0.769	**-0.189**	0.090	-0.099	0.363
Aug III	**-0.186**	0.083	-0.025	0.810	-0.126	0.261	0.022	0.837
Sep I	**-0.180**	0.096	**-0.197**	0.062	-0.034	0.762	-0.163	0.119
Sep II	**-0.236**	0.030	-0.149	0.154	**-0.202**	0.071	-0.038	0.716
Sep III	**-0.370**	0.001	**-0.272**	0.009	-0.124	0.266	**-0.263**	0.012
Oct I	**-0.247**	0.023	-0.119	0.269	0.010	0.930	-0.110	0.293
Oct II	**-0.362**	0.001	**-0.289**	0.007	**-0.414**	0.000	**-0.281**	0.007
Oct III	-0.154	0.157	-0.129	0.229	**-0.305**	0.007	-0.104	0.322
Nov I	**-0.399**	0.000	**-0.252**	0.015	**-0.347**	0.002	**-0.283**	0.007
Nov II	**-0.271**	0.013	**-0.343**	0.001	**-0.239**	0.035	-0.105	0.329
Nov III	**-0.426**	0.000	**-0.362**	0.001	**-0.336**	0.003	**-0.184**	0.078
Dec I	**-0.476**	0.000	**-0.275**	0.009	**-0.357**	0.002	-0.152	0.152
Dec II	**-0.490**	0.000	**-0.316**	0.002	**-0.393**	0.001	-0.094	0.374
Dec III	**-0.531**	0.000	**-0.378**	0.000	**-0.379**	0.001	**-0.270**	0.011

Table 15 (continued)

10-day	**Chittagong**		**Mymensingh**		**Faridpur**		**Chandpur**	
	Correla-tion	**Signifi-cance**	**Correla-tion**	**Signifi-cance**	**Correla-tion**	**Signifi-cance**	**Correla-tion**	**Signifi-cance**
Jan I	**-0.245**	0.046	**-0.327**	0.022	-0.119	0.450	0.012	0.937
Jan II	**-0.298**	0.015	**-0.290**	0.042	-0.113	0.463	-0.004	0.979
Jan III	**-0.387**	0.002	**-0.257**	0.072	**-0.260**	0.091	-0.123	0.413
Feb I	**-0.321**	0.008	0.006	0.965	-0.143	0.352	0.221	0.173
Feb II	**-0.321**	0.008	0.040	0.774	0.017	0.910	0.010	0.952
Feb III	**-0.385**	0.002	0.015	0.912	0.005	0.976	-0.108	0.481
Mar I	-0.015	0.898	0.022	0.888	0.130	0.397	0.166	0.234
Mar II	-0.136	0.265	-0.033	0.823	-0.065	0.672	-0.028	0.843
Mar III	**-0.293**	0.019	**-0.241**	0.107	-0.022	0.888	-0.057	0.691

Apr I	-0.093	0.441	-0.087	0.551	-0.069	0.652	0.143	0.297
Apr II	0.014	0.915	-0.018	0.901	-0.152	0.334	-0.065	0.643
Apr III	**-0.254**	0.045	0.010	0.944	**0.457**	0.004	-0.030	0.833
May I	-0.083	0.506	0.132	0.343	-0.181	0.251	-0.028	0.853
May II	**-0.361**	0.004	-0.018	0.895	0.215	0.174	-0.030	0.844
May III	**-0.306**	0.014	-0.145	0.321	0.014	0.928	-0.059	0.692
Jun I	0.022	0.858	-0.142	0.311	-0.076	0.629	0.116	0.427
Jun II	0.169	0.173	-0.140	0.327	-0.021	0.897	0.029	0.843
Jun III	-0.040	0.745	-0.157	0.272	-0.088	0.600	**-0.290**	0.059
Jul I	-0.177	0.177	-0.087	0.552	0.221	0.173	-0.152	0.334
Jul II	-0.108	0.402	-0.051	0.313	-0.200	0.218	-0.006	0.972
Jul III	-0.009	0.946	**0.313**	0.028	0.063	0.697	0.130	0.397
Aug I	-0.049	0.687	0.020	0.889	0.189	0.243	-0.024	0.880
Aug II	-0.109	0.381	-0.058	0.691	-0.011	0.948	0.011	0.948
Aug III	-0.102	0.398	0.161	0.262	-0.019	0.904	0.228	0.172
Sep I	-0.005	0.966	**0.259**	0.064	0.170	0.310	0.014	0.921
Sep II	-0.152	0.215	0.062	0.673	**-0.257**	0.103	**-0.241**	0.107
Sep III	-0.057	0.635	0.025	0.862	0.085	0.603	-0.138	0.346
Oct I	-0.030	0.808	-0.166	0.234	-0.117	0.446	0.134	0.359
Oct II	-0.258	0.038	-0.033	0.815	-0.182	0.236	-0.217	0.146
Oct III	-0.149	0.230	**-0.393**	0.006	**-0.377**	0.014	**-0.283**	0.053
Nov I	**-0.238**	0.045	-0.130	0.372	-0.019	0.904	-0.162	0.279
Nov II	-0.066	0.588	-0.144	0.315	0.095	0.546	-0.004	0.978
Nov III	**-0.304**	0.010	-0.107	0.455	-0.038	0.809	0.051	0.731
Dec I	**-0.320**	0.009	-0.036	0.804	-0.032	0.846	0.098	0.503
Dec II	**-0.290**	0.020	-0.163	0.264	-0.063	0.697	-0.040	0.785
Dec III	**-0.350**	0.004	-0.107	0.455	-0.126	0.436	0.065	0.655

Note: Boldface values indicate statistically significant decrease in sunshine.

5 Trends in Evaporation

Evaporation data of BMD are available only at two of the eight meteorological stations studied. Therefore, BWDB data were used. The available period of data varies from 1964-65 to 1995-98 depending on stations. Clearly recent data were not available to us. Also, there were many missing values as well as absurd numbers in the data sets. To see the long-term changes in evaporation, the data were divided into two periods: 1964-80 and 1981-98. The average 10-day evaporation for both periods is shown in Table 16. It is seen from the last two columns of the table that the evaporation rate has decreased in Bangladesh except the months of October–February, when the evaporation has increased. The reduction in sunshine duration can be attributed to be the principal reason for such a decrease in evaporation. The decrease is higher in pre-monsoon summer months of March-May. The average decrease during this period is about 15% and this decrease is unambiguous. These findings indicate that irrigation demand during this period has actually decreased, rather than increased which is generally thought, due to climate change. The average increase in the post-monsoon and winter months is about 6.5%. So, irrigation demand during this period has increased due to climate change.

Out of the 11 stations analyzed, three stations (Jessore, Mymensingh and Faridpur) show decreases in almost all 10-day periods. Six stations (Bogra, Dhaka, Chittagong, Sylhet, Noakhali and Sirajganj) show decreases in evaporation in all 10-day periods except the October-February period. During this period, irrigation requirement may increase at these stations and some Rabi crops may experience water stress due to higher evaporation requirement. The peculiar behavior is found in the Comilla and Srimangal evaporation. At these two stations, evaporation has increased during the monsoon which is atypical compared with other stations. The reason is not known.

Table 16: Changes in average decadal evaporation (mm/day) at different stations of Bangladesh

10-day	Faridpur		Jessore		Mymensingh		Bogra	
	Until 1980	**Post-1980**	**Until 1980**	**Post-1980**	**Until 1980**	**Post-1980**	**Until 1980**	**Post-1980**
Jun I	3.67	3.53	3.64	3.10	3.53	2.87	4.35	3.96
Jun II	3.42	2.76	3.30	2.35	2.86	2.74	3.60	3.46
Jun III	2.70	2.51	3.10	2.34	2.95	2.67	3.37	3.34
Jul I	**2.17**	**2.48**	2.98	1.88	3.01	2.40	3.55	2.90
Jul II	**2.33**	**2.56**	2.82	2.11	2.77	2.46	3.29	3.18
Jul III	2.59	2.47	2.98	2.08	2.80	2.31	**3.09**	**3.24**
Aug I	**2.35**	**2.42**	2.72	2.09	3.00	2.29	3.53	3.16
Aug II	**2.37**	**2.52**	2.68	2.36	3.05	2.41	3.54	3.33
Aug III	2.60	2.55	2.71	2.08	2.88	2.26	3.52	3.16
Sep I	2.80	2.53	2.68	2.05	3.02	2.05	3.86	3.36
Sep II	2.99	2.65	2.54	2.17	2.80	2.06	3.43	3.25
Sep III	2.70	2.24	2.87	2.21	2.92	2.20	**3.11**	**3.22**

Oct I	2.87	2.50	2.77	2.10	2.59	2.40	**3.18**	**3.27**
Oct II	2.85	2.41	2.69	2.34	2.89	2.40	3.41	3.34
Oct III	2.54	2.63	2.79	2.43	2.73	2.32	**3.25**	**3.64**
Nov I	2.74	2.33	2.64	2.19	2.65	2.24	**3.09**	**3.37**
Nov II	2.45	2.26	2.46	2.02	2.51	2.11	3.18	2.97
Nov III	2.26	2.01	2.24	1.97	2.20	1.91	2.92	2.86
Dec I	2.15	1.94	2.28	1.82	2.09	1.60	**2.69**	**2.82**
Dec II	1.97	1.82	2.10	1.79	1.99	1.52	**2.40**	**2.72**
Dec III	2.00	1.63	2.00	1.60	2.13	1.47	**2.33**	**2.55**
Jan I	1.65	1.53	2.01	1.48	1.72	1.39	**2.12**	**2.28**
Jan II	1.83	1.55	2.03	1.51	1.82	1.41	**2.16**	**2.18**
Jan III	1.85	1.68	2.17	1.75	1.99	1.52	**2.14**	**2.38**
Feb I	2.08	1.87	2.49	2.04	2.25	1.79	**2.43**	**2.58**
Feb II	2.34	2.16	2.82	2.18	2.52	2.03	**2.74**	**2.86**
Feb III	2.72	2.15	3.26	2.29	2.93	2.21	3.27	2.97
Mar I	2.96	2.59	3.43	2.73	3.14	2.67	**3.46**	**3.88**
Mar II	3.80	3.16	4.25	3.14	3.87	2.99	**4.07**	**4.21**
Mar III	3.60	3.40	4.29	3.54	3.92	3.21	4.55	4.19
Apr I	4.91	3.54	4.77	3.81	4.11	3.34	5.18	4.35
Apr II	4.86	3.96	5.16	4.13	**3.46**	**3.50**	5.13	4.83
Apr III	4.82	3.54	5.01	3.81	3.58	3.21	5.12	4.39
May I	4.43	3.68	4.54	3.33	3.99	3.05	5.11	3.87
May II	4.37	3.55	4.24	3.38	3.50	3.28	4.85	4.26
May III	4.61	3.40	4.19	3.39	3.78	2.92	4.53	3.95

Table 16 (continued)

10-day	**Sirajganj**		**Dhaka**		**Chittagong**		**Noakhali**	
	Until 1980	**Post-1980**	**Until 1980**	**Post-1980**	**Until 1980**	**Post-1980**	**Until 1980**	**Post-1980**
Jun I	**3.59**	**3.77**	3.12	2.76	3.87	2.89	2.86	2.41
Jun II	3.66	3.39	2.98	2.30	3.37	2.10	2.59	1.62
Jun III	3.37	3.31	2.88	2.64	3.60	2.20	2.43	1.70
Jul I	3.60	2.95	3.05	2.28	3.14	1.77	2.60	1.40
Jul II	3.26	3.19	3.05	2.41	3.30	2.15	2.33	1.30
Jul III	3.47	3.15	3.02	2.08	3.00	2.09	2.36	1.43
Aug I	3.60	3.40	2.99	2.55	2.99	2.08	2.17	1.40
Aug II	**3.36**	**3.42**	2.85	2.68	2.98	2.28	2.07	1.55
Aug III	3.25	3.10	2.75	2.52	3.27	2.07	2.08	1.48
Sep I	3.38	3.37	2.71	2.59	2.92	2.56	2.58	1.65
Sep II	3.23	3.14	2.69	2.74	3.39	2.98	2.31	1.70

Sep III	3.46	3.18	2.92	2.68	3.11	2.77	2.54	1.91
Oct I	**2.90**	**3.21**	**2.59**	**2.83**	3.49	2.74	2.40	2.10
Oct II	**3.10**	**3.17**	2.89	2.79	3.28	2.94	2.91	2.52
Oct III	**2.91**	**3.21**	**2.73**	**3.49**	3.16	3.02	**2.54**	**2.57**
Nov I	**2.85**	**2.94**	**2.65**	**3.64**	**3.19**	**3.19**	**2.42**	**2.67**
Nov II	**2.51**	**2.72**	**2.51**	**3.67**	**3.14**	**3.62**	**2.27**	**2.57**
Nov III	**2.28**	**2.43**	**2.20**	**3.70**	**3.01**	**3.60**	**2.14**	**2.65**
Dec I	**2.14**	**2.23**	**2.09**	**3.41**	**2.90**	**3.56**	**2.02**	**2.66**
Dec II	**2.01**	**2.06**	**1.99**	**3.34**	**2.67**	**3.61**	**1.87**	**2.41**
Dec III	1.96	1.87	**2.13**	**3.26**	**2.74**	**3.49**	**1.86**	**2.36**
Jan I	1.93	1.79	**2.17**	**3.29**	**2.87**	**3.34**	**1.88**	**2.39**
Jan II	2.04	1.76	**2.24**	**3.31**	**2.99**	**3.22**	**1.84**	**2.44**
Jan III	2.16	1.83	**2.45**	**3.42**	**3.46**	**3.76**	**2.04**	**2.61**
Feb I	2.40	2.21	**2.73**	**3.42**	**3.45**	**3.80**	**2.27**	**2.59**
Feb II	3.25	2.54	**3.11**	**3.49**	**3.56**	**3.77**	**2.70**	**2.79**
Feb III	3.93	2.74	**3.36**	**3.50**	3.92	3.58	3.09	2.78
Mar I	4.21	3.16	**3.70**	**3.96**	4.21	3.85	3.31	2.85
Mar II	4.99	3.64	4.28	4.16	4.47	4.19	3.67	3.19
Mar III	4.83	3.99	**3.93**	**4.35**	4.32	3.71	3.61	2.91
Apr I	5.47	4.52	4.39	4.21	4.85	3.54	3.90	3.05
Apr II	5.37	4.92	3.83	3.66	4.87	3.64	4.07	3.22
Apr III	5.06	4.36	4.21	2.90	4.80	3.63	4.20	3.41
May I	4.89	3.89	4.14	3.40	4.14	3.21	3.88	2.71
May II	4.52	4.01	3.74	3.26	4.57	3.02	3.80	3.39
May III	4.47	3.99	3.81	3.33	4.38	2.91	3.44	2.56

Table 16(continued)

10-day	**Sylhet**		**Srimangal**		**Comilla**		**Bangladesh**	
	Until 1980	**Post-1980**	**Until 1980**	**Post-1980**	**Until 1980**	**Post-1980**	**Until 1980**	**Post-1980**
Jun I	2.91	2.67	**2.78**	**2.96**	3.70	3.59	*3.46*	*3.14*
Jun II	2.42	2.38	**2.37**	**2.70**	**2.89**	**3.17**	*3.04*	*2.63*
Jun III	2.86	2.46	**2.74**	**2.81**	3.12	3.06	*3.01*	*2.64*
Jul I	2.88	2.22	2.80	2.70	2.96	2.80	*2.98*	*2.34*
Jul II	2.95	2.36	**2.39**	**2.65**	**3.25**	**3.32**	*2.89*	*2.52*
Jul III	2.62	2.36	**2.56**	**2.71**	**2.96**	**3.04**	*2.86*	*2.45*
Aug I	3.09	2.48	**2.59**	**2.78**	**2.76**	**3.18**	*2.89*	*2.53*
Aug II	3.25	2.61	**2.67**	**2.82**	**3.03**	**3.32**	*2.90*	*2.66*
Aug III	3.05	2.81	**2.37**	**3.02**	**2.65**	**2.97**	*2.83*	*2.55*
Sep I	2.75	2.58	2.75	2.73	3.15	3.05	*2.96*	*2.59*

Sep II	2.84	2.58	**2.42**	**2.71**	**2.73**	**3.19**	*2.85*	*2.65*
Sep III	3.03	2.70	2.73	2.58	**2.93**	**3.10**	*2.94*	*2.62*
Oct I	3.12	2.92	**2.51**	**2.61**	**2.80**	**3.10**	*2.84*	*2.71*
Oct II	**3.06**	**3.26**	3.13	2.39	**2.72**	**2.89**	*2.99*	*2.77*
Oct III	**2.98**	**3.41**	2.67	2.25	**2.63**	**2.75**	***2.81***	***2.88***
Nov I	**2.89**	**3.57**	2.30	1.95	**2.55**	**2.56**	***2.72***	***2.79***
Nov II	**2.82**	**3.57**	2.24	1.85	2.58	2.38	***2.61***	***2.70***
Nov III	**2.44**	**3.58**	1.89	1.65	2.11	1.97	***2.34***	***2.58***
Dec I	**2.49**	**3.43**	1.85	1.51	**2.12**	**2.35**	***2.26***	***2.48***
Dec II	**2.27**	**3.23**	1.50	1.50	**1.76**	**2.12**	***2.05***	***2.37***
Dec III	**2.07**	**3.25**	1.59	1.28	**1.70**	**1.96**	***2.05***	***2.25***
Jan I	**1.99**	**3.06**	1.46	1.23	1.77	1.69	***1.96***	***2.13***
Jan II	**2.08**	**3.04**	1.64	1.20	1.94	1.73	***2.06***	***2.12***
Jan III	**2.16**	**2.97**	1.92	1.38	2.15	1.90	***2.23***	***2.29***
Feb I	**2.14**	**2.97**	2.07	1.64	2.64	2.40	***2.45***	***2.48***
Feb II	**2.52**	**3.01**	2.65	2.01	2.96	2.46	*2.83*	*2.66*
Feb III	3.12	2.76	3.43	2.01	3.45	2.54	*3.32*	*2.68*
Mar I	3.13	2.96	3.54	2.52	3.53	3.25	*3.51*	*3.13*
Mar II	3.37	3.03	3.67	2.99	4.24	3.49	*4.06*	*3.47*
Mar III	3.40	3.37	4.16	3.21	4.10	3.51	*4.06*	*3.58*
Apr I	3.56	3.44	4.01	3.64	4.19	3.40	*4.49*	*3.71*
Apr II	3.21	3.24	**3.75**	**3.85**	4.22	3.70	*4.36*	*3.88*
Apr III	3.96	2.84	3.65	3.10	3.96	3.53	*4.40*	*3.52*
May I	3.35	2.83	3.58	3.15	4.08	3.52	*4.19*	*3.33*
May II	3.52	2.98	**3.43**	**3.57**	**3.87**	**3.93**	*4.04*	*3.51*
May III	3.38	2.97	**3.28**	**3.32**	3.82	3.45	*3.97*	*3.29*

Note: Boldface values indicate increase in evaporation

6 Changes in Irrigation Water Requirement

6.1 Trends in reference crop evapotranspiration (ET_0)

To estimate irrigation demand, crop water requirement (ET_c) is to be estimated first. ET_c is obtained by multiplying the reference crop evapotranspiration (ET_0) with an appropriate crop factor (K_c). There are a large number of empirical methods, such as Blaney-Criddle, radiation, modified Penman, pan evaporation, etc., for estimating ET_0 from different climatic variables. After an evaluation of the performances of these methods under different climatological conditions, Allen et al. (1998) recommended the Penman-Monteith method of the Food and Agriculture Organization (FAO) as the standard method for determining ET_0. They have strongly discouraged the use of other methods, as well as other terms such as potential evapotranspiration. Therefore, the Penman-Monteith method was followed here for ET_0 computation. It is to be noted that the reference crop, according to this method, is hypothetical with a height of 12 cm, surface resistance of 70 s/m and albedo of 0.23. It closely resembles an extensive surface of green grass of uniform height, actively growing, completely shading the ground and with adequate water.

Maximum and minimum air temperature, air humidity, wind speed at a height of 2 m above the ground surface and solar radiation data are required to estimate ET_0. Bangladesh Meteorological Department (BMD) keeps records of daily values of these variables and the BMD data were used in this study. From the daily values, the ten-day average for each 10-day period having complete data for the period was obtained for each year and each month. There are 21 ten-day periods in the seven-month dry season (November-May). The first and second 10-day periods of each month always have 10 days, whereas the third 10-day period can have 10, 11, 8, or 9 days depending on the month and the year. From the 10-day maximum and minimum temperature, relative humidity, wind speed, and sunshine duration, the 10-day ET_0 for each year, each month and for each 10-day period was computed using the FAO software package, CROPWAT. This ET_0 computation process takes a lot of time as the input data require new entries for each ET_0 estimation and as there is no option for reading the input file. The trends in ET_0 values are shown in the graphs in Appendix IV for Bogra.

It is seen from these graphs that the ET_0 values have in general decreasing trends. The decreasing sunshine duration is mainly responsible for this decreasing trend in ET_0.

6.2 Trends in net irrigation requirement

The net irrigation requirement (NIR) is the difference between ET_c and rainfall. The ET_c depends on crop coefficient (K_c), which varies with the development stage of a crop. The objective of this report is to see the long term changes in irrigation requirement. So, ET_0 was used in place of ET_c for the estimation of NIR. This will give crop water requirement which is very close to the combined rice and non-rice crop evapotranspiration during the dry season (November-May). The estimated NIR for the dry season is shown in Figure 26 for two time periods: 1960-1980 and 1981-2001. It is seen from the figure that NIR has generally decreased during 1981-2001 compared to 1960-1980. The average dry season NIR was found to be about 2.6 mm/day (551 mm per season) during 1960-1980 and 2.4 mm/day (509 mm per season) during 1981-2001. The decrease is about 7.8%. This result indicates that, due to climate change, the overall irrigation demand has not increased rather it has decreased. This finding is contrary to the general belief that, due to global warming induced climate change, irrigation demand would increase. The decrease in demand is due to the decrease in ET_0 values and increase in rainfall as reported earlier.

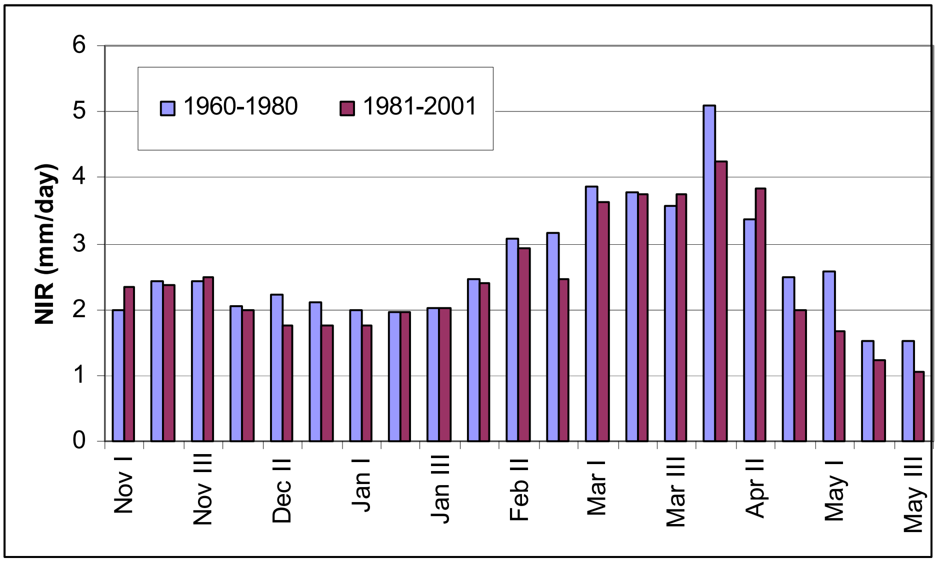

Figure 26: Bar diagram of net irrigation requirement (NIR) at Bogra during different 10-day periods of the dry season for two time periods.

The 10-day trends during the dry season in NIR values were also estimated. The trends were found to be 1.0, 0.3, -0.2, 0.5, -0.8, -0.6, -0.4, 0.6, -0.6, -0.2, -0.7, -2.7, -1.9, 0.8, -0.1, -2.2, 2.5, -2.6, -4.1, -1.1 and -1.4 mm/day per century from the first 10-day period of November to the last 10-day period of May, respectively. These trends, however, are not statistically significant, except for the last 10-day period of February. It is to be noted that if a non-parametric method is applied, the positive trend of the second 10-day period of November becomes negative.

7 Agricultural Aspects

The implication of the long-term changes in climatic variables on agricultural productivity, and hence food security, of the country is an area where Bangladesh needs to explore intensively. Under this small assignment, the trends are found out for years, months and 10-day periods. If the trends reported herein for temperature, rainfall, sunshine, etc. are considered along with the crop calendar (Figure 27) it may be possible to anticipate the impact of climate changes on crop yields by comparing the critical values of the climate variability for different crops in different stages of growing periods. For example, under a study, CEGIS prepared the length of the development stages of different crops as shown in Tables 17 and 18 based on field information and available literatures. The presented values can be adjusted on the basis of the specific varieties of crop, location and growing season. If the critical values of temperature, rainfall and other parameters are known at different stages of crops, the impact on yield can be evaluated.

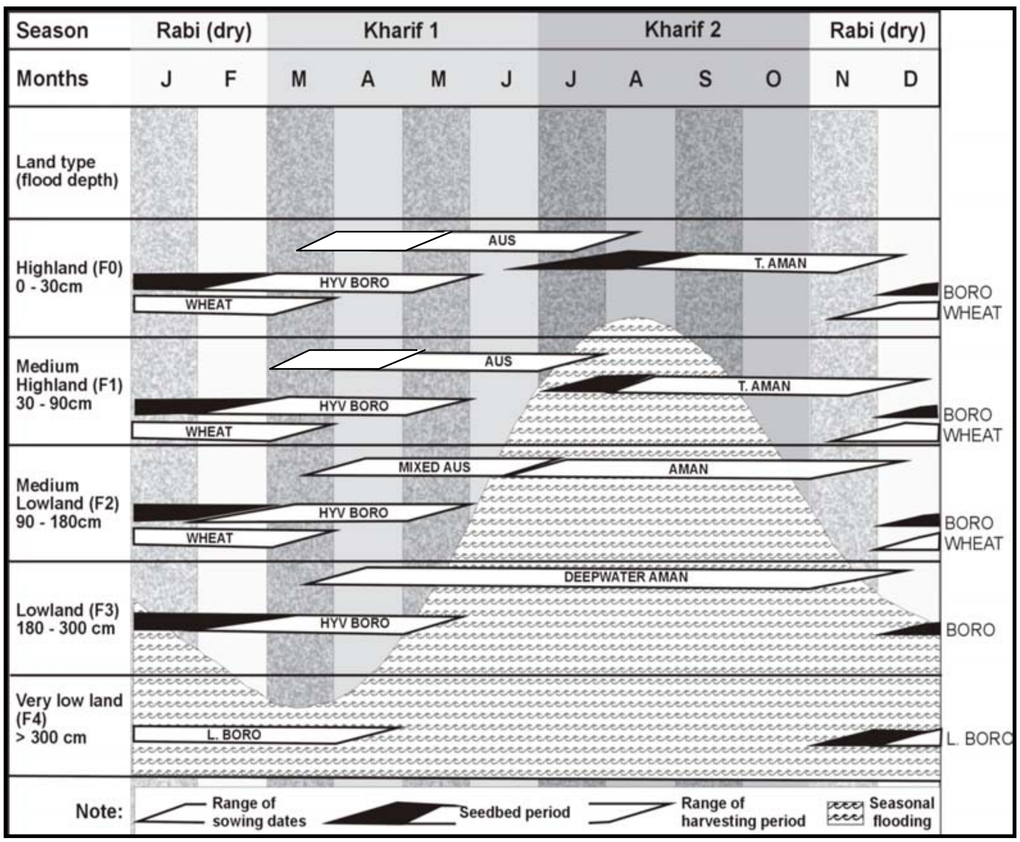

Figure 27: Generalized flood phase/land type with crop calendar for rice crops

Table 17: Length of the growing stages of transplanted rice crops

Crop	Stages in days						Median transplanting date
	Nursery	Vegetative	Flowering	Yield formation	Ripening	Total	
T. Aus	25	50	15	15	10	115	May-1
T. Aman	30	65	15	20	10	140	Jul-21
Boro	35	70	15	25	10	155	Jan-21

Table 18: Length of the growing stages of other crops

Crop	Stages in days					Median sowing date
	Initial	Development	Mid	Late	Total	
Wheat	15	25	45	25	110	Nov-21
Pulses	20	25	35	25	105	Nov-11
Mustard	20	30	20	20	90	Nov-1
Potato	25	25	20	20	90	Nov-11
Onion	15	25	40	20	100	Dec-11
B. Aus	25	45	20	20	110	Apr-21
Jute	25	35	40	20	120	Apr-21
Til	20	30	20	20	90	Mar-21
Sugarcane	30	60	180	90	360	Dec-1
Banana	90	90	90	90	360	May-1

To evaluate the impact of changes in climatic variables on agriculture, knowledge of physiological processes and phenological development of a crop with climatic variables is essential. The increase in temperature may have a positive impact on rice production. In the range of temperature between 10 ^{0}C and 28-32 ^{0}C, any increase in temperature is considered to be beneficial for rice yield. The production level remains stagnant till the temperature of 40 ^{0}C, and beyond this temperature, yield decreases with the increase in temperature. The most adverse impact on crop production may come from the reduction in sunshine duration. The optimum day length for rice is about 8-10 hours. The relation between light and CO_2 assimilation due to photosynthesis is non-linear and convex in shape. Due to a reduction in day length of 25%, the yield may reduce by 15-20% in typical day length experienced in Bangladesh. It appears that we should pay much attention to the dimming of solar radiation caused by pollution, land use change and urbanization. To investigate the combined effects of temperature and sunshine on crop production can be an interesting topic for further investigation.

8 Concluding Remarks, Limitations and Future Directions

Based on the findings of this study, the following conclusions are drawn:

I. Mean winter (November-February) rainfalls during the period of 1981-2001 are found to be 33% higher than that of 1960-80. Average summer (March-May) rainfalls were 428 mm during 1960-80 and 544 mm during 1981-2001; the increase is 27%. Critical period (11 March-10 May) rainfalls have increased by 31% from 238 mm during 1960-80 to 313 mm during 1981-2001. Monsoon (June-October) rainfall changes are mixed – five stations show decreases and 3 stations show increases. At a monthly scale, the rainfalls are found to have increasing trends except for the months of June and July when they are found to have decreasing trends. Analysis of 10-day data revealed that rainfalls have increasing trends at all stations during 21 April to 31 May. This increase is unambiguous and consistent across all stations. The decrease in July rainfall is mainly due to the decrease in the second 10-day rainfall of this month which is the peak monsoon period. This decrease was also reflected in the annual maximum rainfall which shows a decreasing trend. However, the annual maximum rainfall shows increasing trends along the east and north of the country which is the main route of traverse of the monsoon. The results of rainfall analysis are consistent with that of Rahman et al. (1997), Singh and Sontakke (2002) and Mondal and Wasimi (2004). The results are also consistent with the IPCC (2007) projections for South Asia for summer and critical period. However, they are not supportive of IPCC (2007) projections for winter and monsoon.

II. The temperature data of all 34 stations were analyzed. Both daytime (maximum) and night-time (minimum) temperature are found to have increasing trends. The increasing trends have become stronger in recent decades since 1980 compared with the long-term trends since 1948 for all periods except winter. The trends in mean temperature are found to be +1.33, +2.15 and +2.44 ^{0}C per century during winter, summer and monsoon seasons, respectively, since 1980. The annual trend is found to be +2.14 ^{0}C per century. The IPCC projection is higher than the current trend, however, it is realistic in that the current trend is higher than the long-term trend and it may strengthen in future. It appears from this study that the use of recent data, rather than the long-term data, may provide better inference about future changes in temperature and hence warming.

III. The bright sunshine duration at 34 stations of Bangladesh were analyzed. It is found that the winter, summer and monsoon sunshine are declining at 5.7%, 3.9% and 3.8% per decade, respectively. The overall annual decrease for the entire Bangladesh is about 4.7% per decade. There are some spatial patterns in the declining rates – the rate increases from the south to the north and from the east to the west. Urban areas show somewhat more dimming compared with nearby less urbanized areas.

IV. Evaporation at 11 stations was analyzed and found to be decreasing.

V. Evapotranspiration (ET) for dry season was estimated using the Penman-Monteith method and observed climatic data and was found to be decreasing. This is the first time in Bangladesh an ET time series has been computed to investigate its trend. ET represents the combined effect of temperature, sunshine, humidity and wind on evaporation from soil and transpiration from crops (typical dry season crops, such as rice, wheat, potato, etc., in this case).

VI. Net irrigation requirement depends on crop evapotranspiration requirement and rainfall. Since ET has a decreasing trend and rainfall has increasing trend, the net irrigation requirement is found to be decreasing over time. This is contrary to the general belief and results reported in literature based on modeling studies that due to climate change irrigation water demand will increase. The increases in demand were found either because all the climatic variables were not considered to see their combined effects or inappropriate projection about possible changes in some variables due to modeling limitations.

VII. The reduction in sunshine duration is likely to adversely affect the rice yield. The optimum day length for rice is about 8-10 hours. The relation between light and CO_2 assimilation due to photosynthesis is non-linear and convex in shape. Due to a reduction in day length of 25%, the yield may reduce by 15-20% in typical day length experienced in Bangladesh provided that other factors remain constant. However, this aspect needs further study.

The conclusions drawn above from this study have the following limitations:

I. Rainfall and evaporation were analyzed at eight and eleven stations, respectively. The recent data since 2002 were not available. The conclusions would have been robust if more stations and recent data could be included.

II. The quality of BWDB evaporation data is suspected in many cases. Many missing and absurd values were in the data sets. The results of the analysis should be interpreted with due consideration of this limitation.

III. In this study, a very preliminary assessment of the effect of decreasing sunshine on rice yield is made. As other parameters are simultaneously changing with the sunshine, the combined effect of these parameters should be assessed.

In light of the experience gained during the course of this work, the following recommendations are made:

I. Some of the results reported in various literatures from modeling studies appear to be inconsistent with the existing climatic trends in Bangladesh. Rainfalls in winter and monsoon, crop evapotranspiration and dry season irrigation demand are among them. The reasons could be that all the processes, dynamics and feedbacks involved in the sun, atmosphere and earth systems are still not adequately represented in the climate models. We recommend for such representation, and updating of future projections in light of the existing trends found in this study. This report may serve as a base document in that respect.

II. This study, for the first time, reveals that sunshine is decreasing in Bangladesh. The potential effects and impacts of such decreases on different sectors including agriculture and health should be investigated. One such study could employ a crop growth model to simulate the effect of such changes in climatic variables on grain and biomass production. Measured field data on crop physiology and management practices would also be used in such studies. Furthermore, national, regional and global initiative and action should be undertaken to arrest atmospheric pollution, land use change, spiraling energy consumption, population growth, etc., as mitigation measures.

III. Humidity, wind and cloud coverage data were not analyzed in this study. In future, the study can be updated incorporating these variables. A standard software package can be developed with embedded GIS and Statistical modules so that DoE can update the climatic data and carry out the analysis on its own. A technical training can be arranged for the DoE juniors to mid level officials in this purpose.

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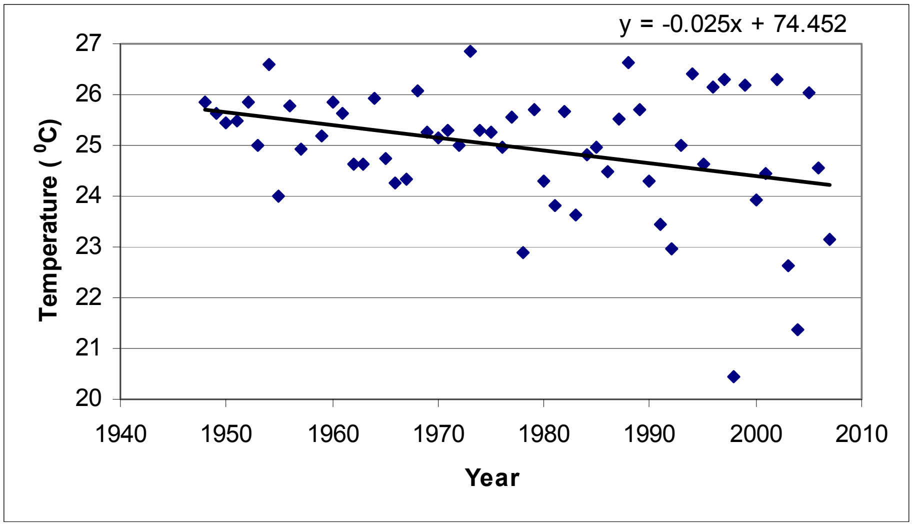
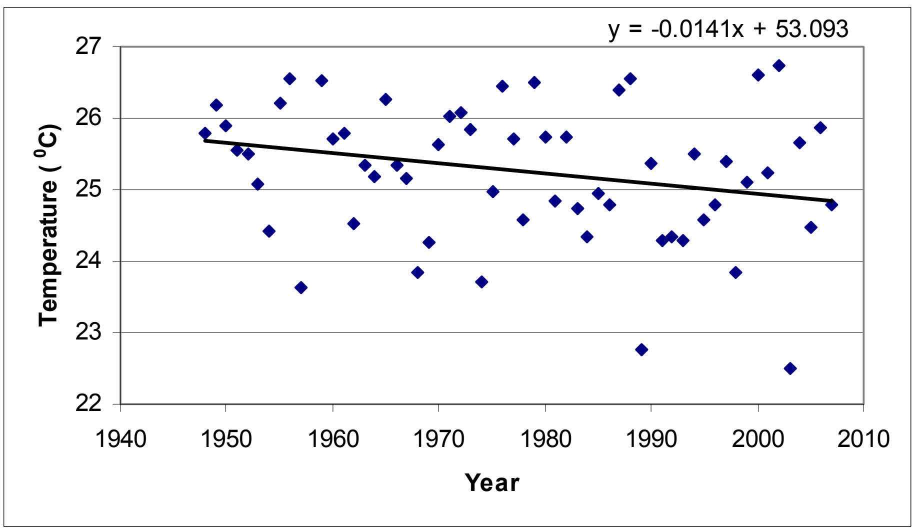
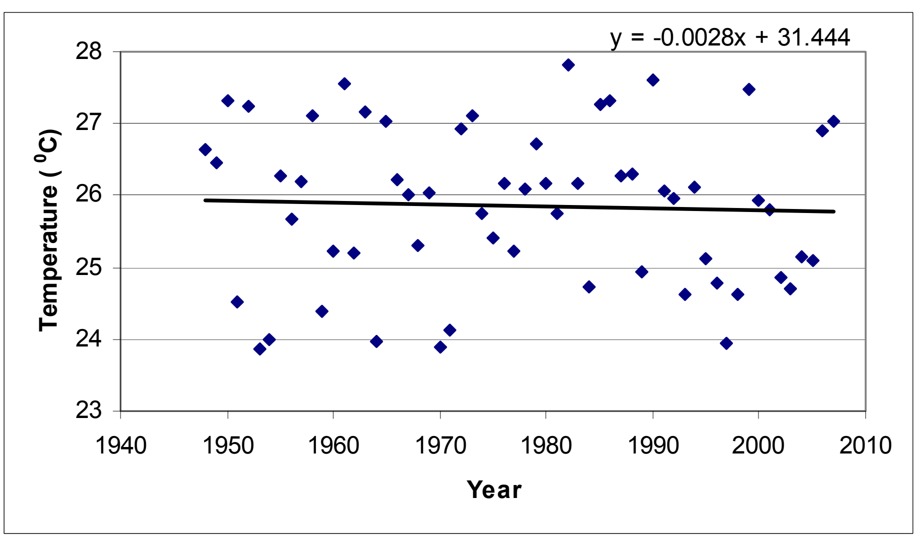
Annex I:

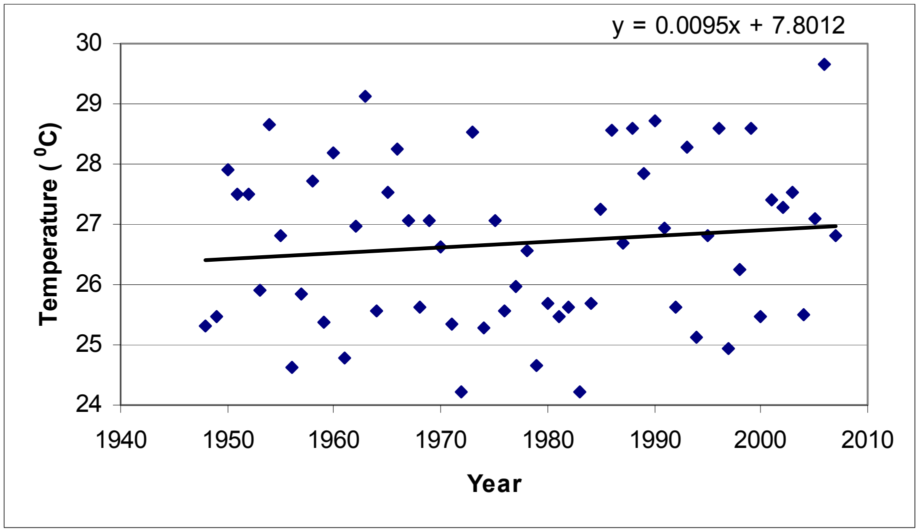
Graphs on trends in 10-day average maximum temperature in Bangladesh

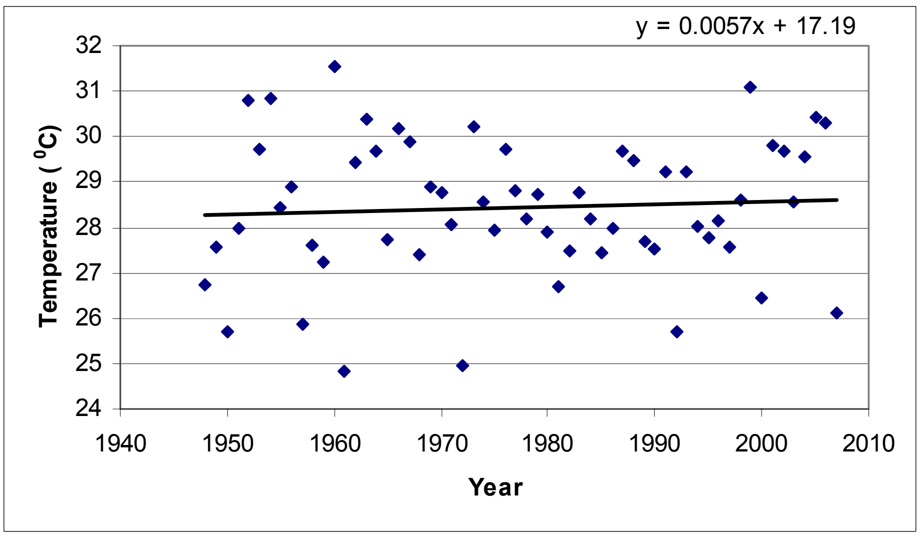


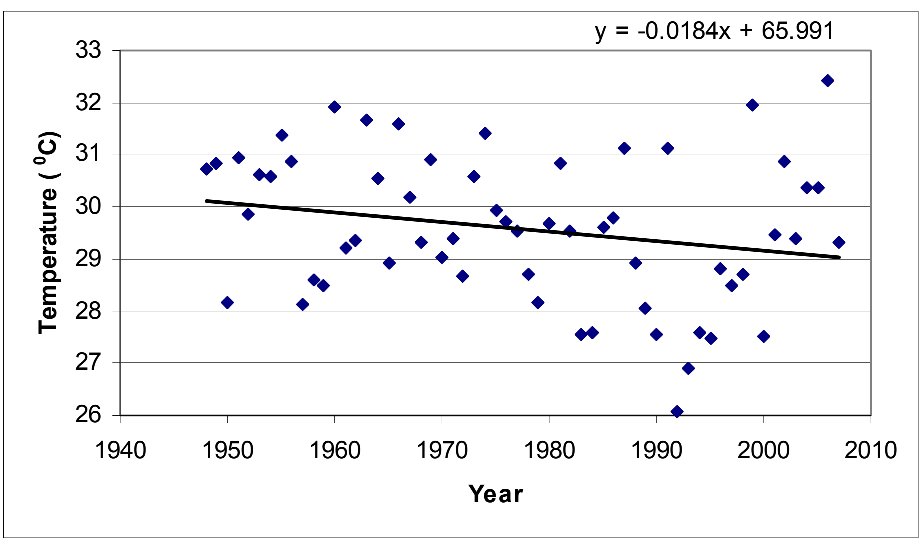




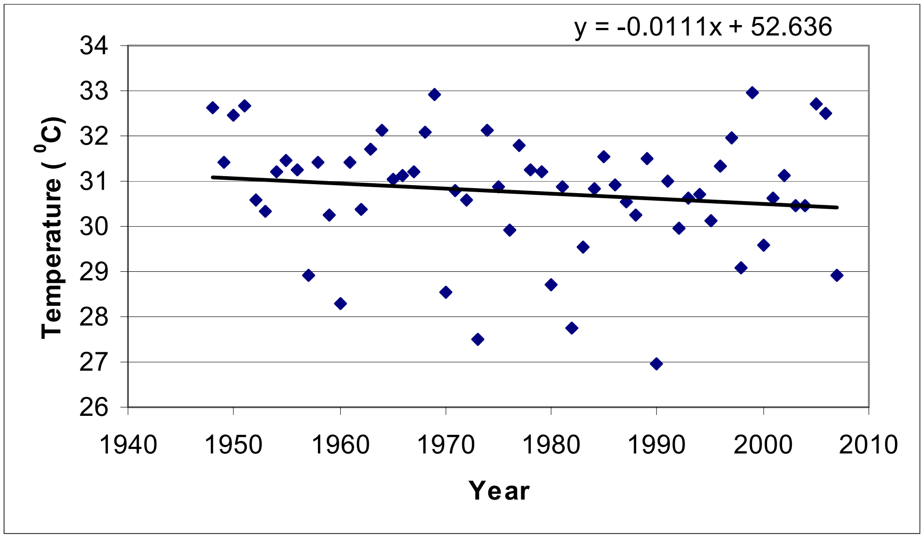
Annex I: Trends in 10-day average maximum temperature in Jan I, Jan II and Jan III (from top to bottom)

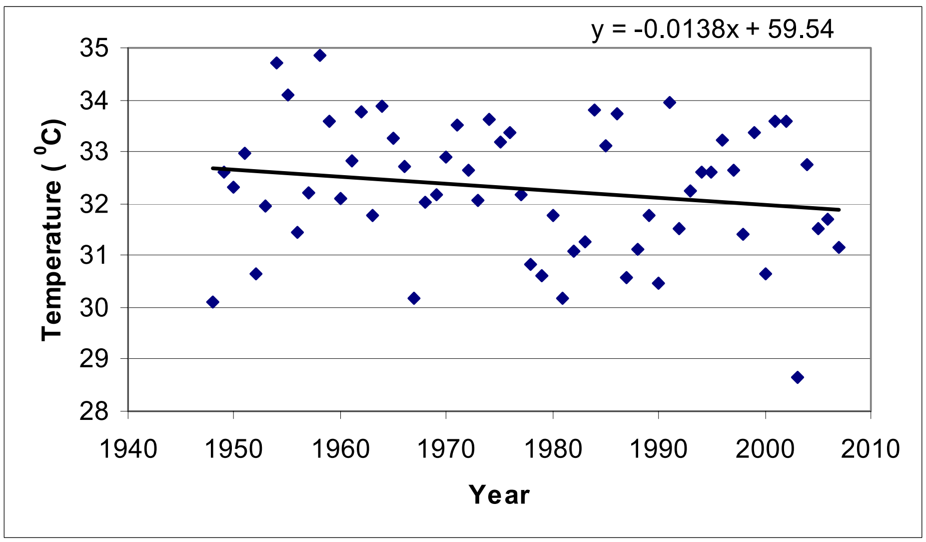


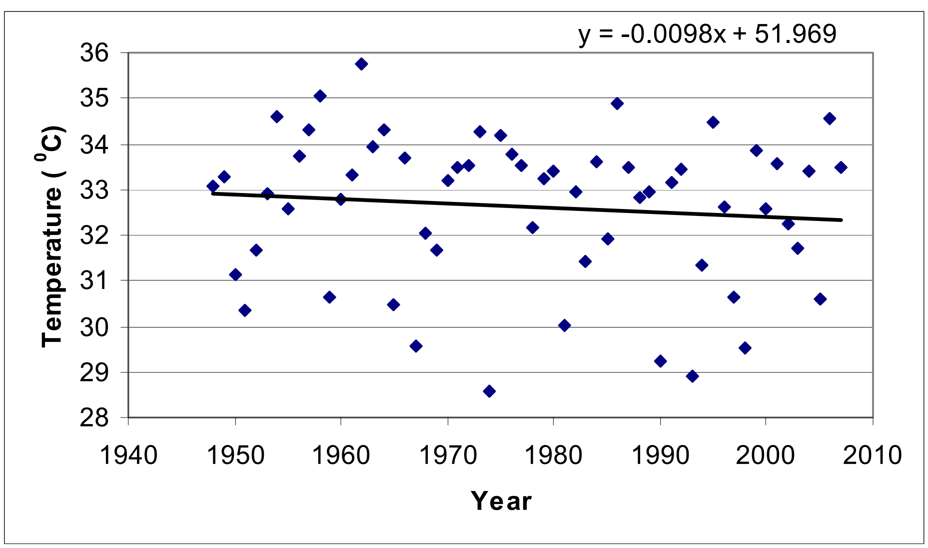




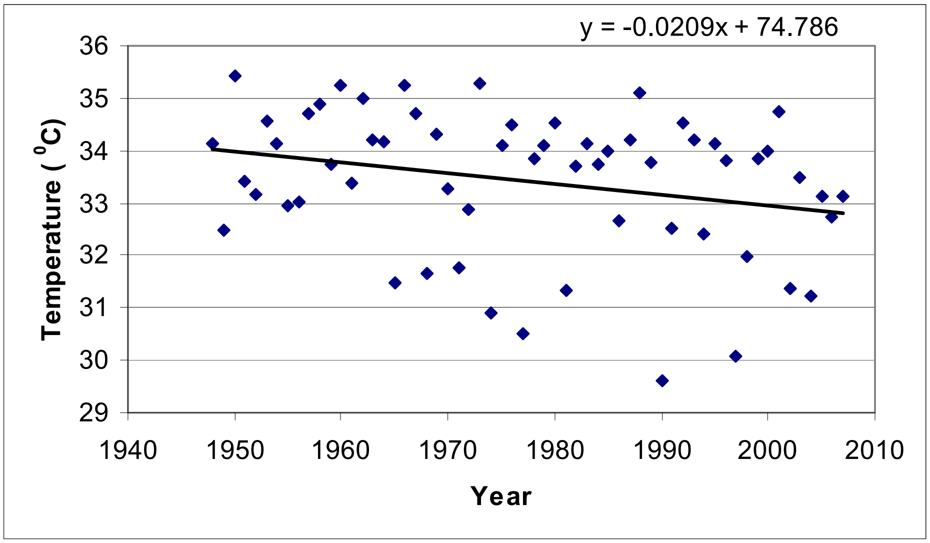
Annex I: (continued) for Feb I, Feb II and Feb III (from top to bottom)

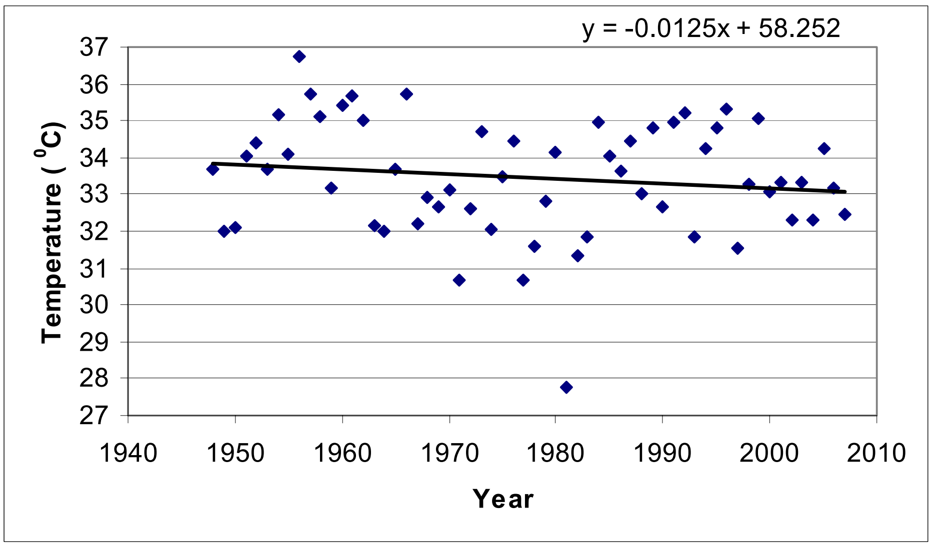


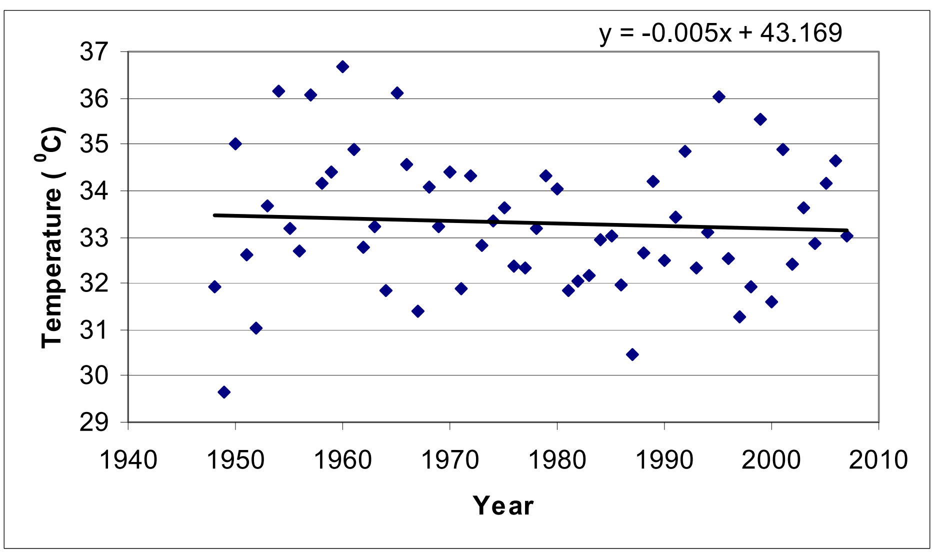




Annex I: (continued) for Mar I, Mar II and Mar III (from top to bottom)







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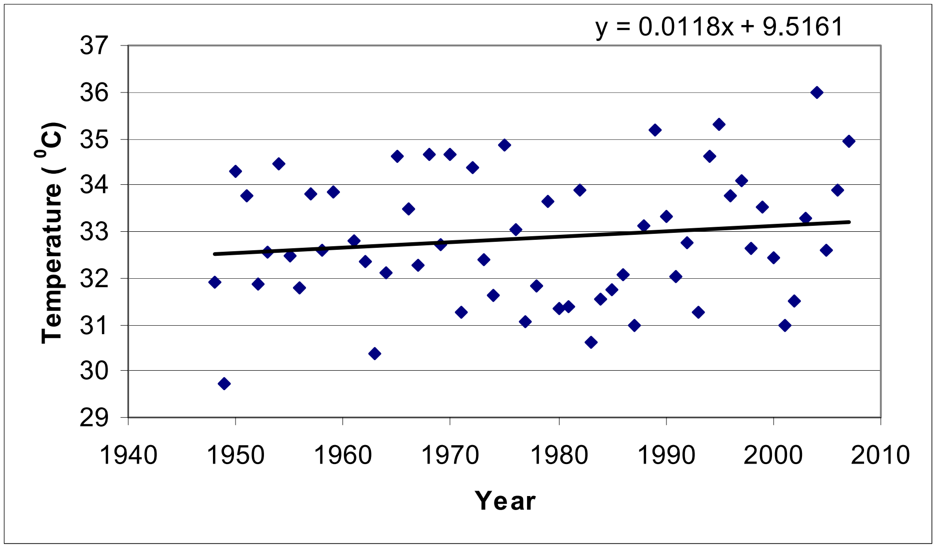
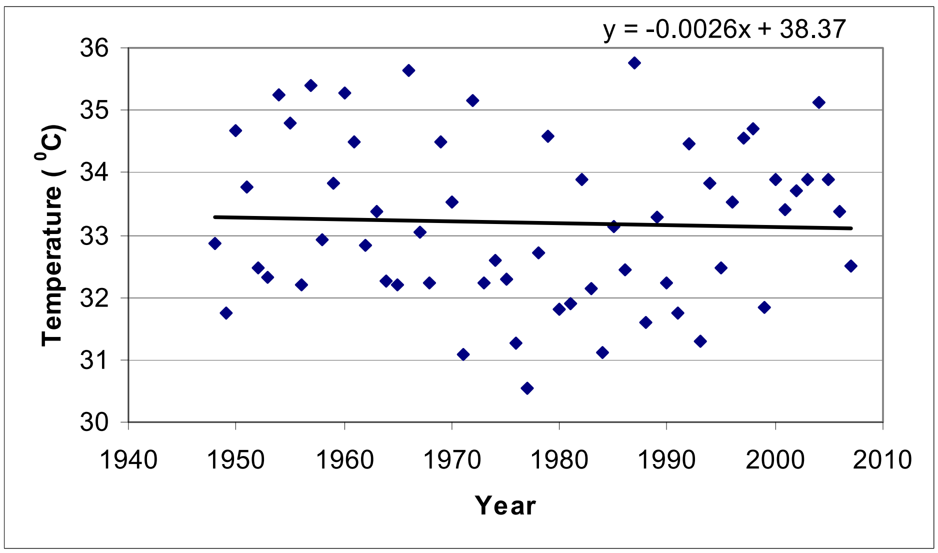
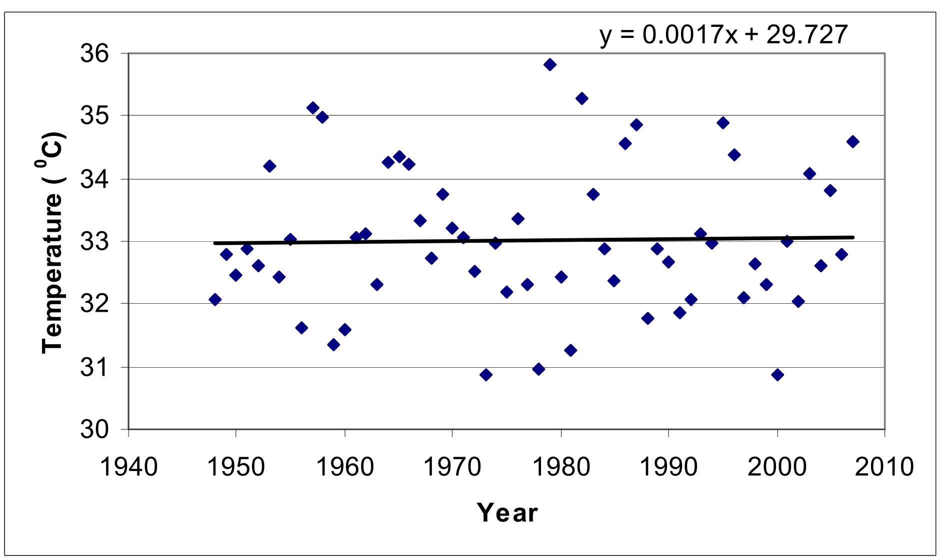
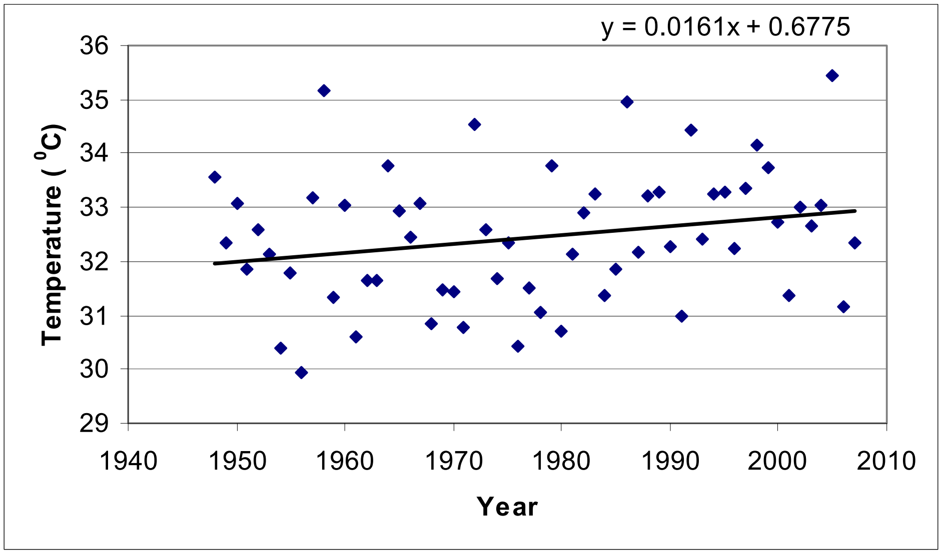
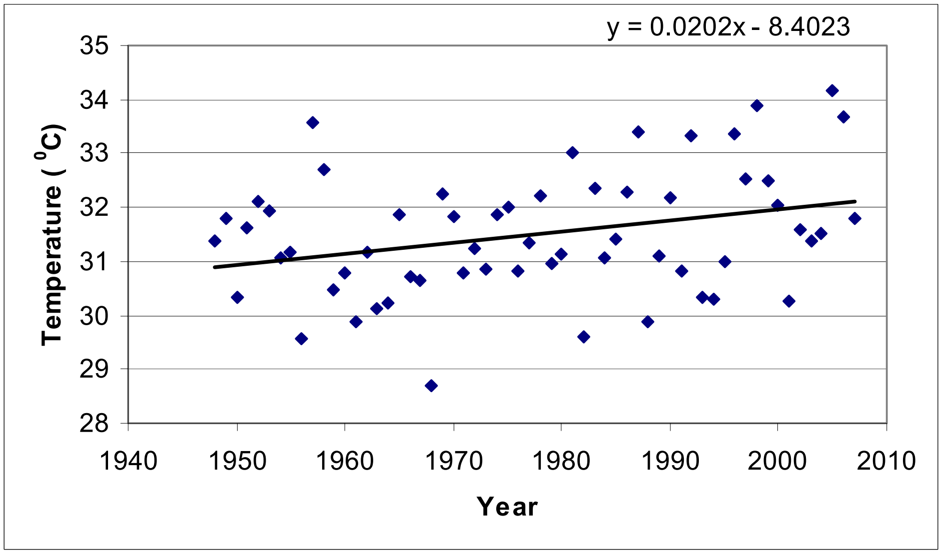


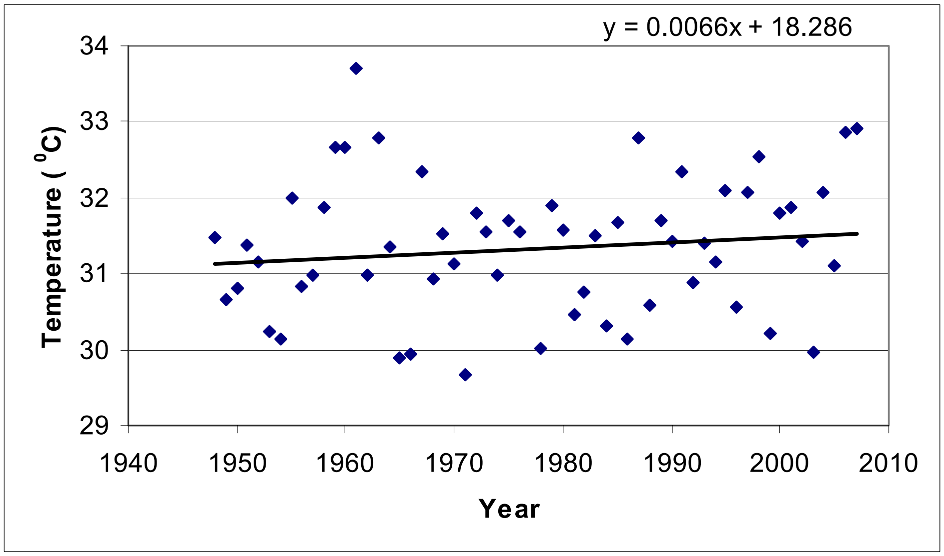




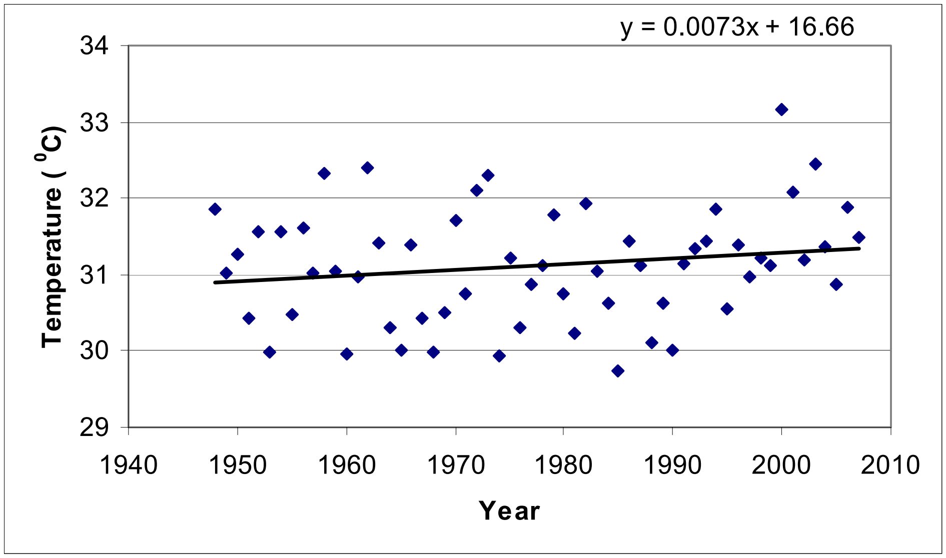
Annex I: (continued) for May I, May II and May III (from top to bottom)

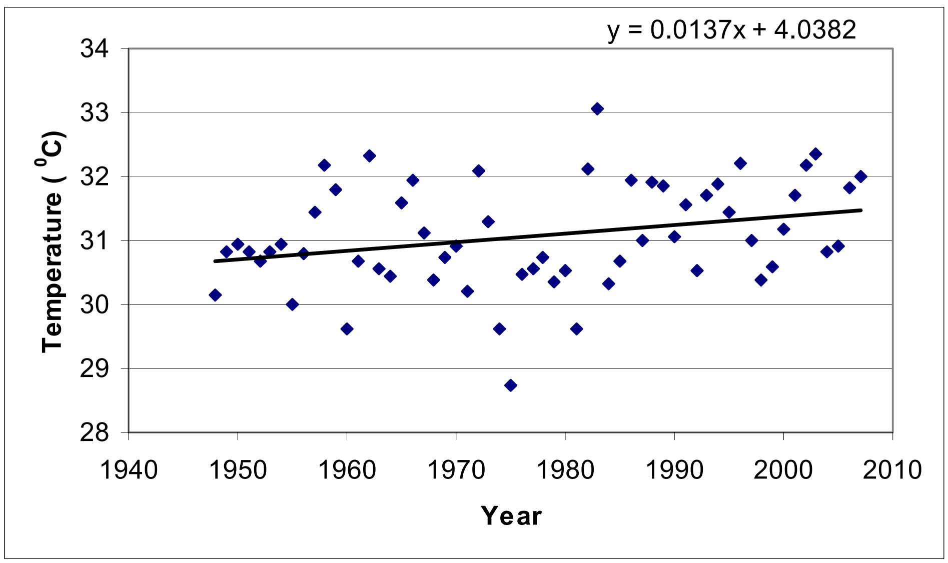


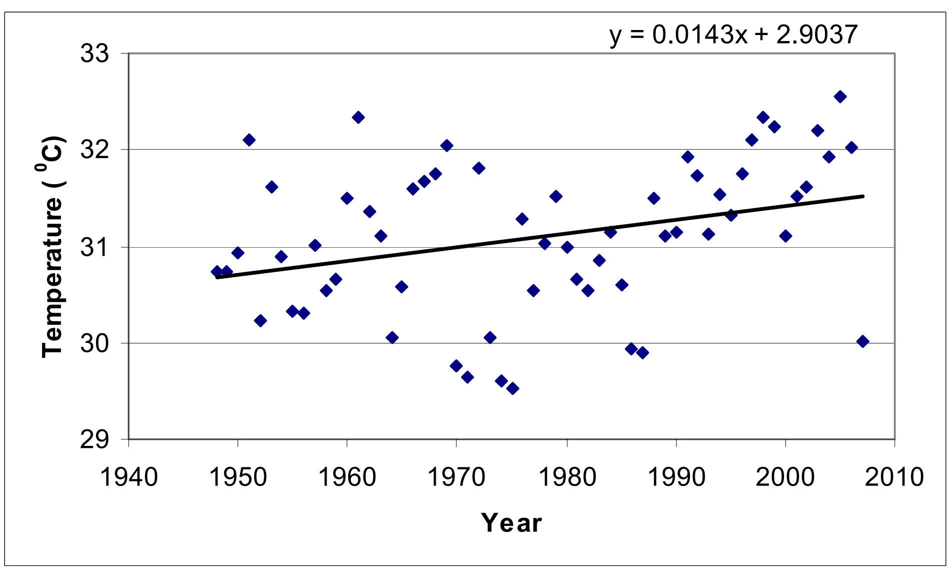




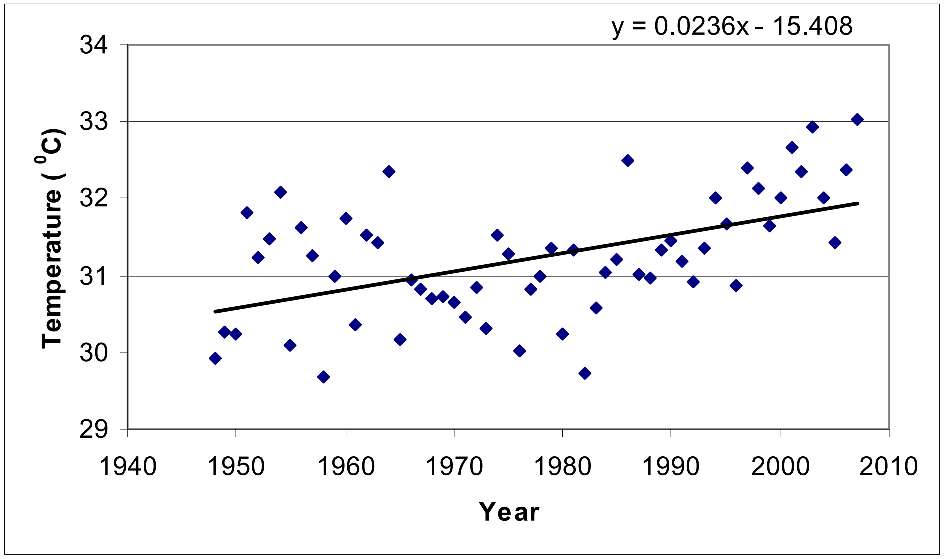
Annex I: (continued) for Jun I, Jun II and Jun III (from top to bottom)

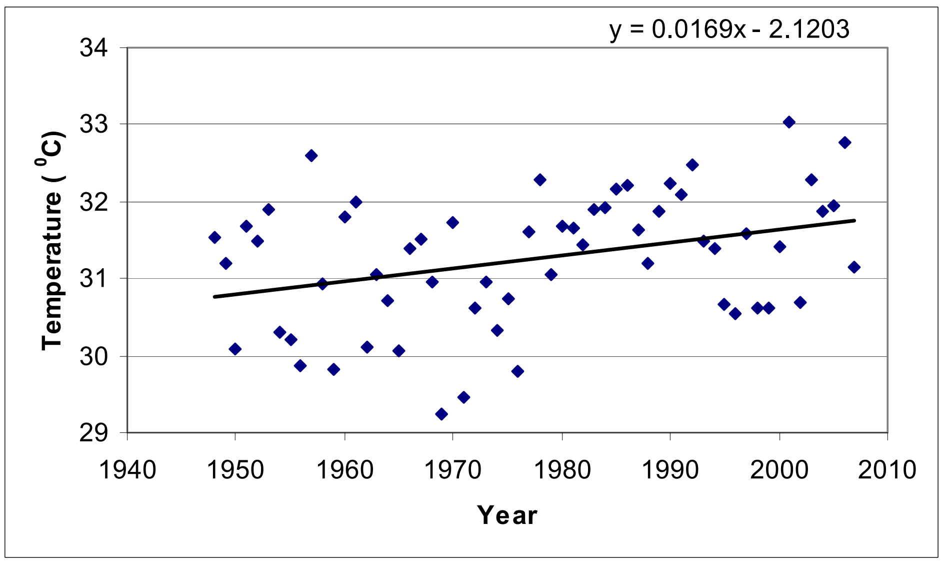


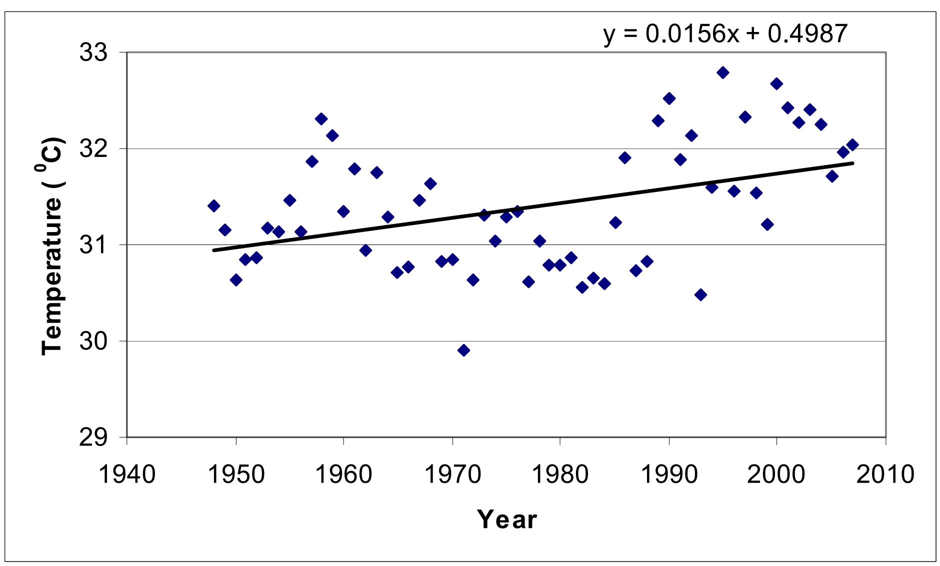




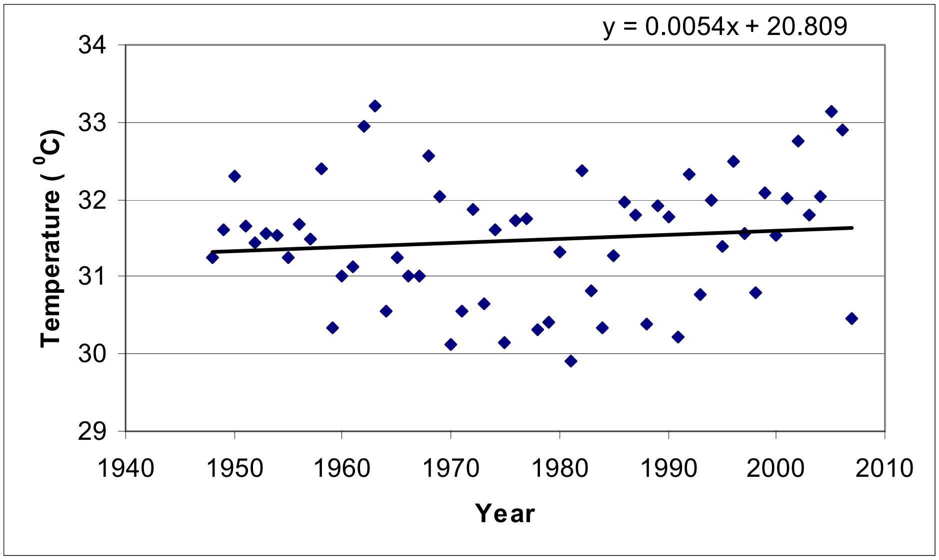
Annex I: (continued) for Jul I, Jul II and Jul III (from top to bottom)

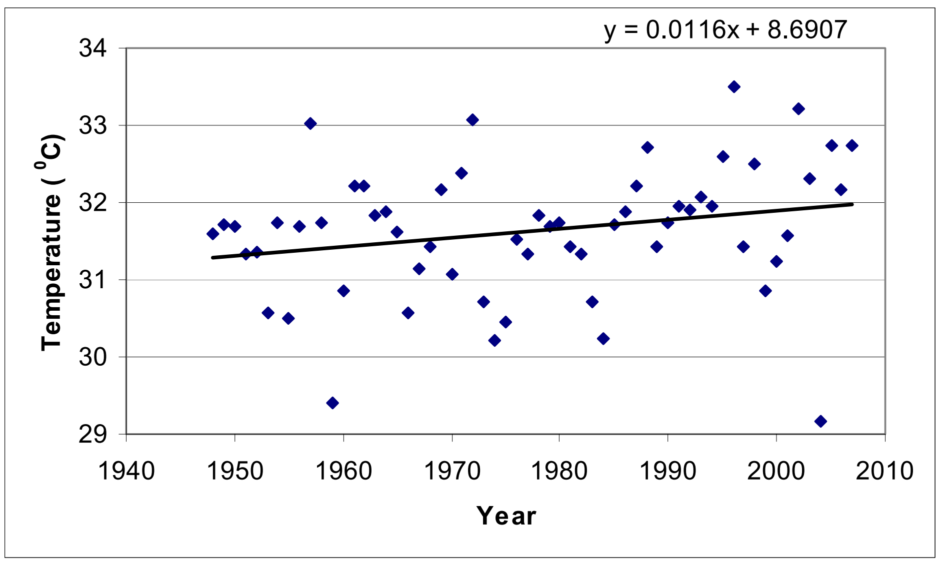


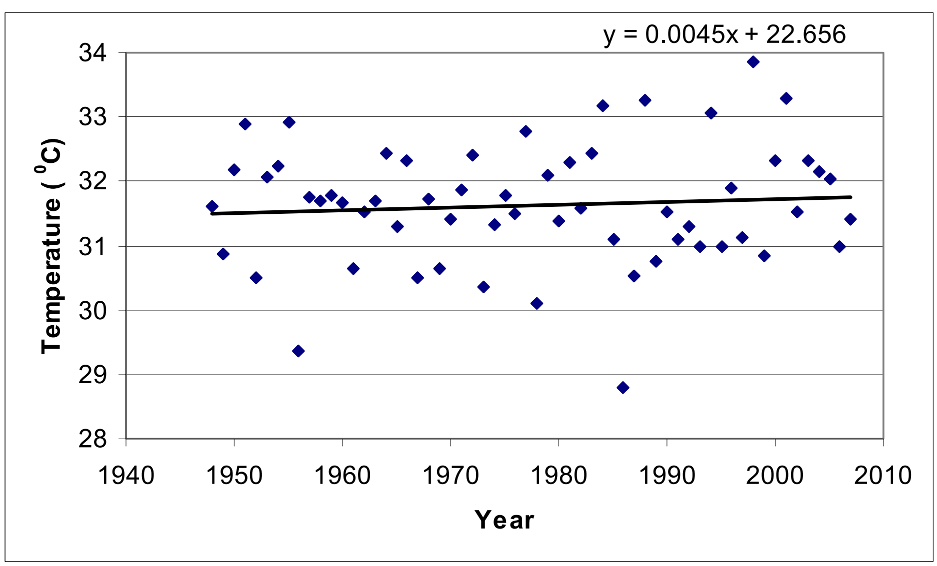




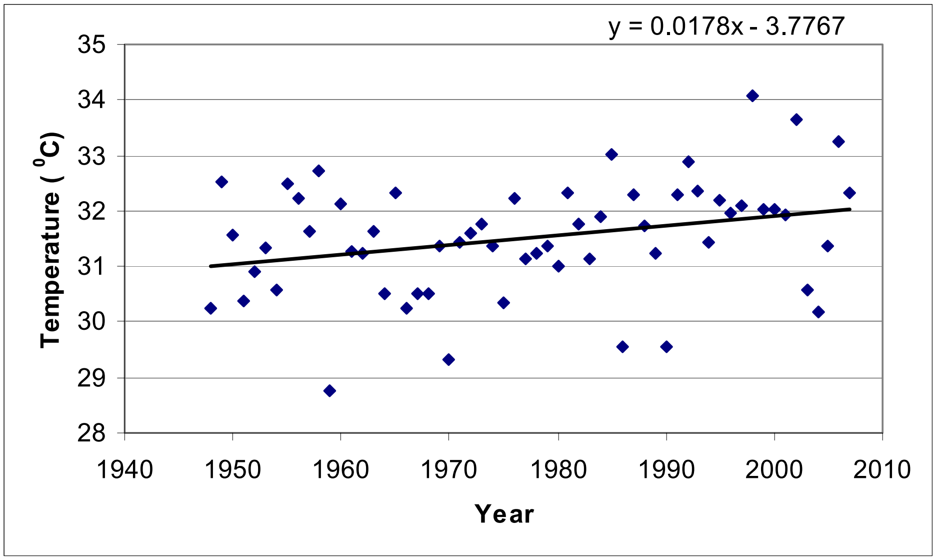
Annex I: (continued) for Aug I, Aug II and Aug III (from top to bottom)

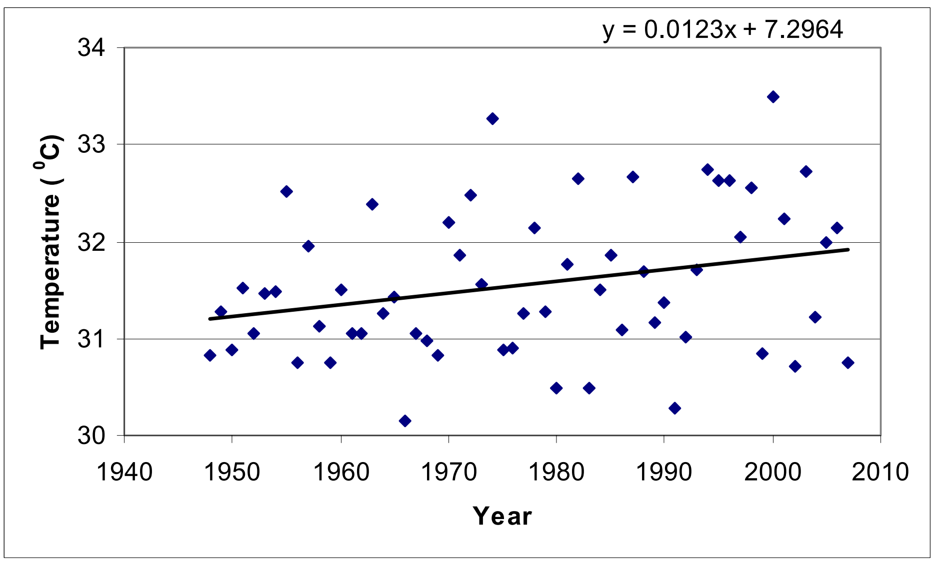


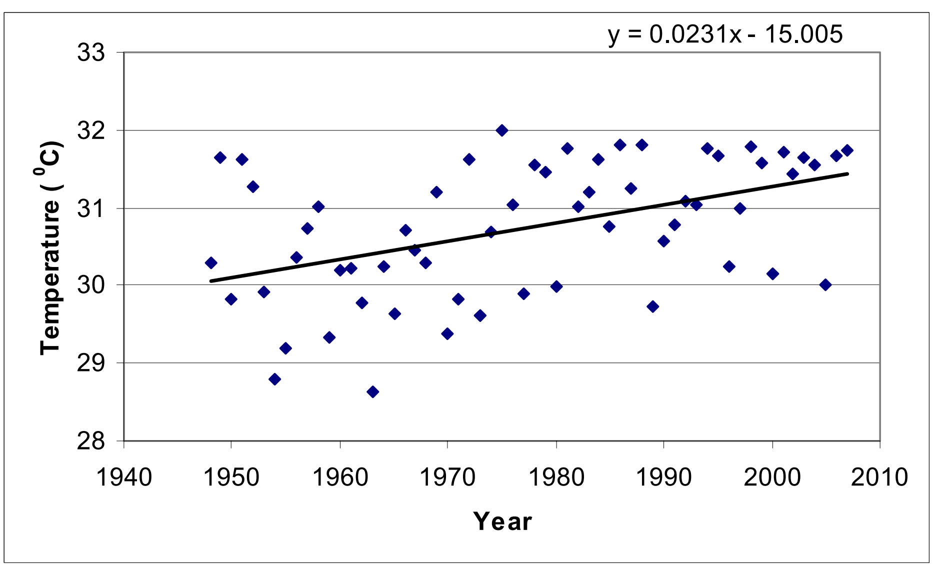




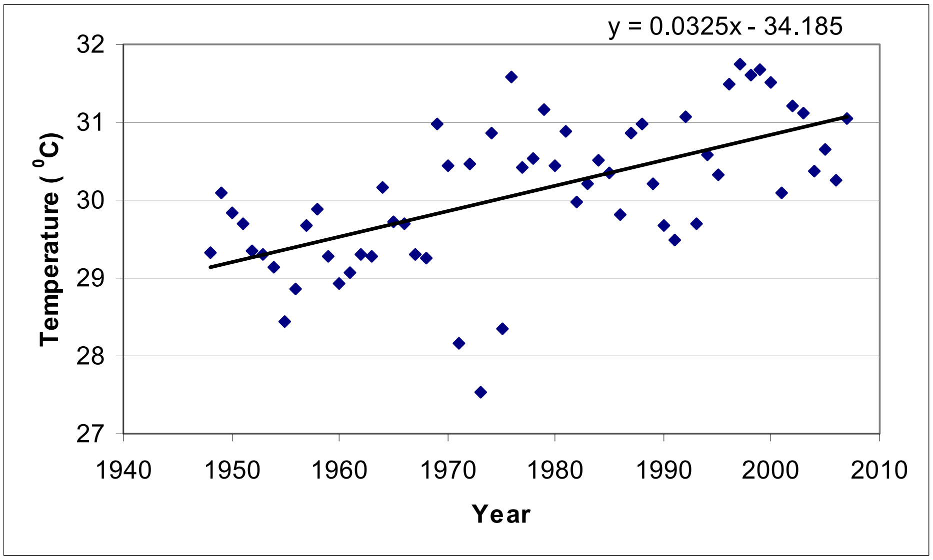
Annex I: (continued) for Sep I, Sep II and Sep III (from top to bottom)

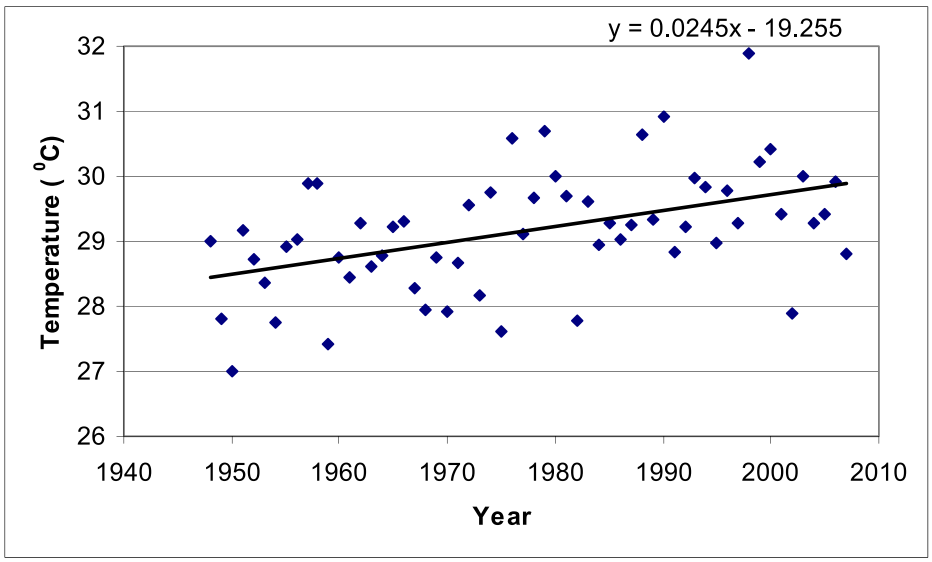


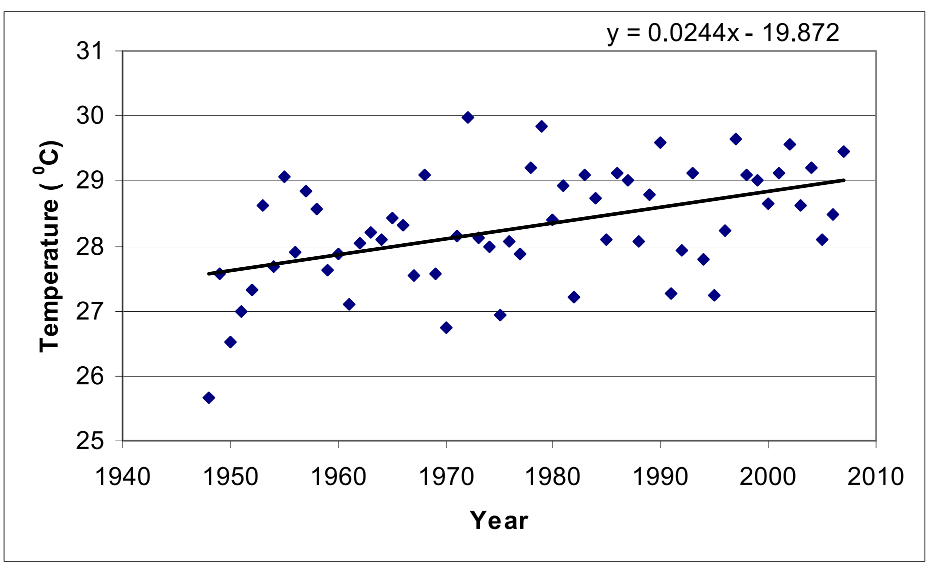




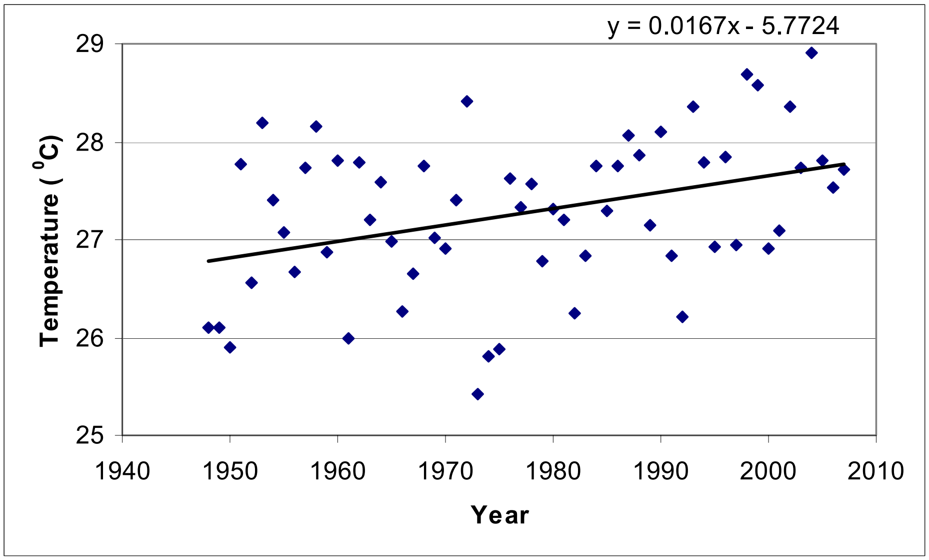
Annex I: (continued) for Oct I, Oct II and Oct III (from top to bottom)

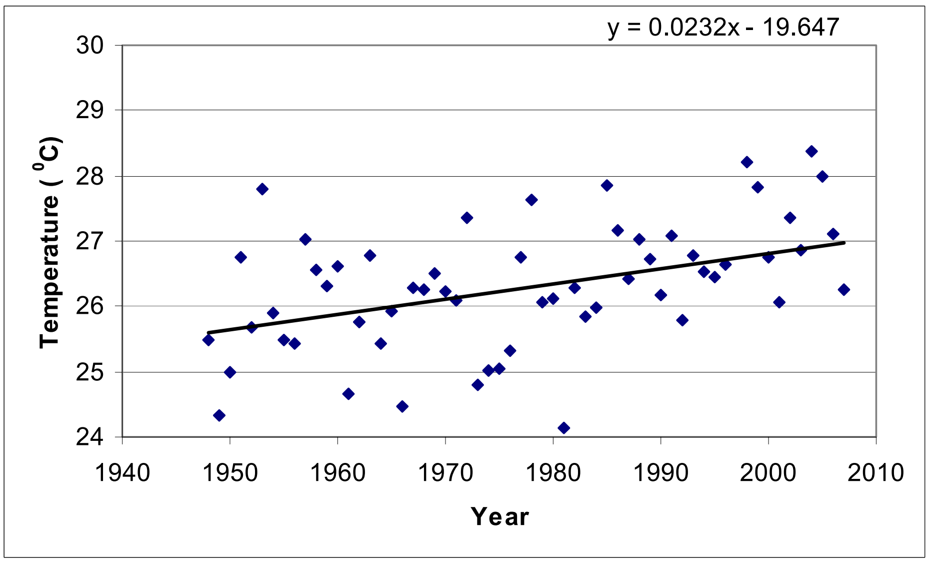


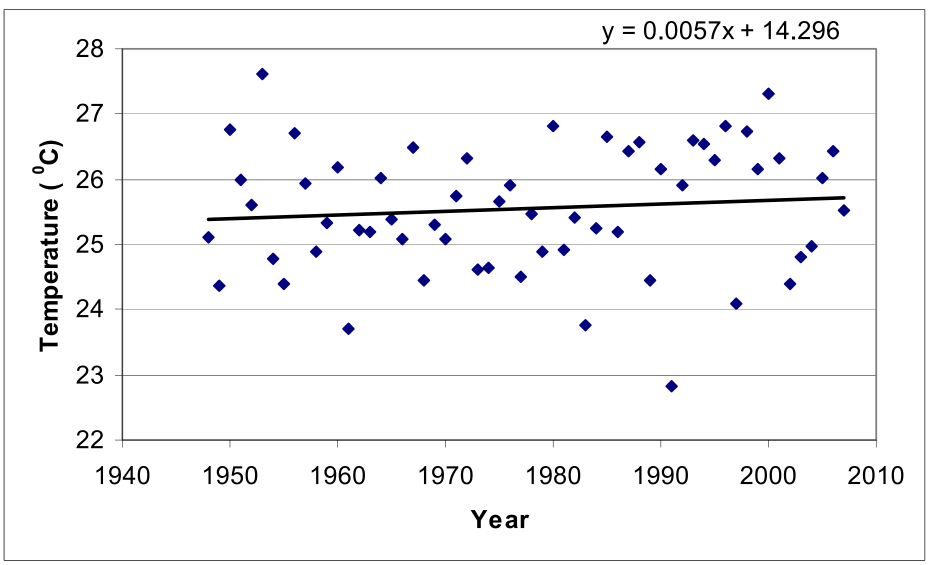




Annex I: (continued) for Nov I, Nov II and Nov III (from top to bottom)



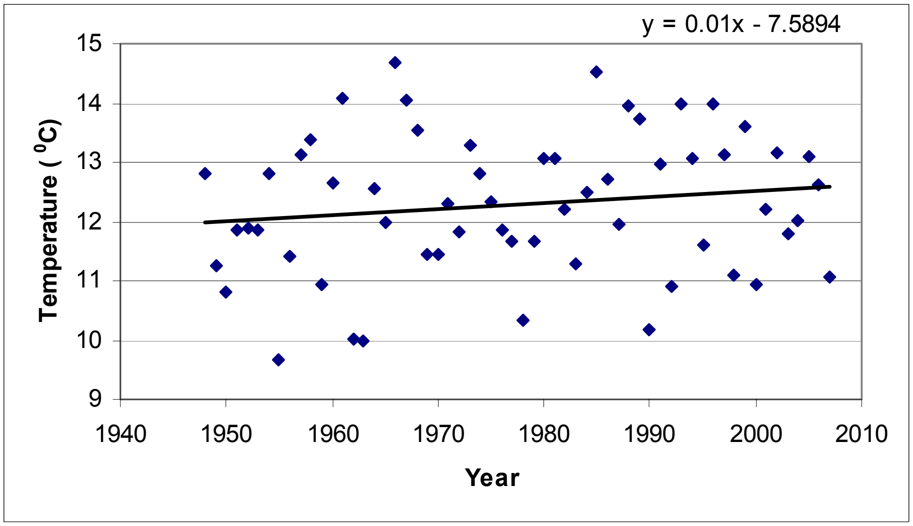


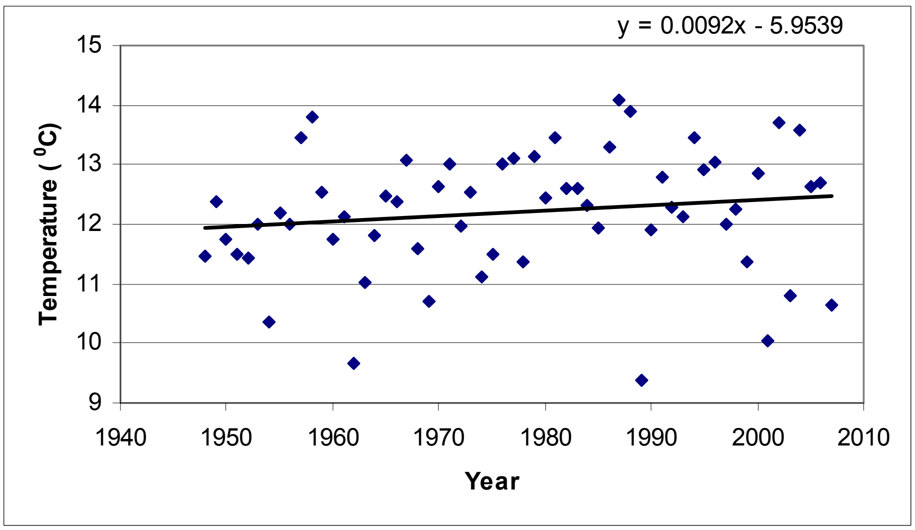


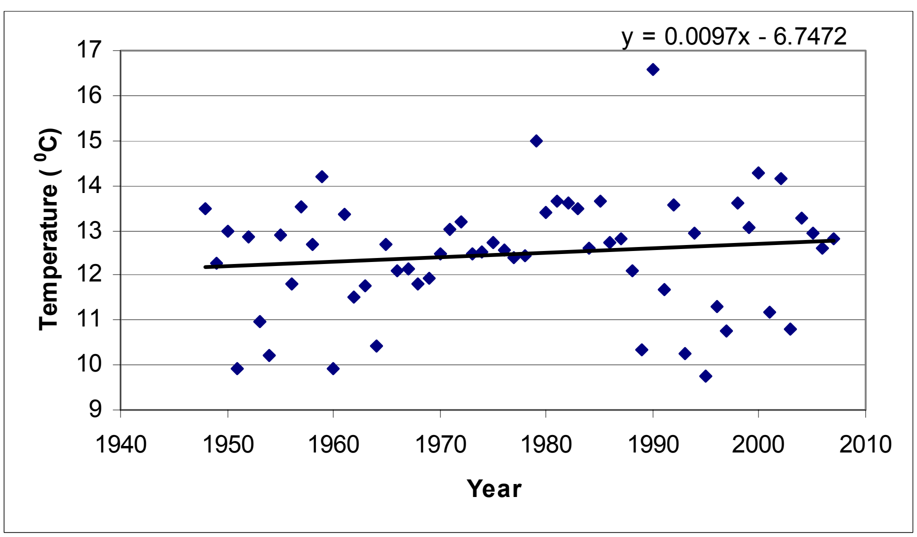
Annex I: (continued) for Dec I, Dec II and Dec III (from top to bottom)

Annex II:

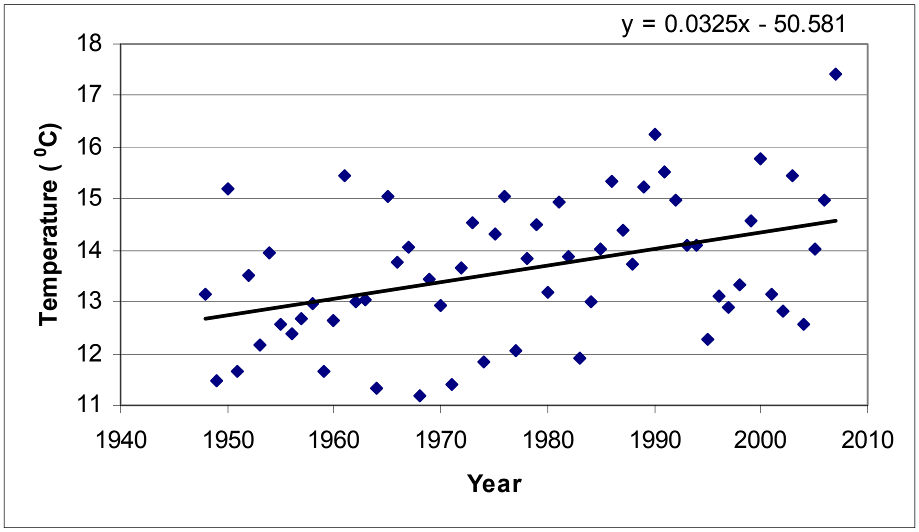
Graphs on trends in 10-day average minimum temperature in Bangladesh

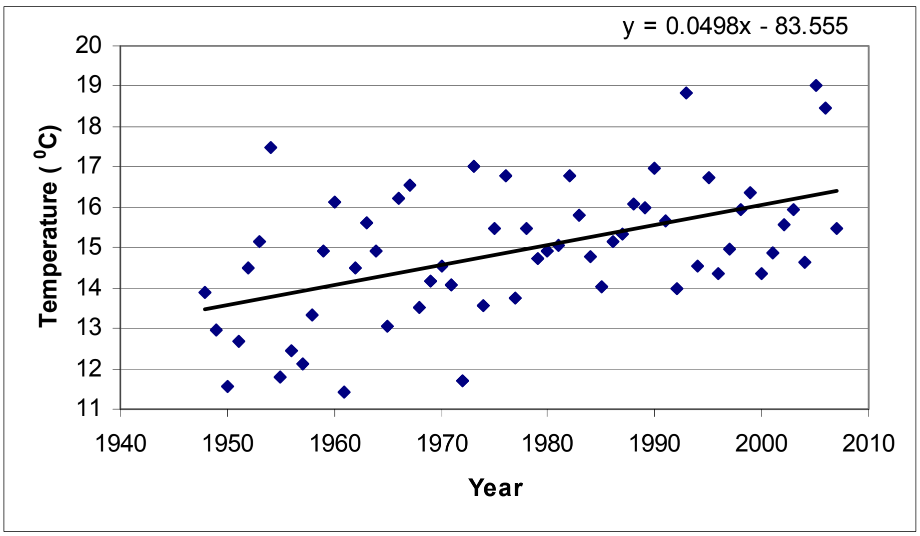


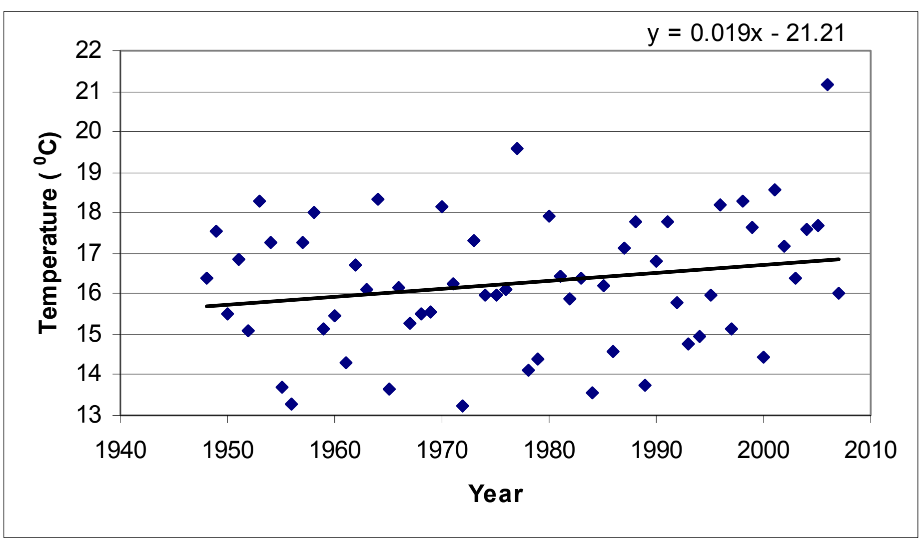




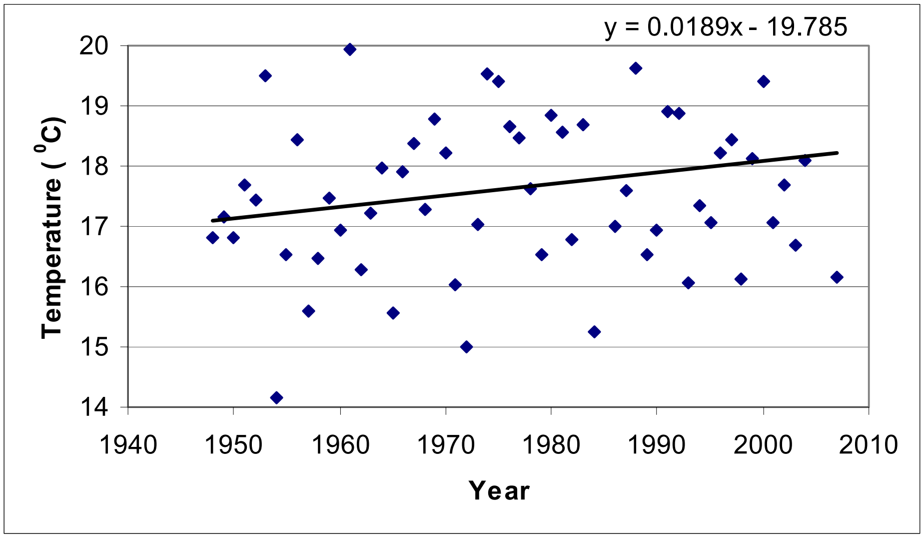
Annex II: Trends in 10-day average of minimum temperature in Jan I, Jan II and Jan III (from top to bottom)

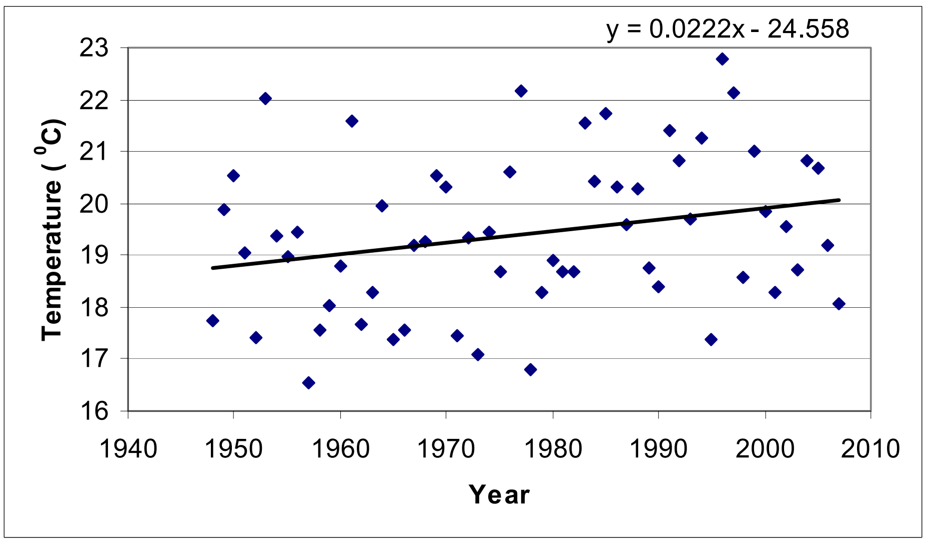


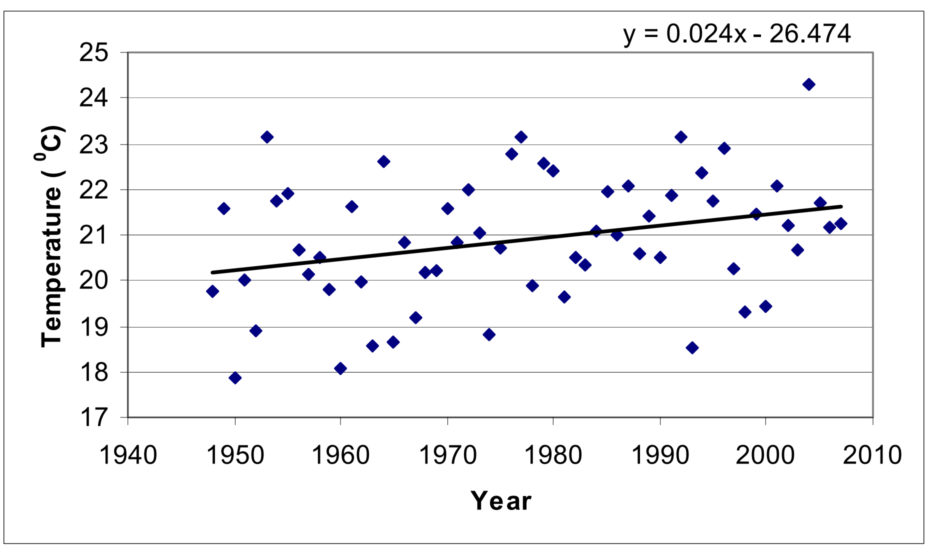




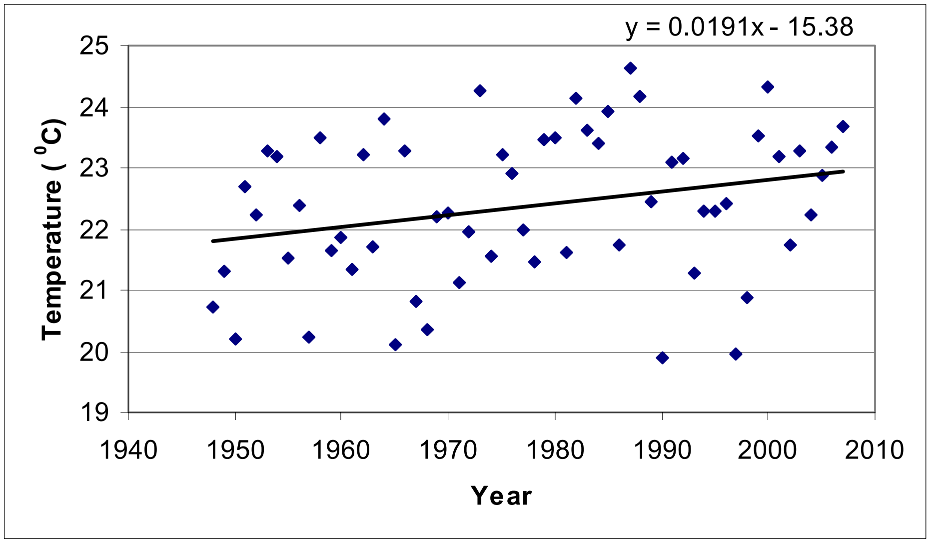
Annex II: (continued) for Feb I, Feb II and Feb III (from top to bottom)

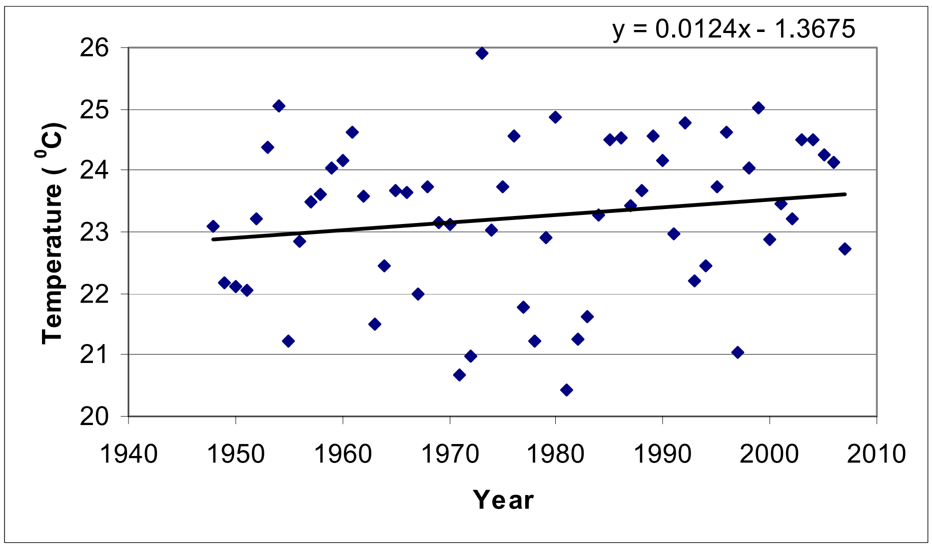


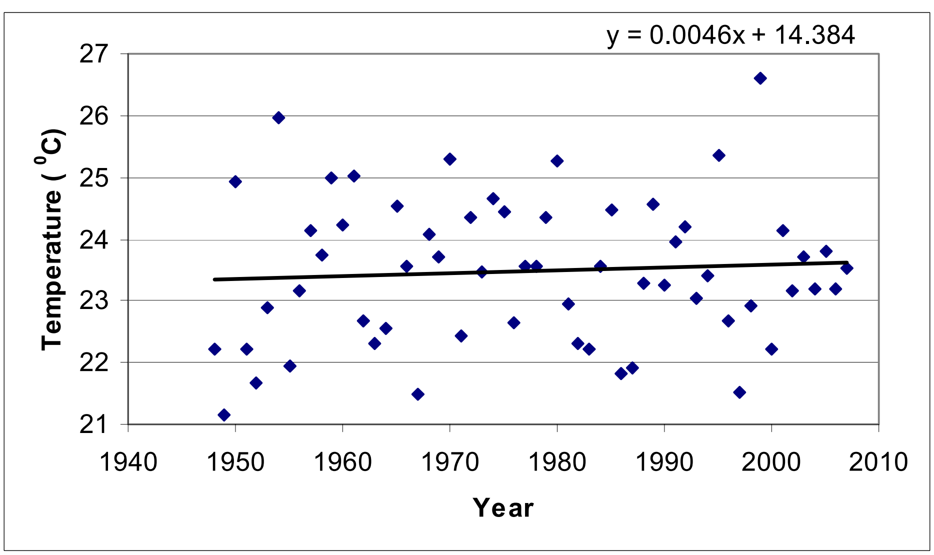




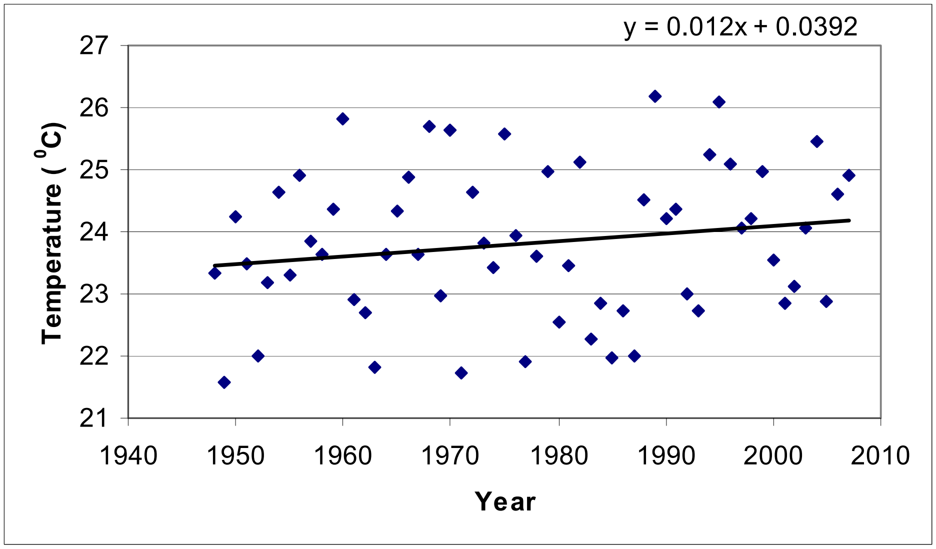
Annex II: (continued) for Mar I, Mar II and Mar III (from top to bottom)

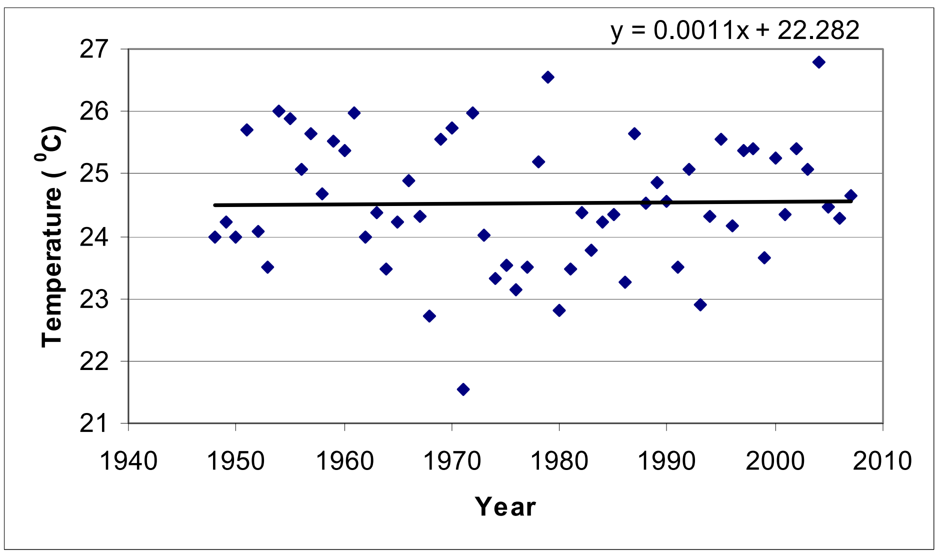


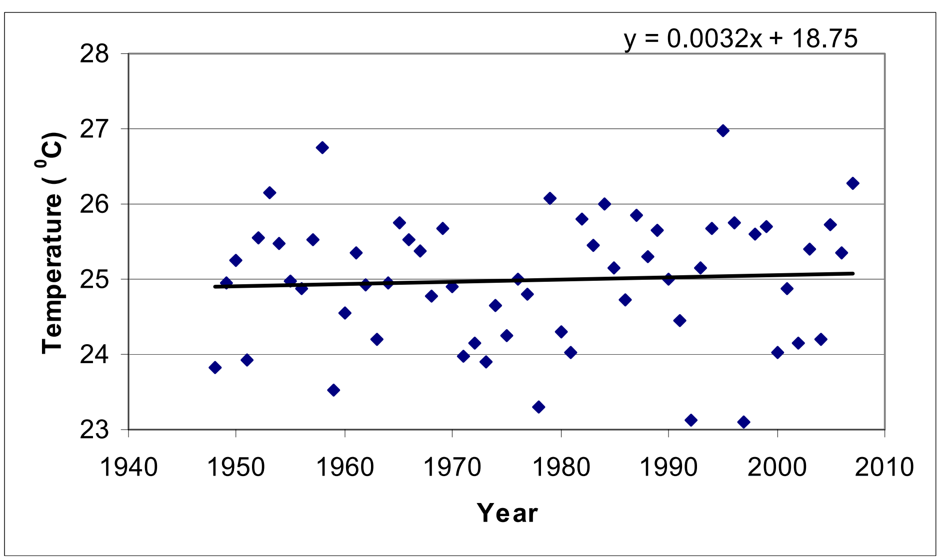




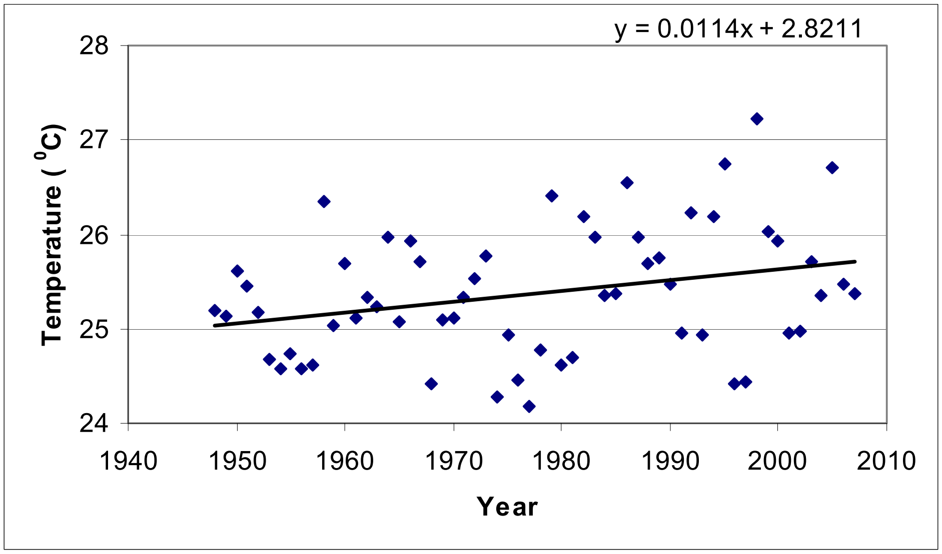
Annex II: (continued) for Apr I, Apr II and Apr III (from top to bottom)

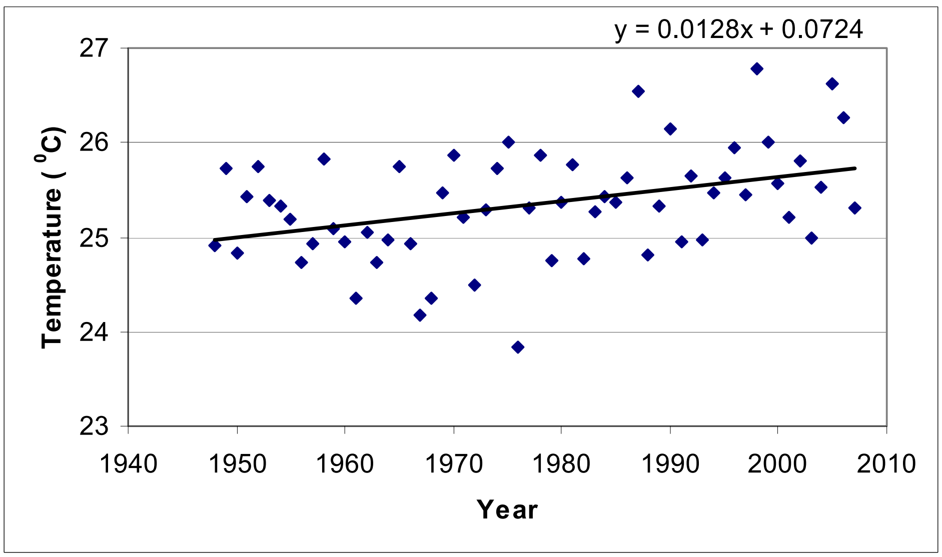


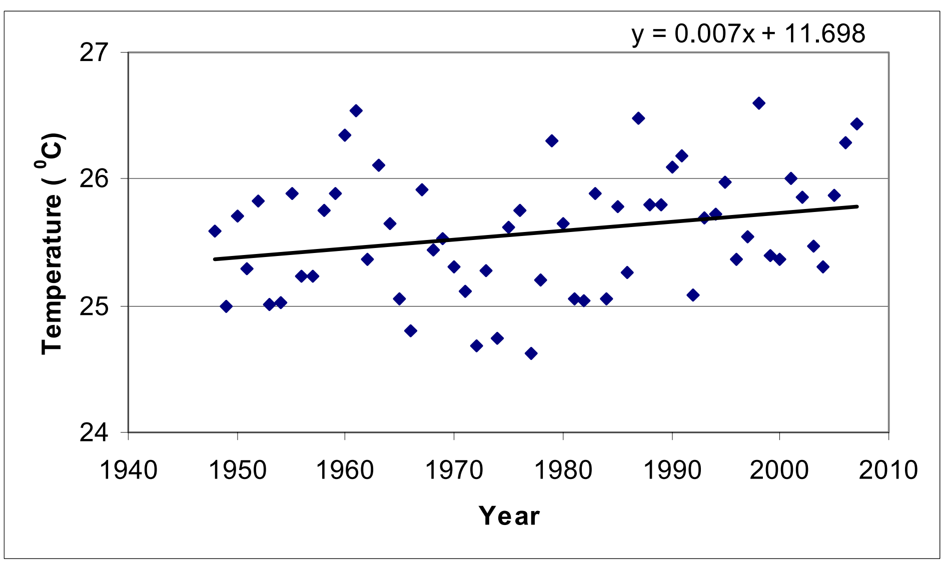




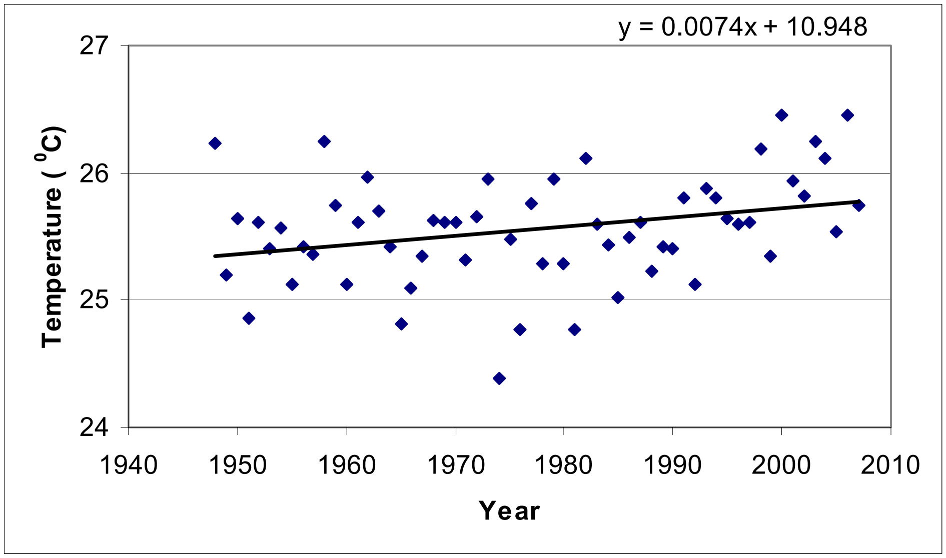
Annex II: (continued) for May I, May II and May III (from top to bottom)

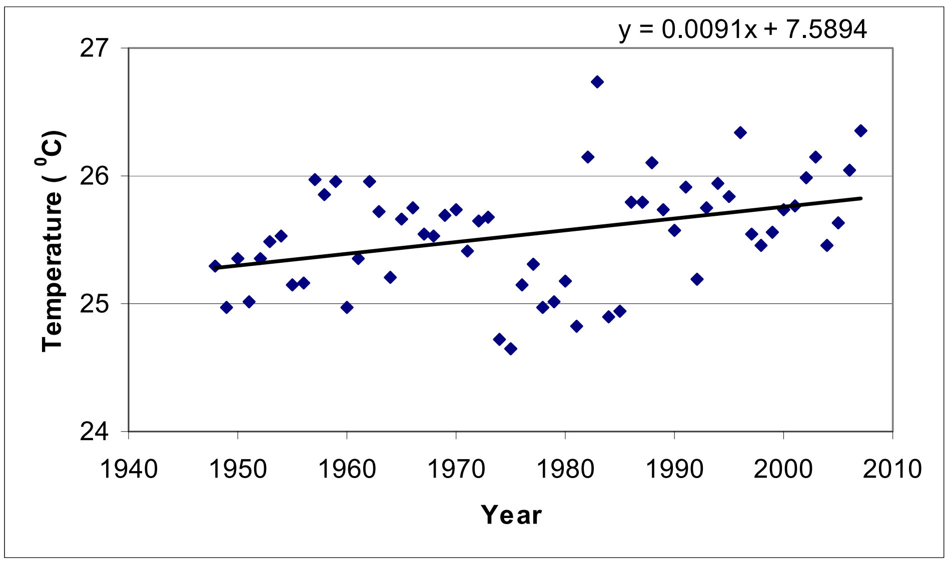


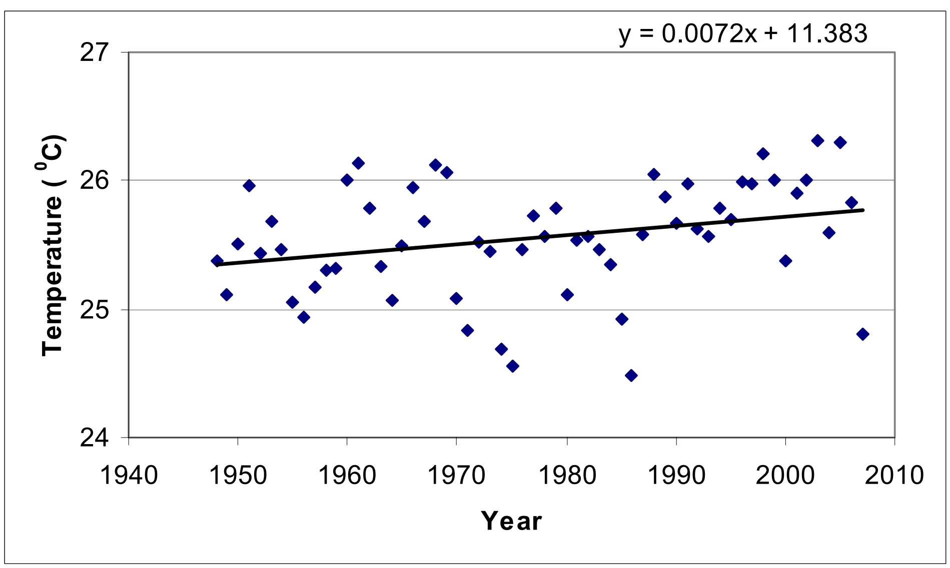




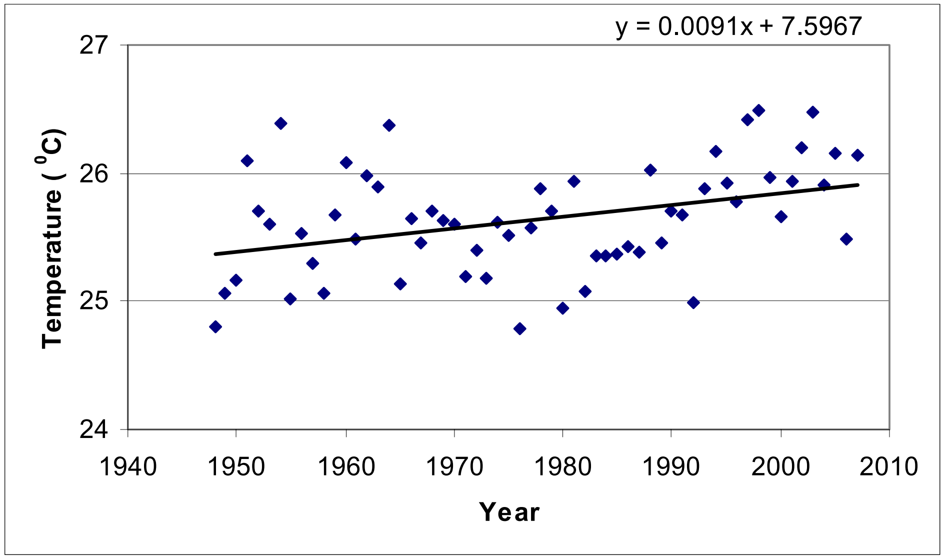
Annex II: (continued) for Jun I, Jun II and Jun III (from top to bottom)

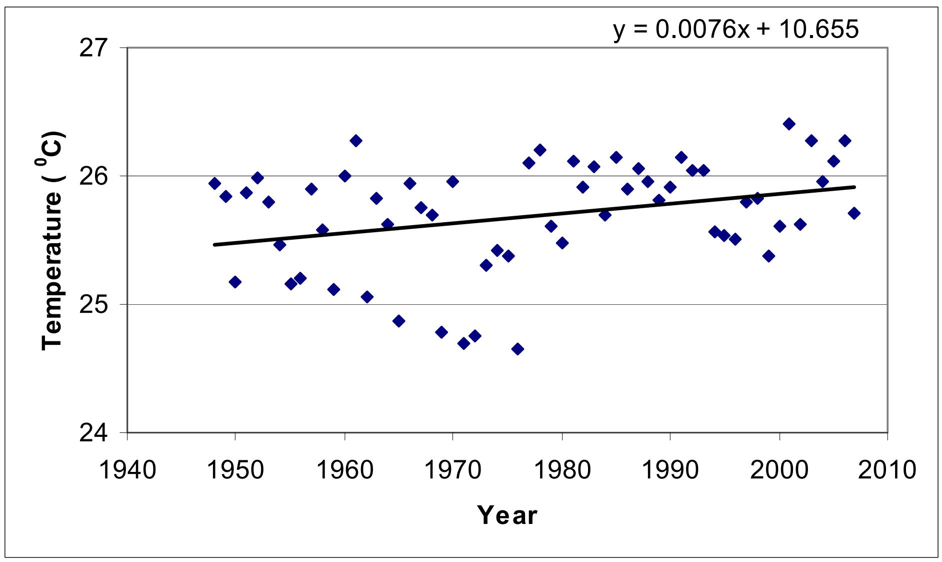


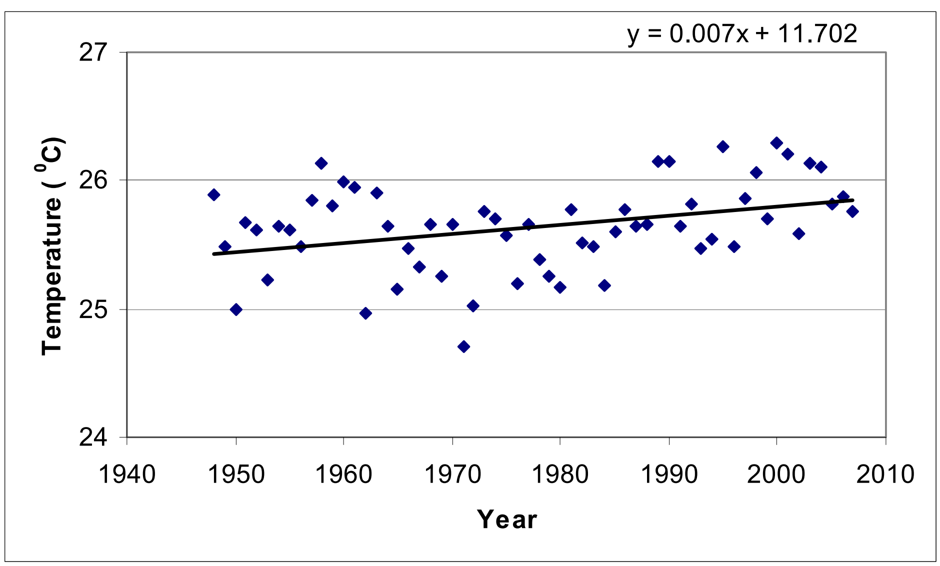




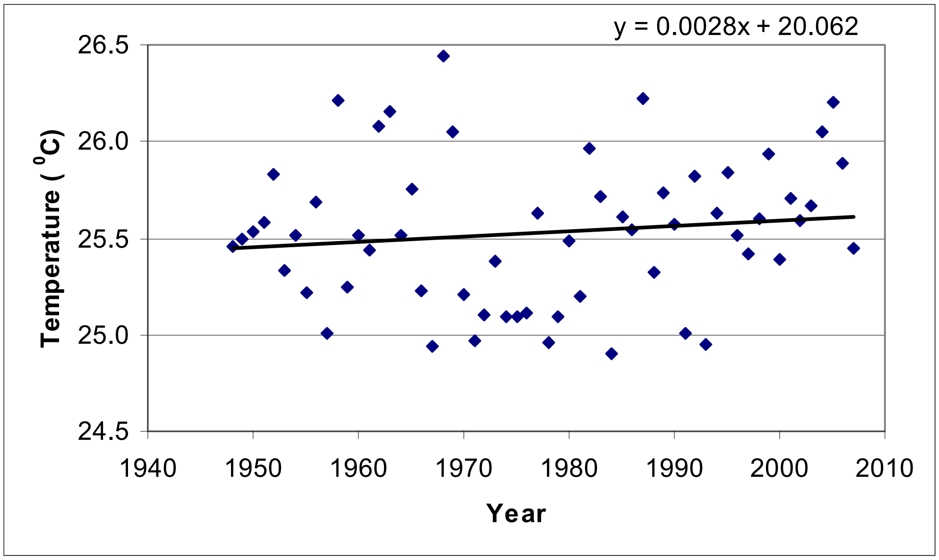
Annex II: (continued) for Jul I, Jul II and Jul III (from top to bottom)

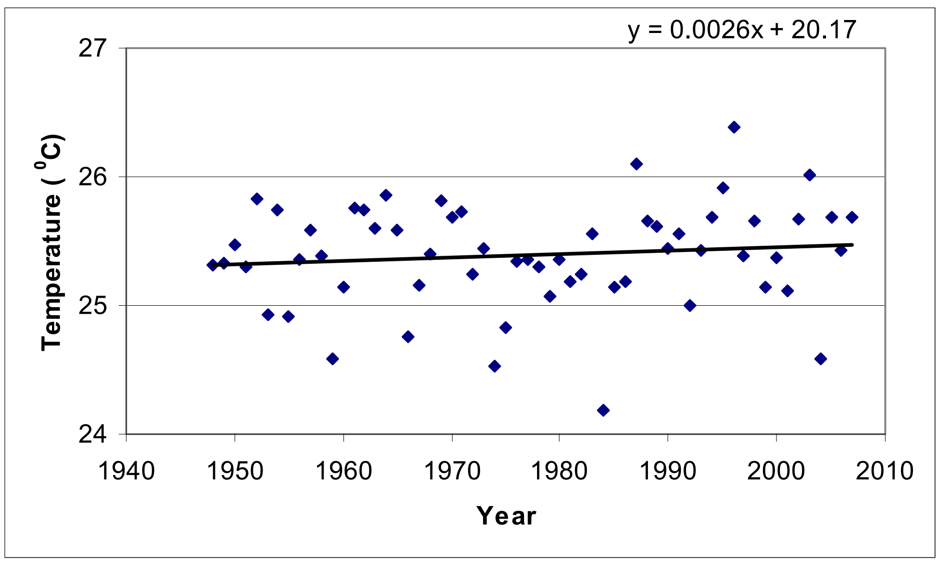


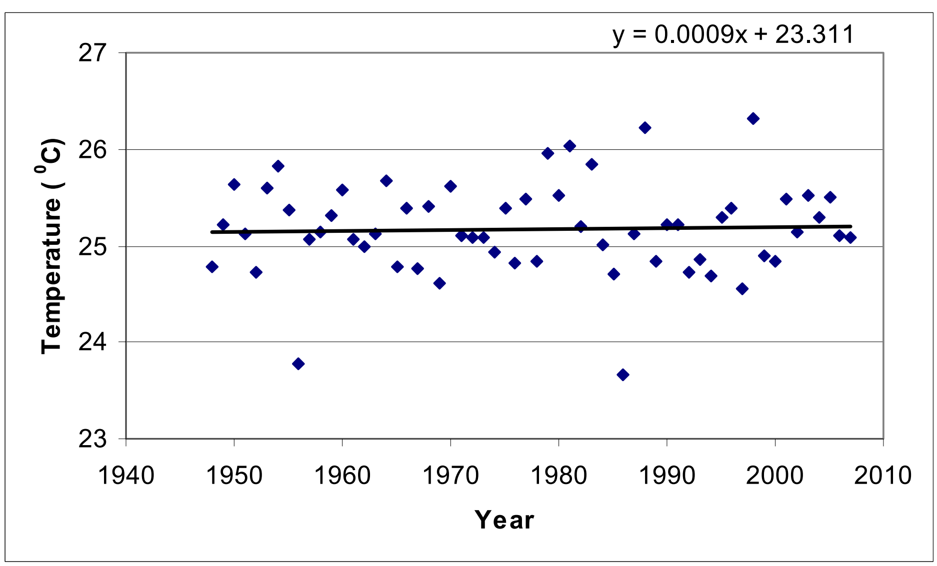




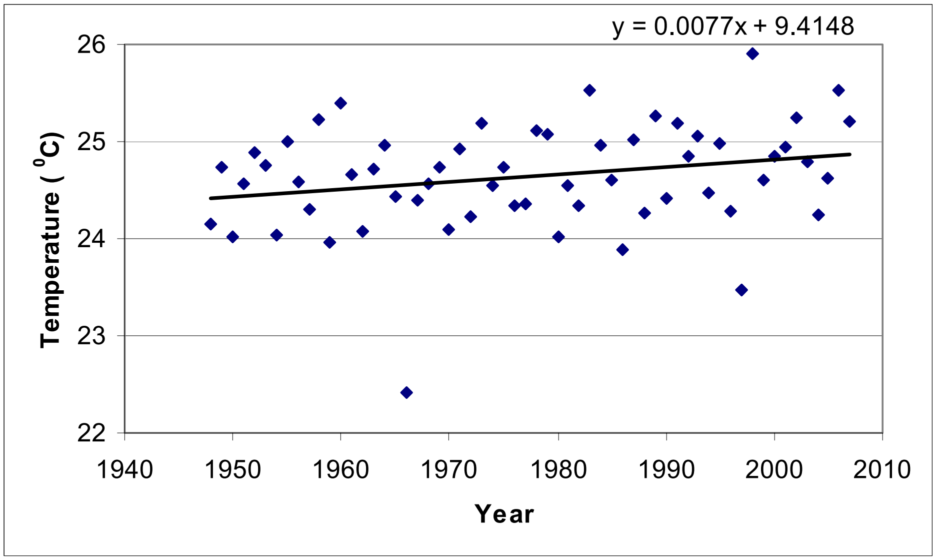
Annex II: (continued) for Aug I, Aug II and Aug III (from top to bottom)

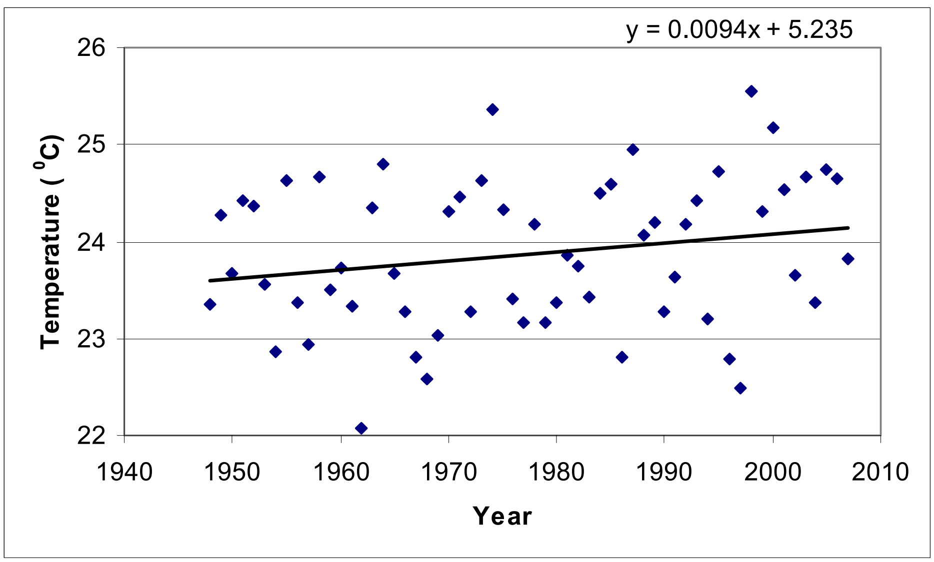


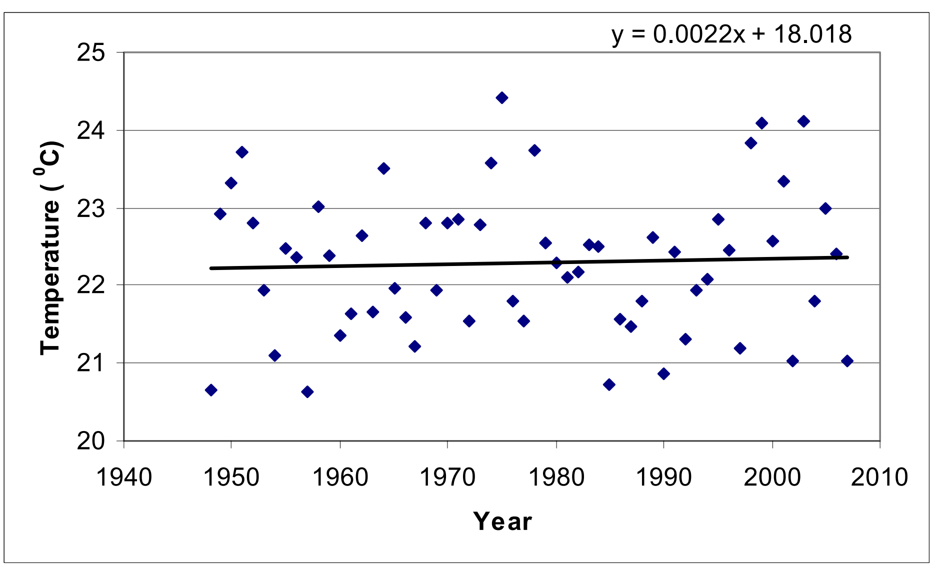




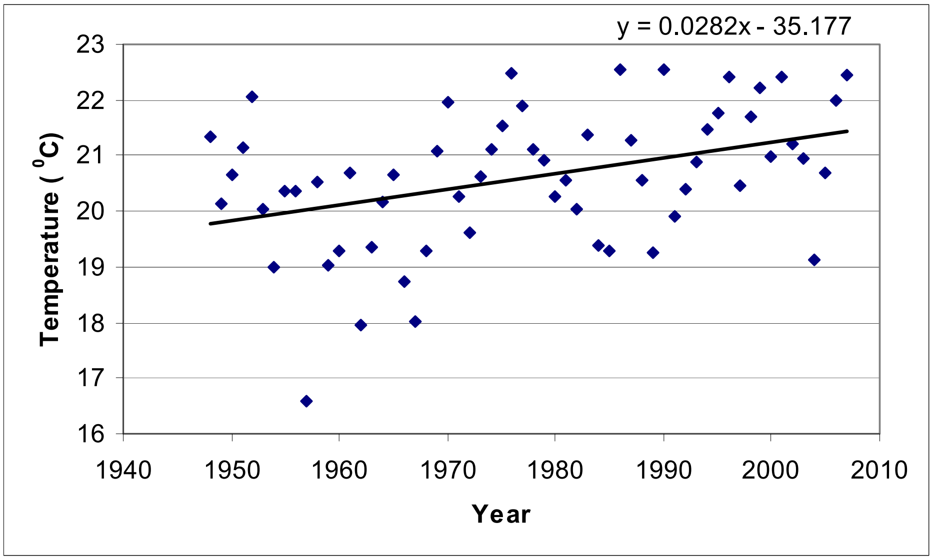
Annex II: (continued) for Sep I, Sep II and Sep III (from top to bottom)

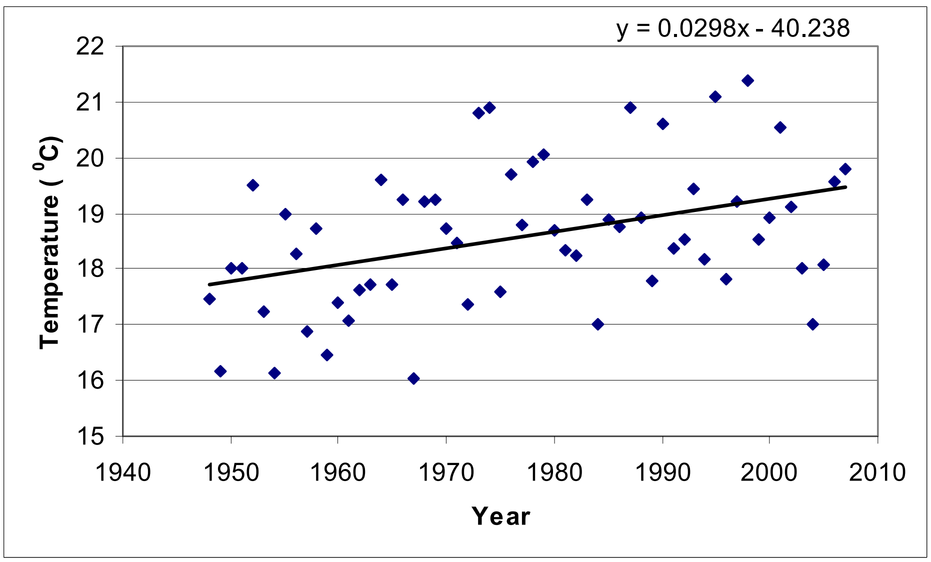


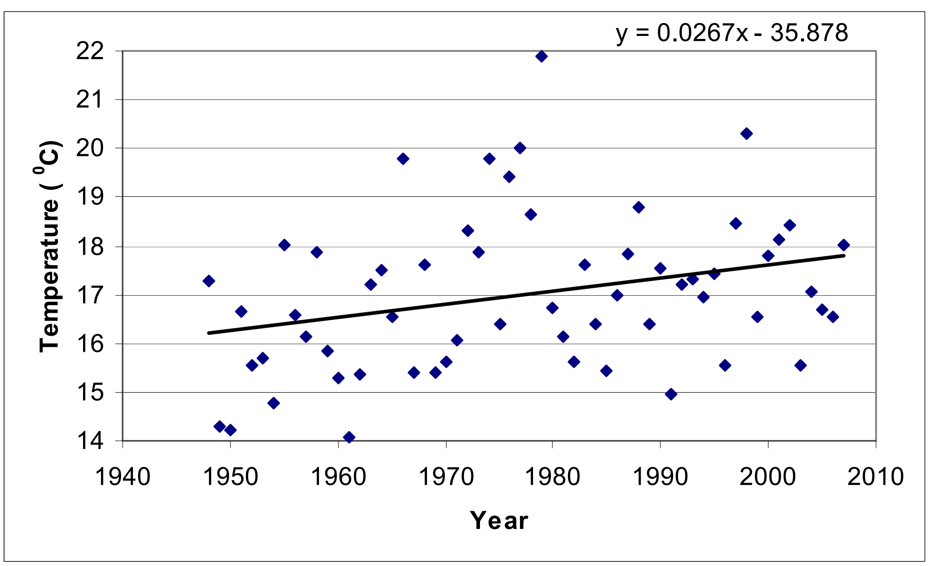




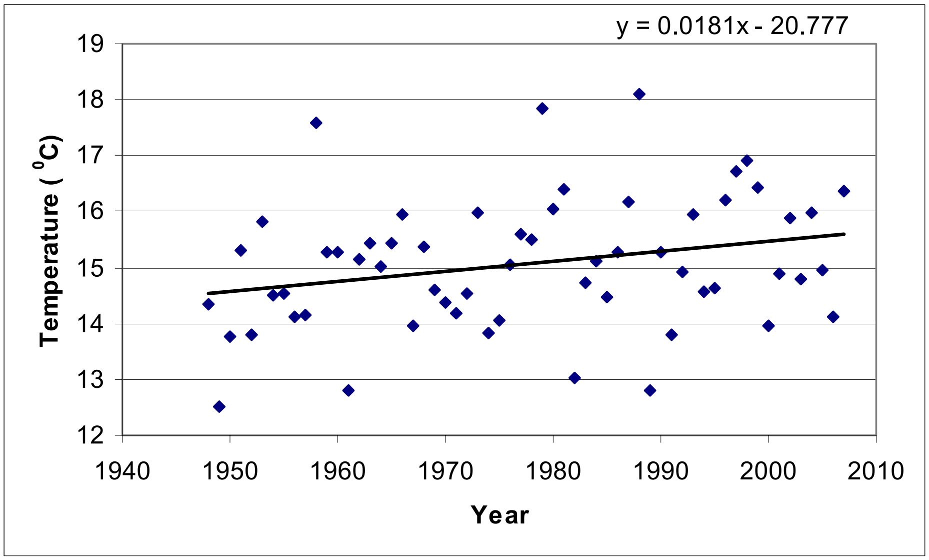
Annex II: (continued) for Oct I, Oct II and Oct III (from top to bottom)

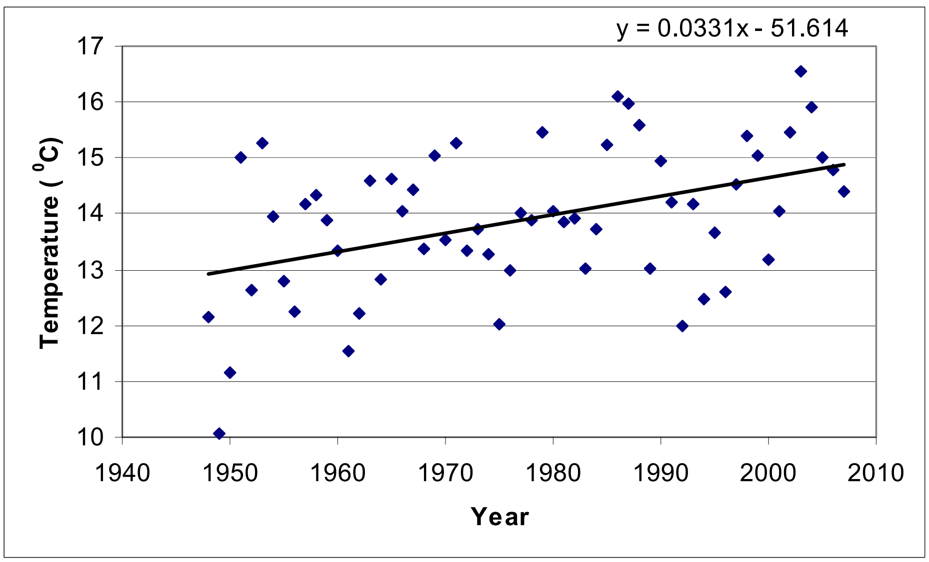


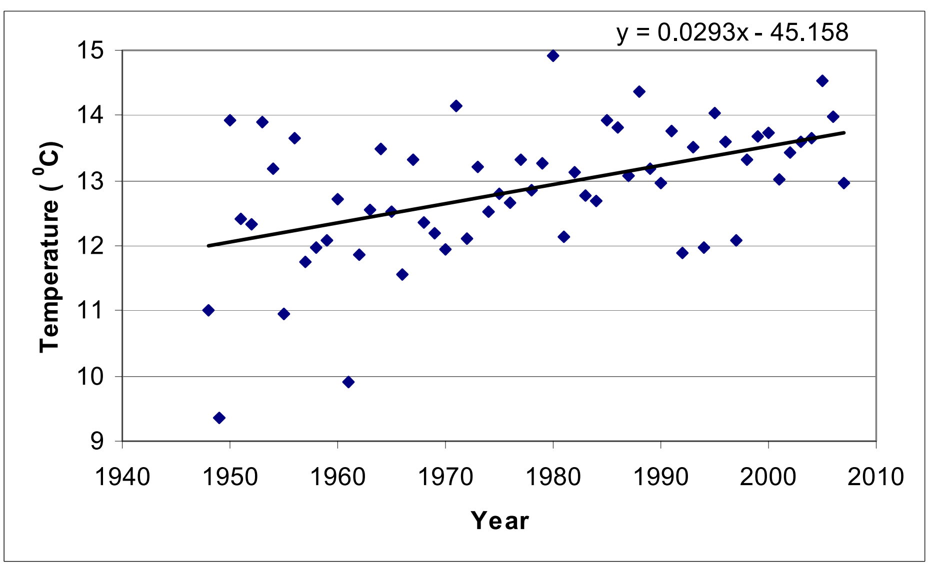




Annex II: (continued) for Nov I, Nov II and Nov III (from top to bottom)



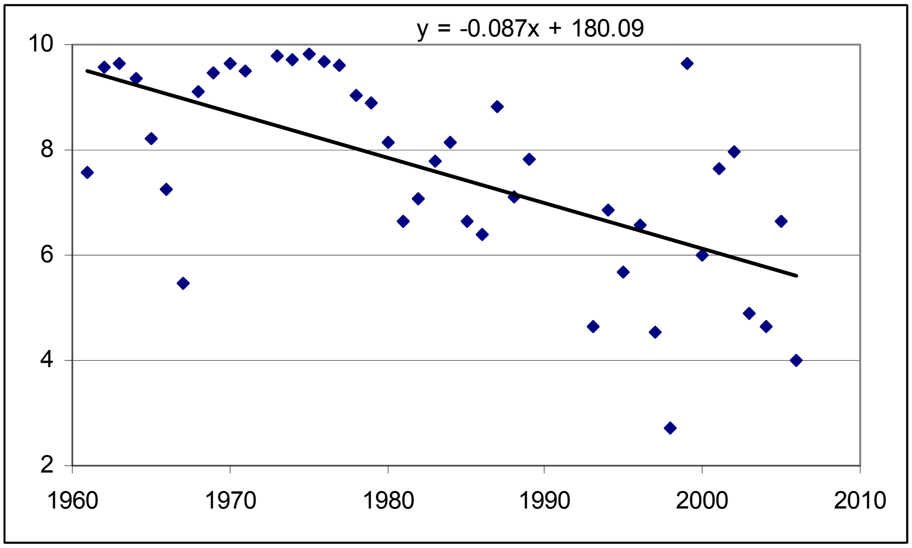


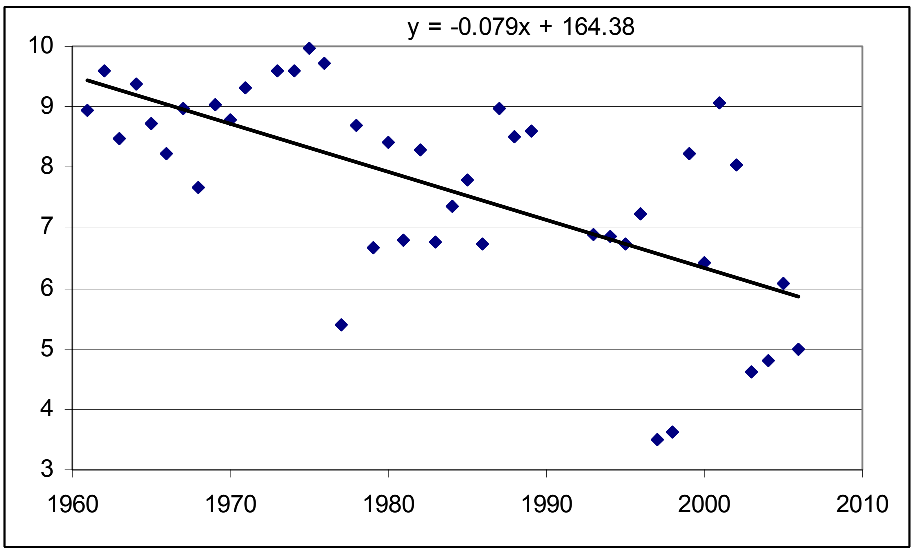


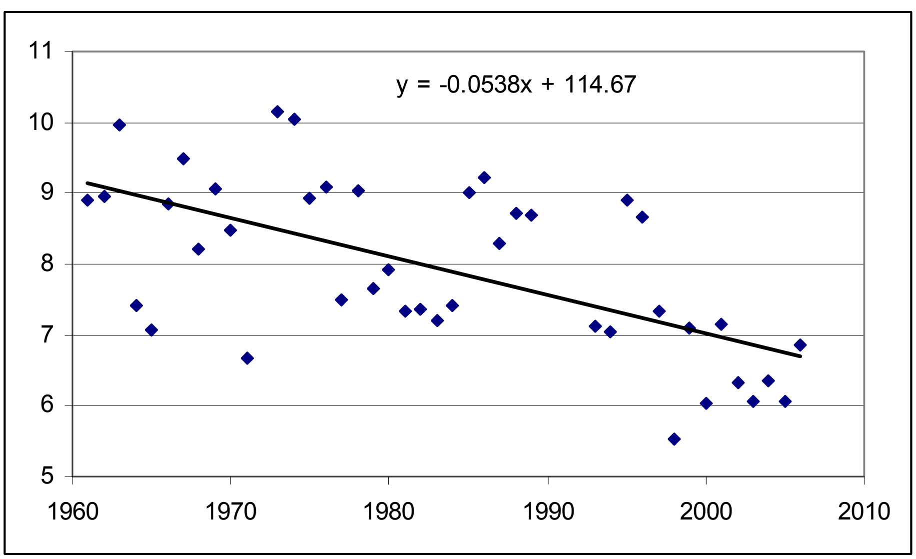
Annex II: (continued) for Dec I, Dec II and Dec III (from top to bottom)

Annex III:

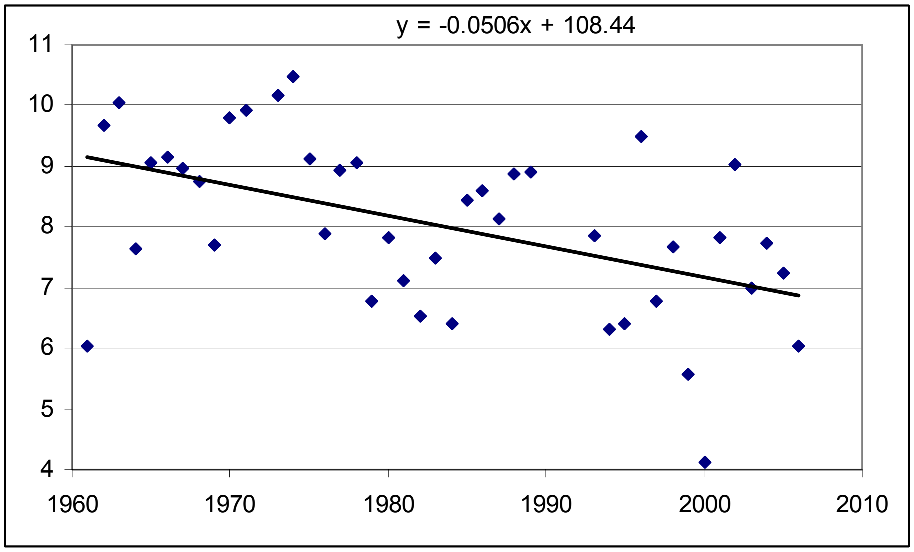
Graphs on trends in 10-day average sunshine duration at Dhaka

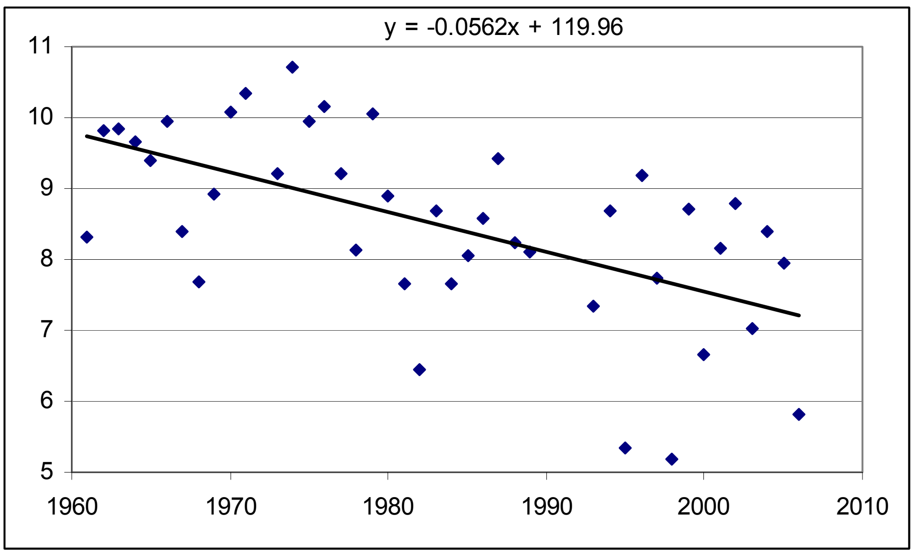


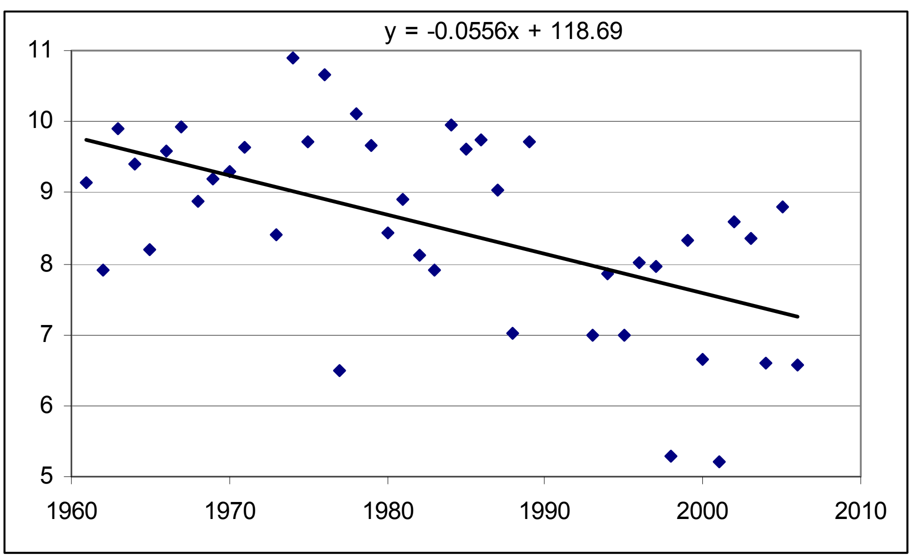




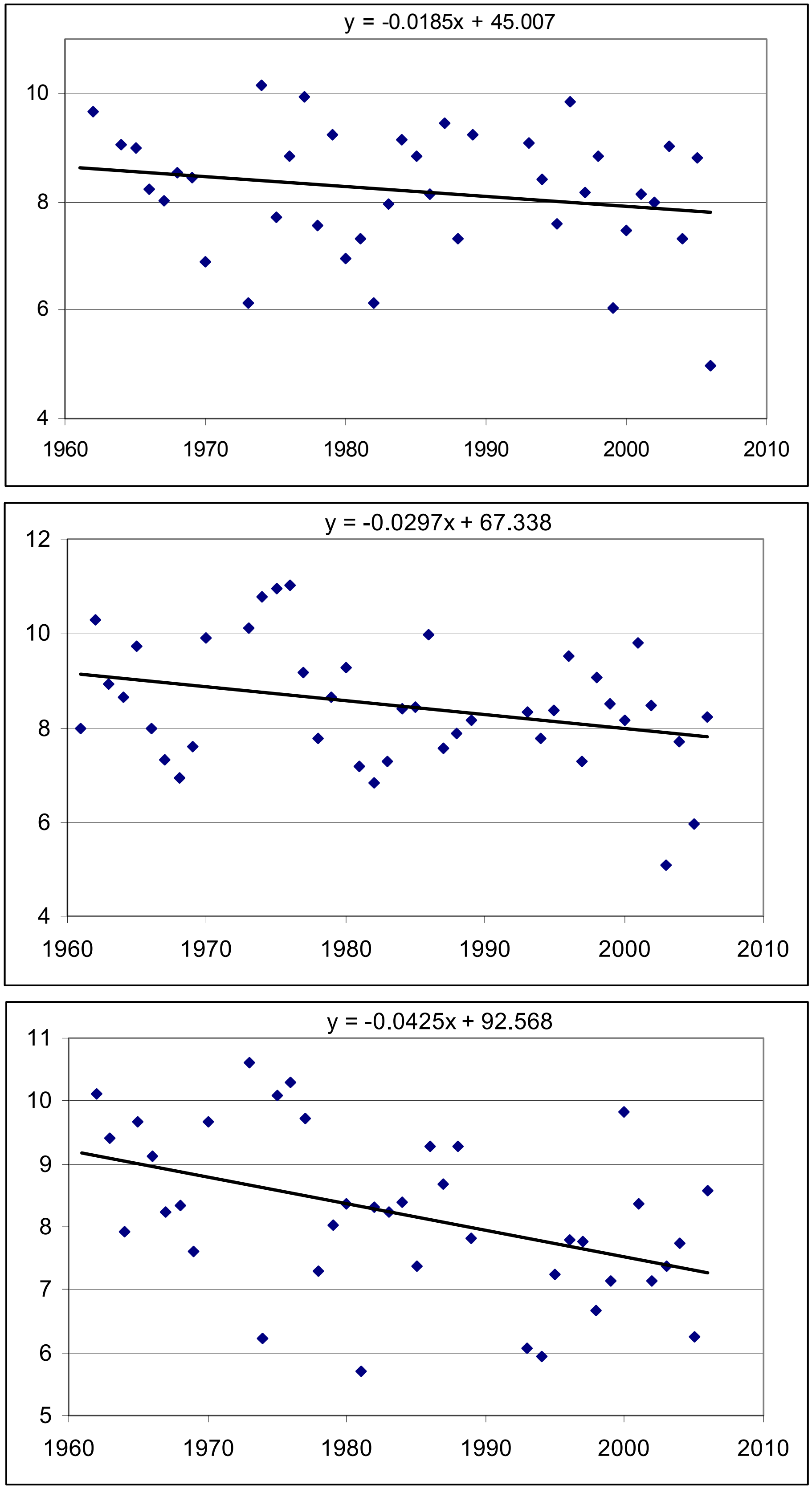
Annex III: Trends in 10-day average sunshine duration in Jan I, Jan II & Jan III (from top to bottom; horizontal axis is year & vertical axis is sunshine hour)



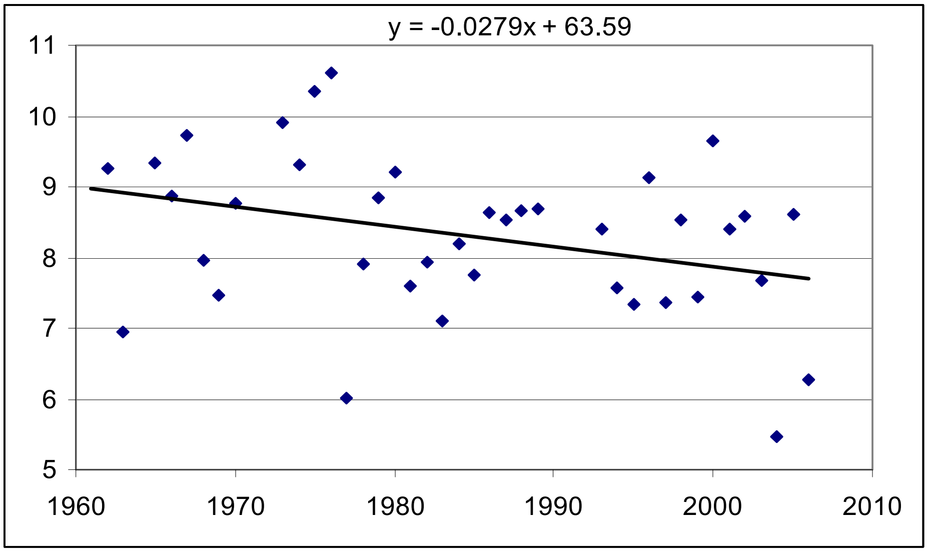


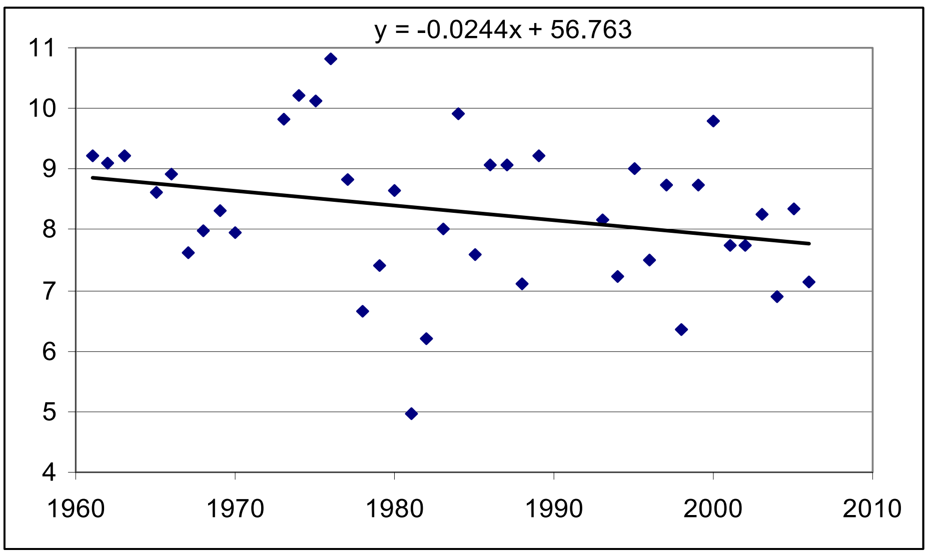


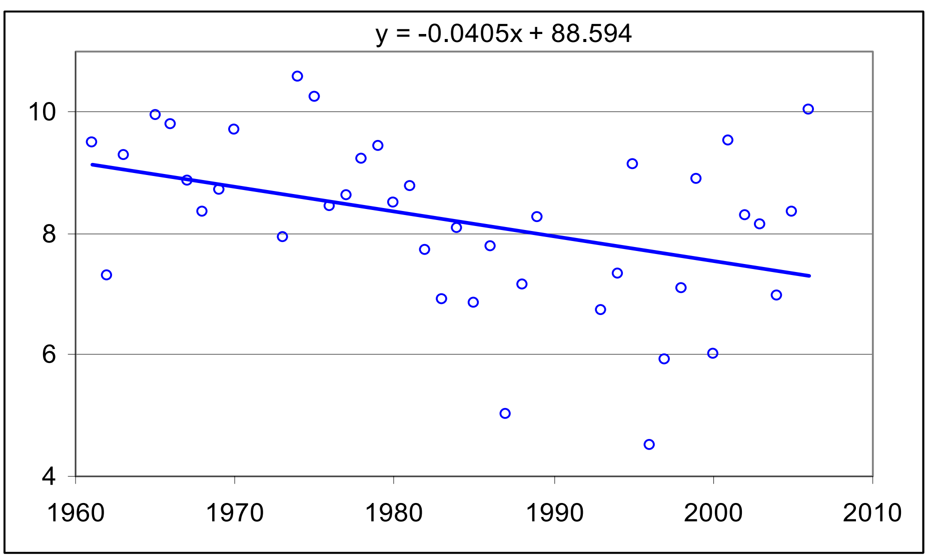
Annex III: (continued) for Feb I, Feb II and Feb III (from top to bottom; horizontal axis is year & vertical axis is sunshine hour)



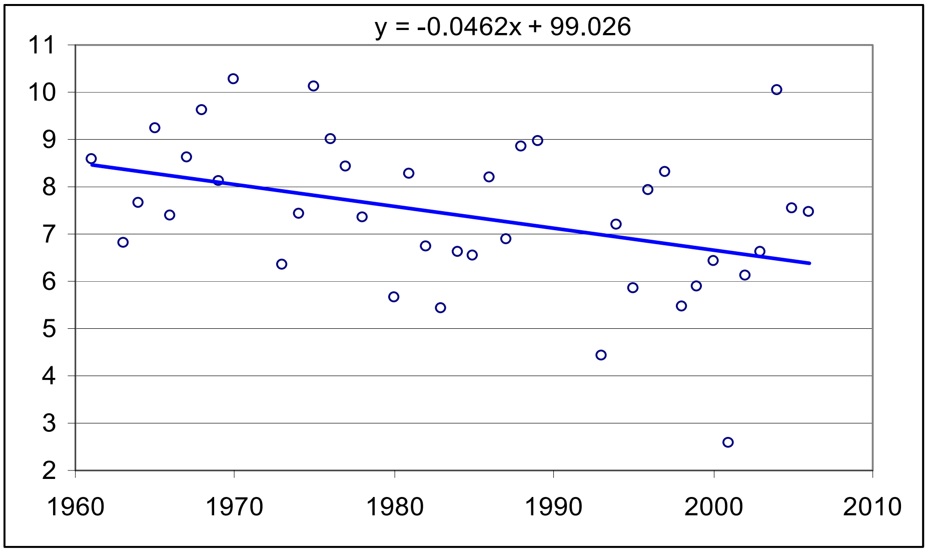
Annex III: (continued) for Mar I, Mar II and Mar III (from top to bottom; horizontal axis is year & vertical axis is sunshine hour)

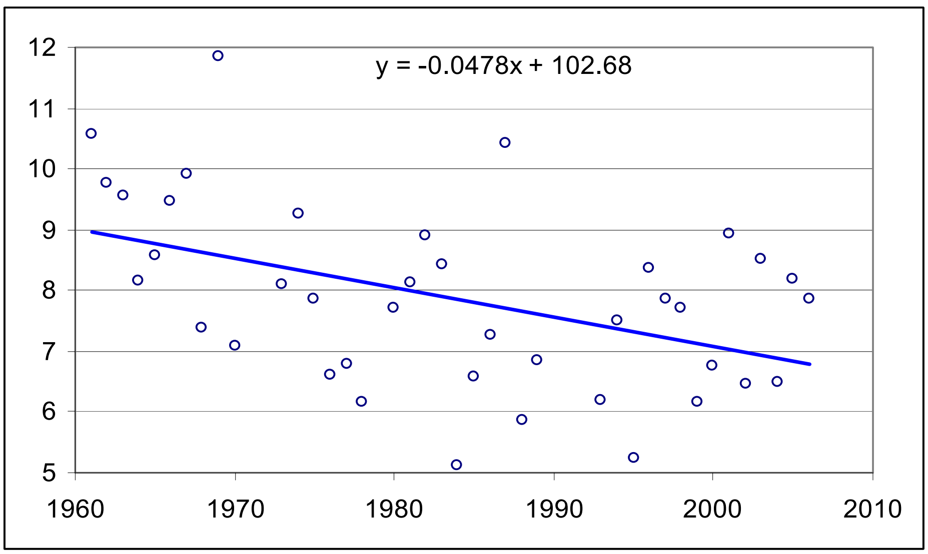


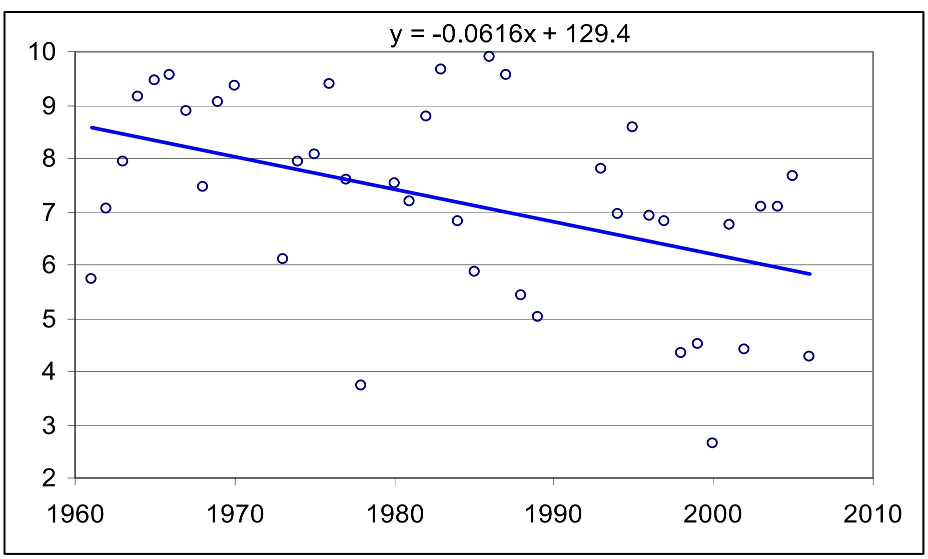




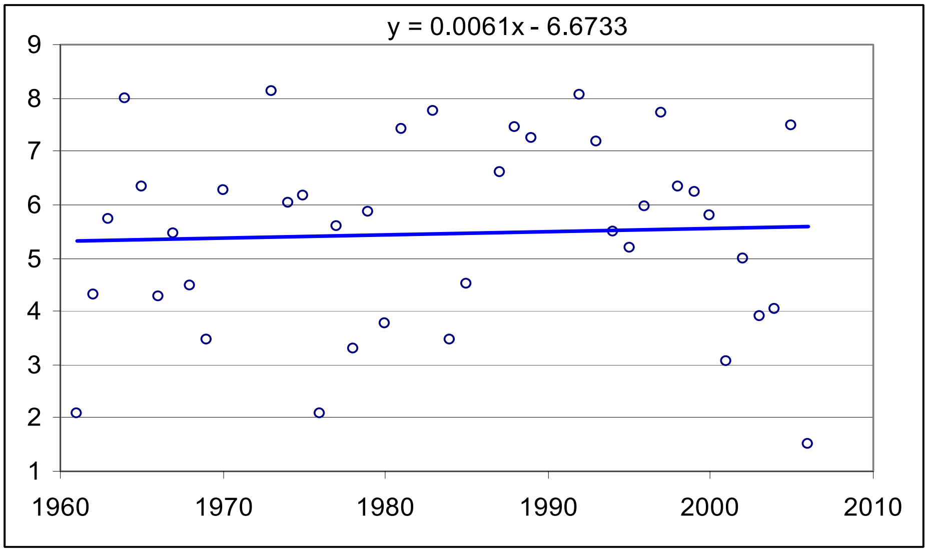
Annex III: (continued) for Apr I, Apr II and Apr III (from top to bottom; horizontal axis is year & vertical axis is sunshine hour)

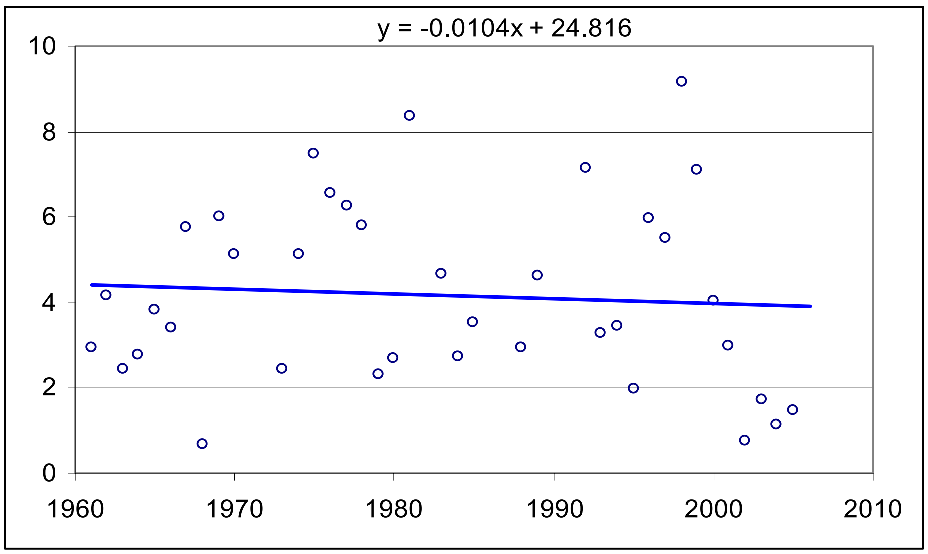


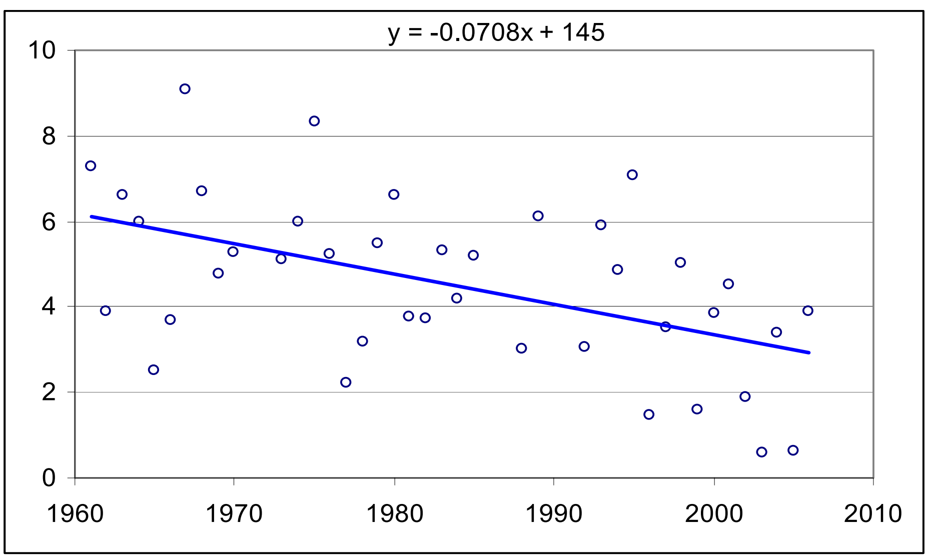




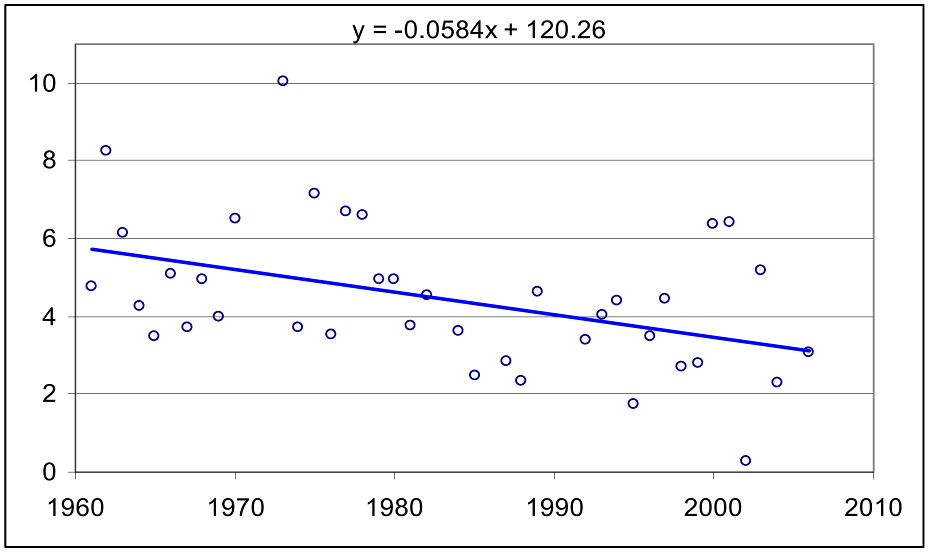
Annex III: (continued) for May I, May II and May III (from top to bottom; horizontal axis is year & vertical axis is sunshine hour)

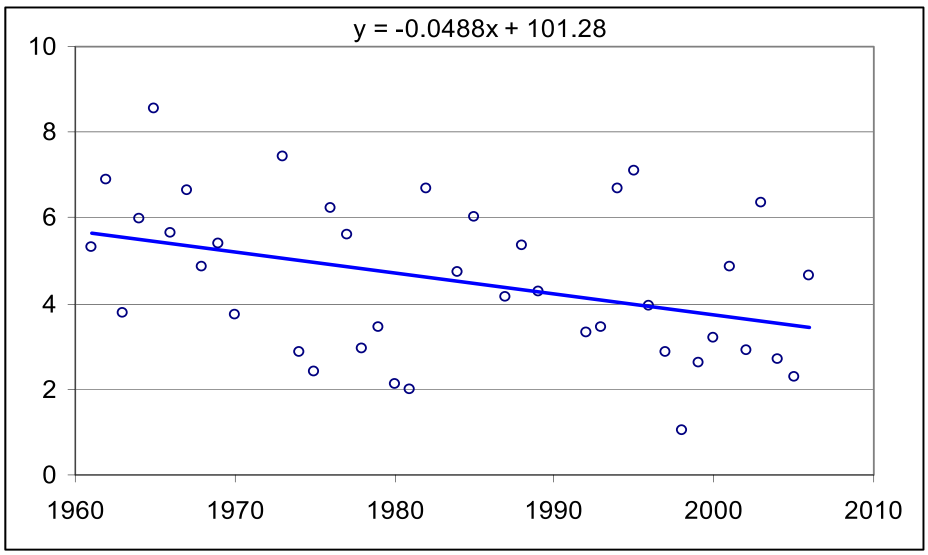


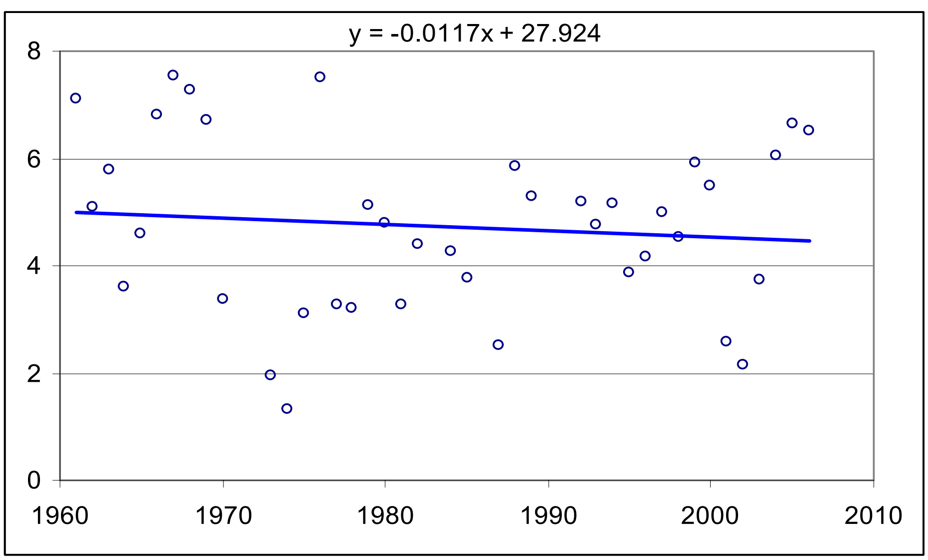




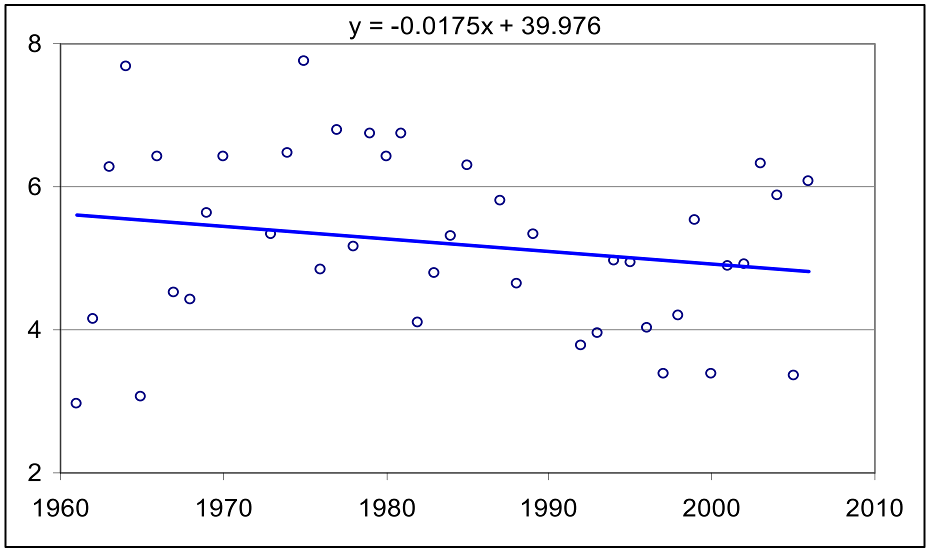
Annex III: (continued) for Jun I, Jun II and Jun III (from top to bottom; horizontal axis is year & vertical axis is sunshine hour)

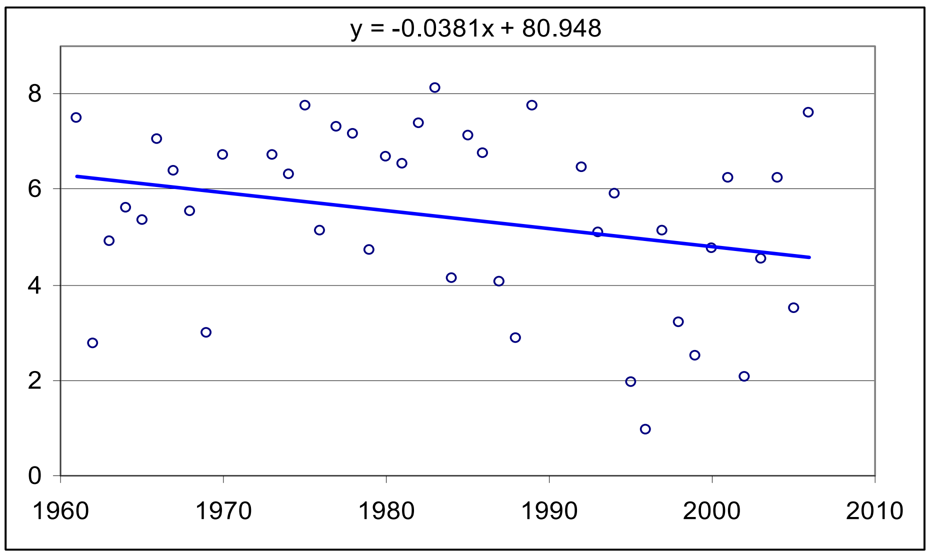


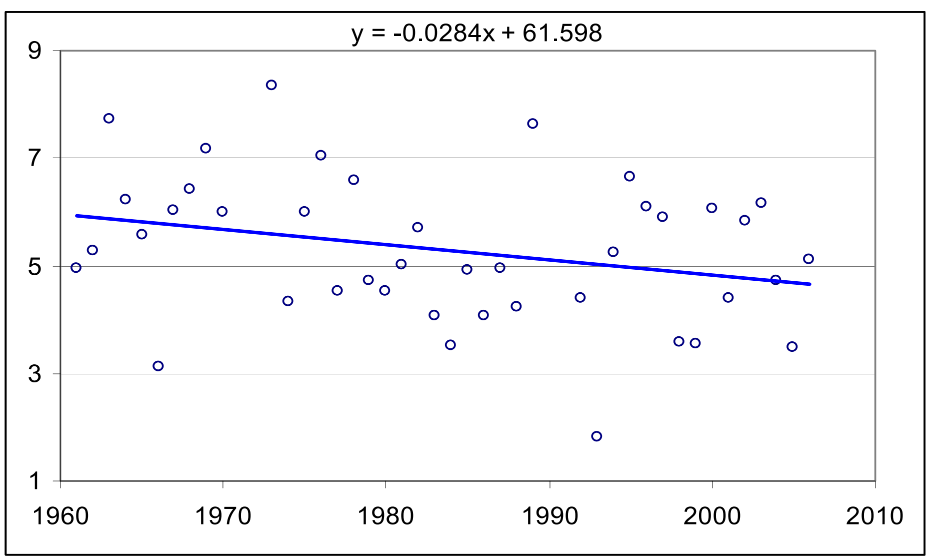




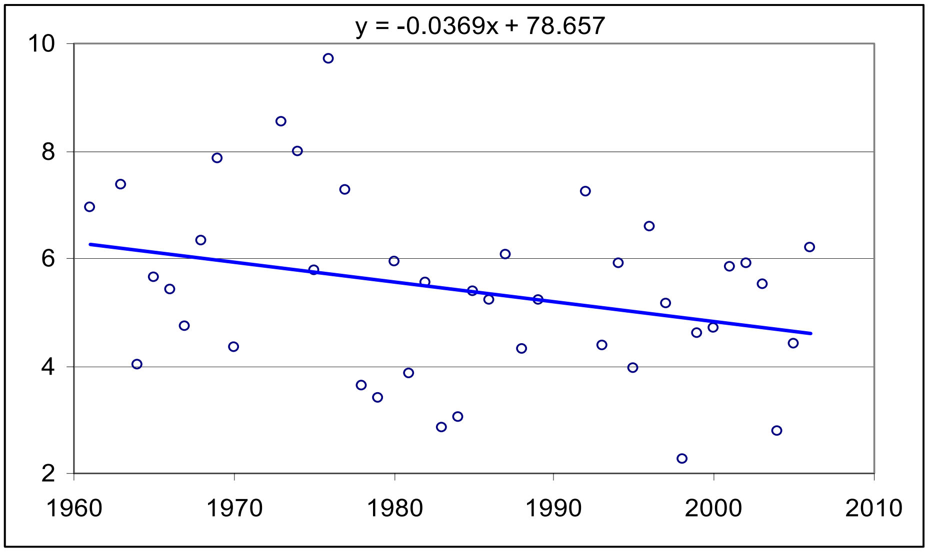
Annex III: (continued) for Jul I, Jul II and Jul III (from top to bottom; horizontal axis is year & vertical axis is sunshine hour)

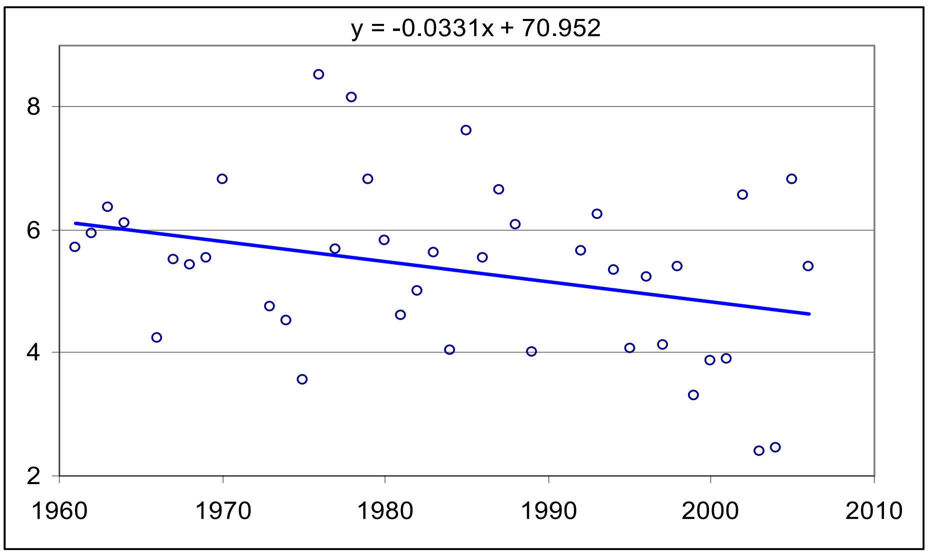


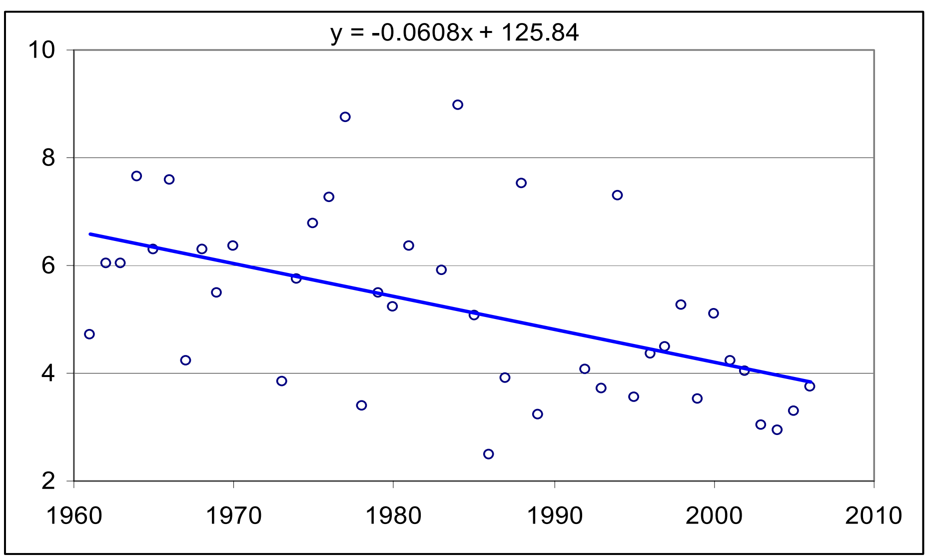




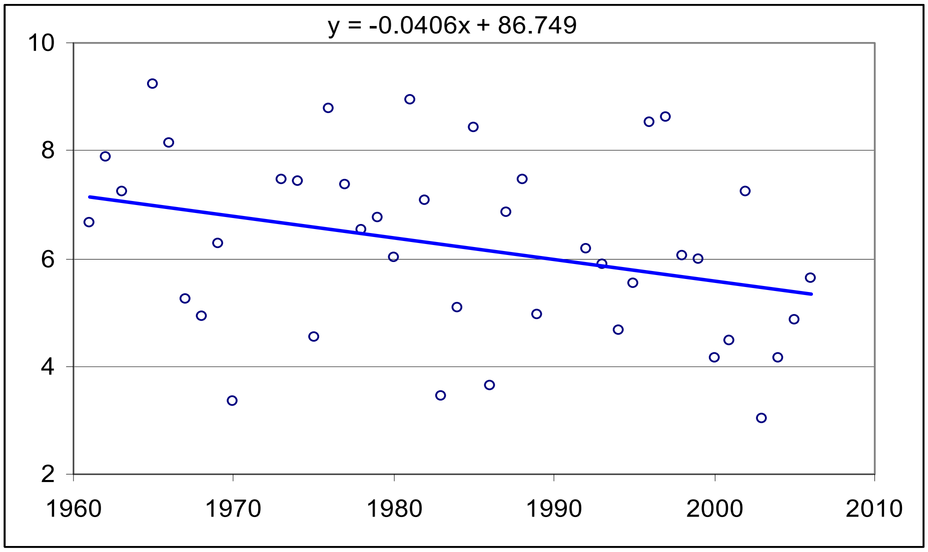
Annex III: (continued) for Aug I, Aug II and Aug III (from top to bottom; horizontal axis is year & vertical axis is sunshine hour)

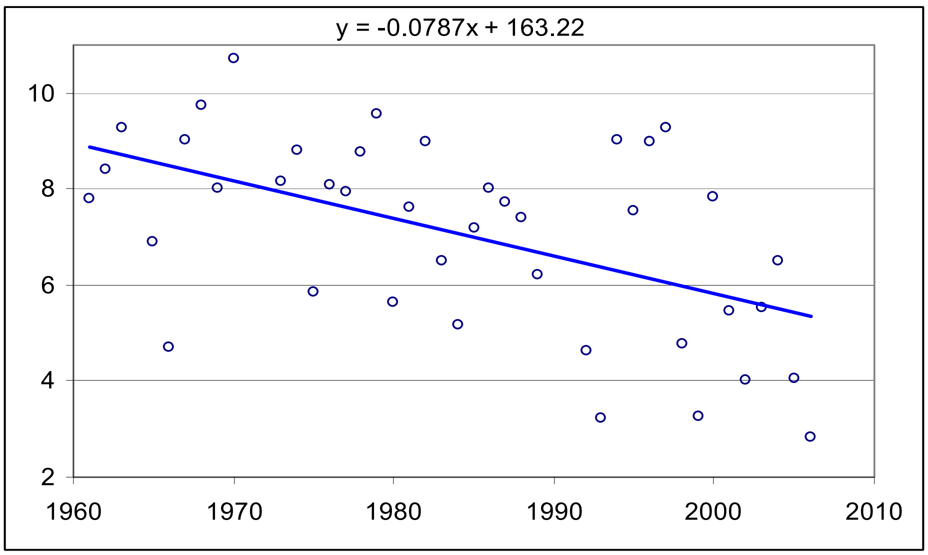


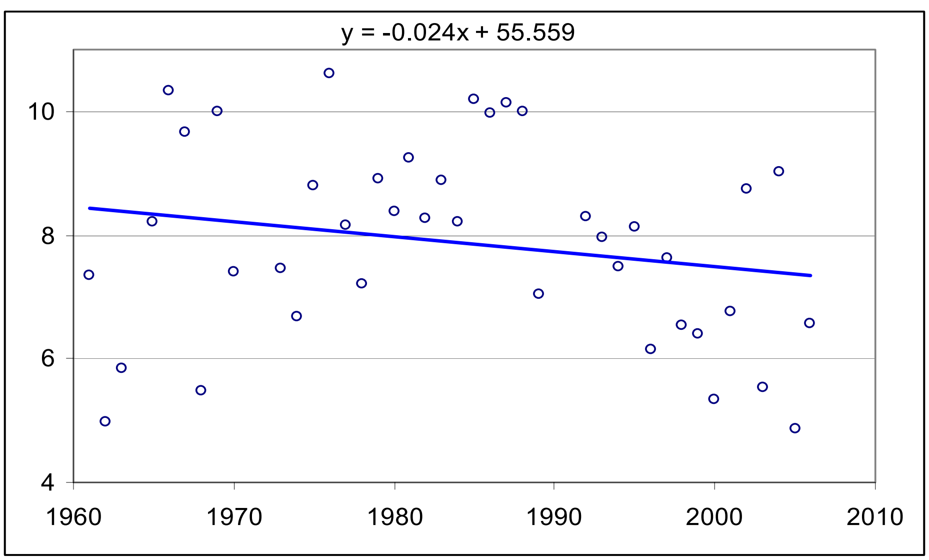




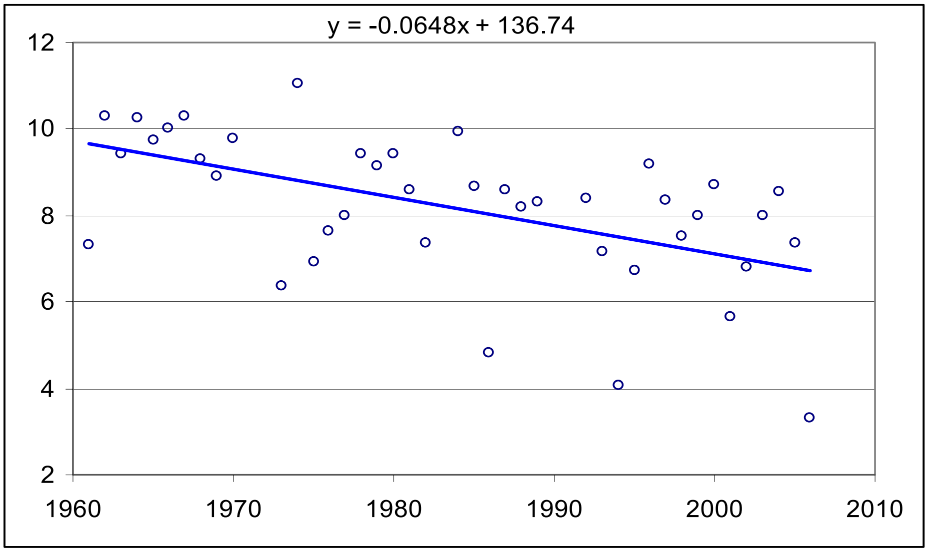
Annex III: (continued) for Sep I, Sep II and Sep III (from top to bottom; horizontal axis is year & vertical axis is sunshine hour)

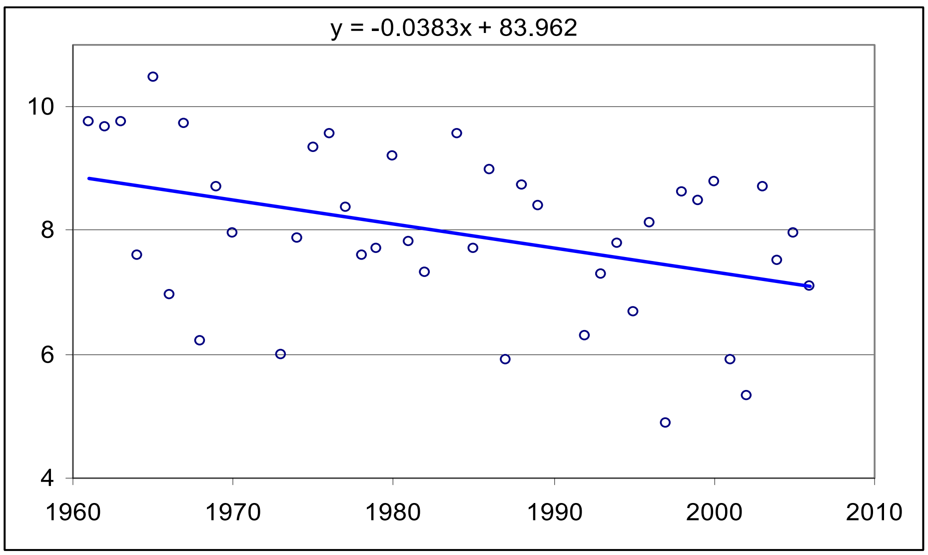


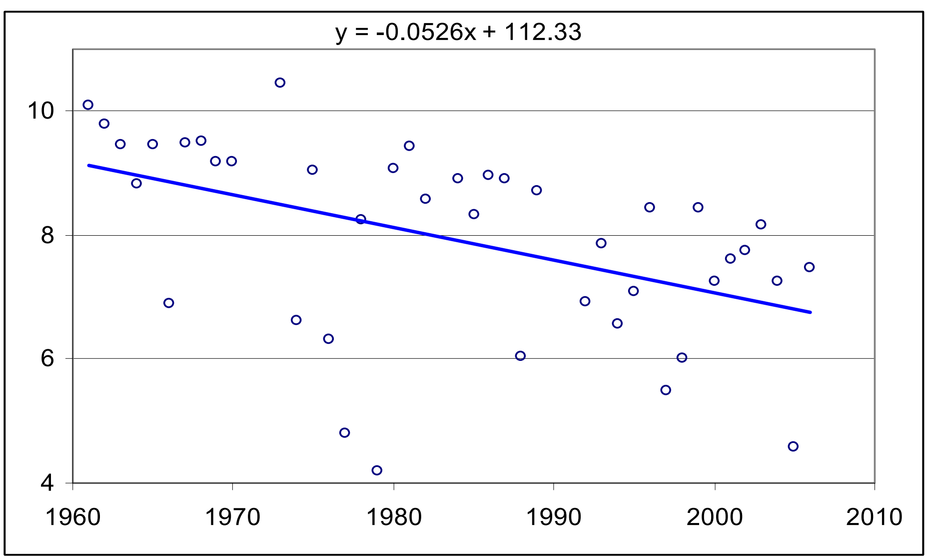




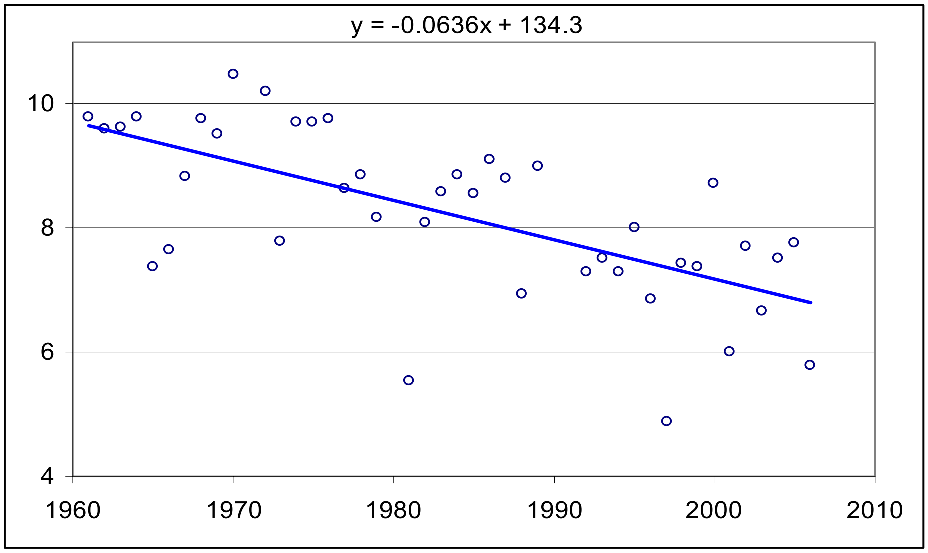
Annex III: (continued) for Oct I, Oct II and Oct III (from top to bottom; horizontal axis is year & vertical axis is sunshine hour)

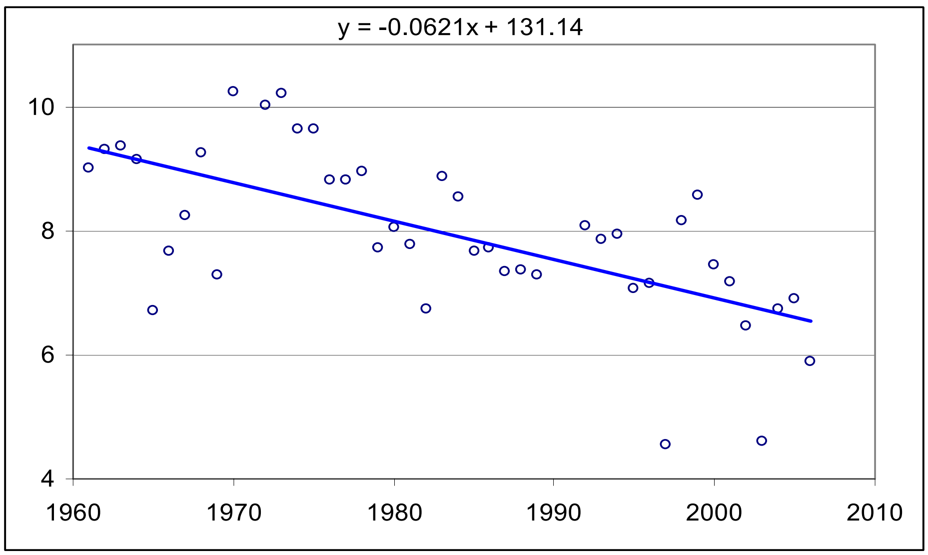


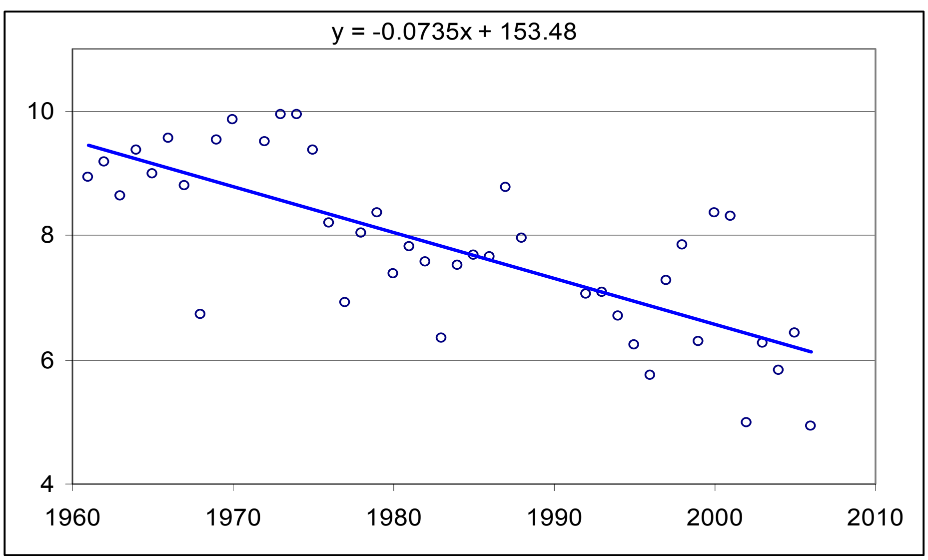




Annex III: (continued) for Nov I, Nov II and Nov III (from top to bottom; horizontal axis is year & vertical axis is sunshine hour)



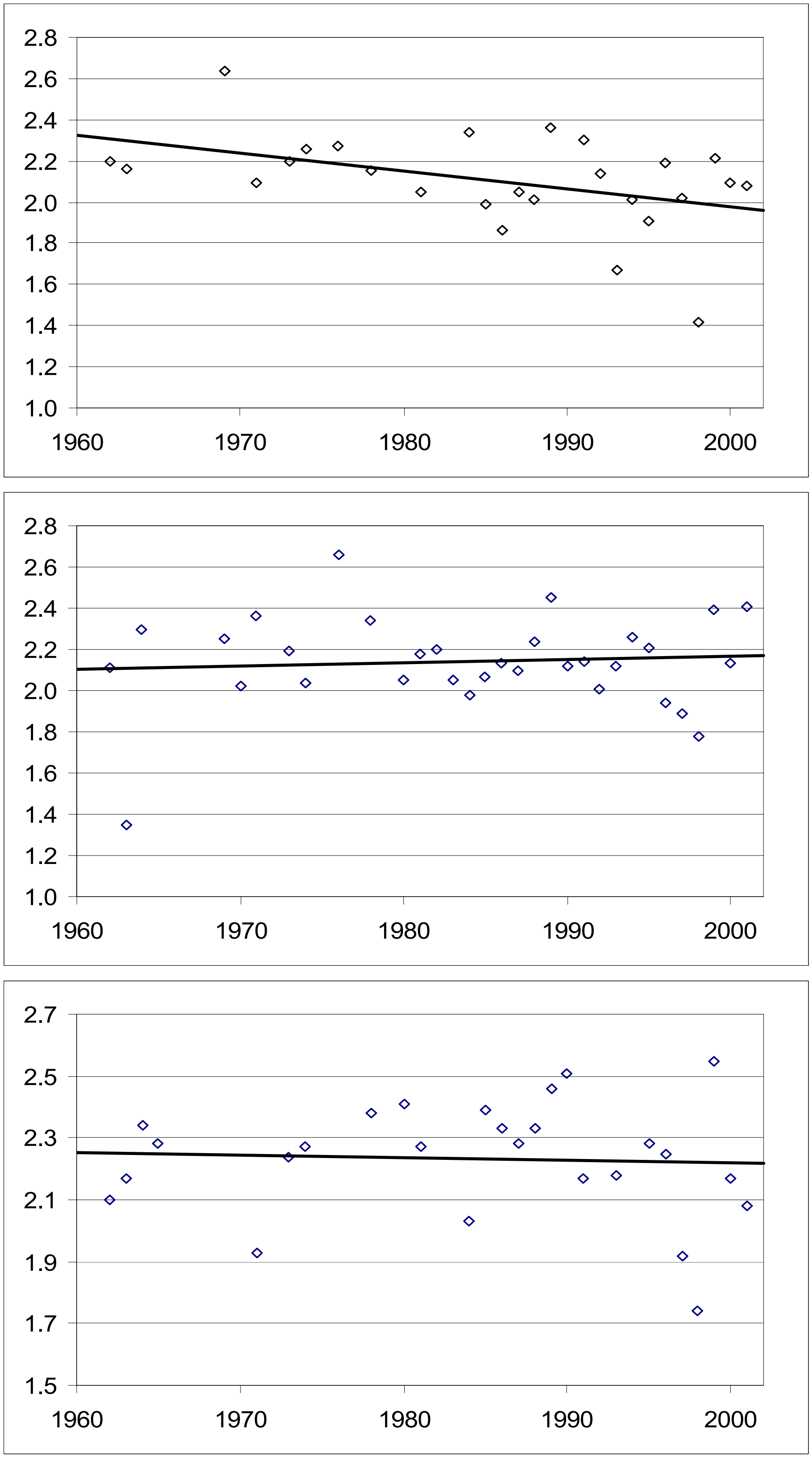




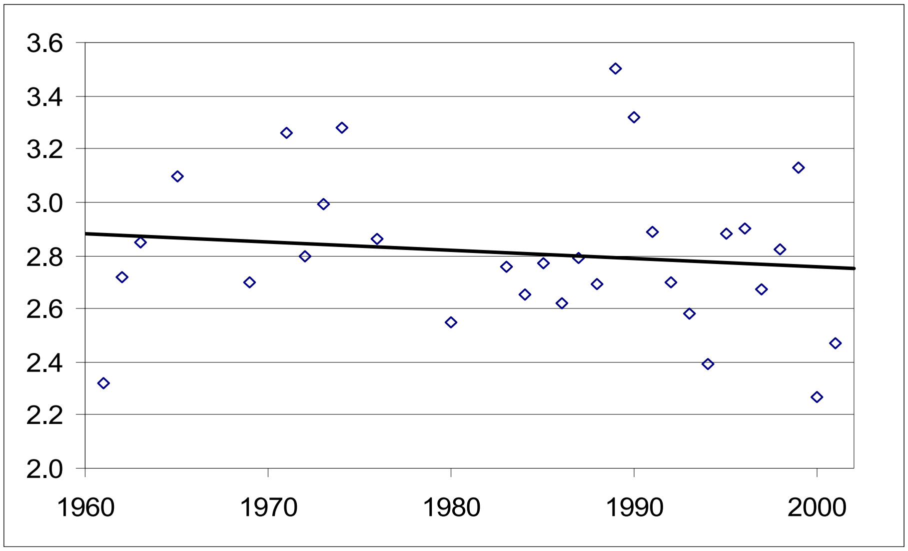
Annex III: (continued) for Dec I, Dec II and Dec III (from top to bottom; horizontal axis is year & vertical axis is sunshine hour)

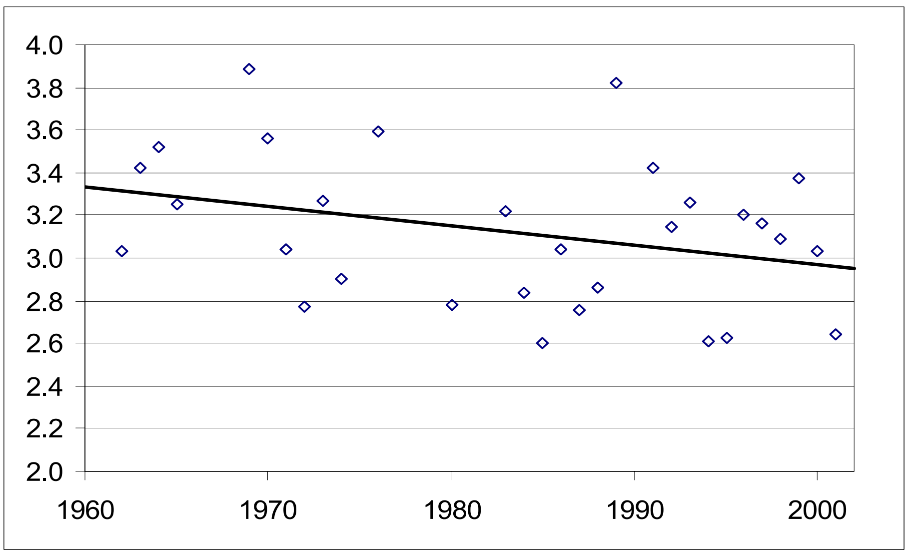
Annex IV:

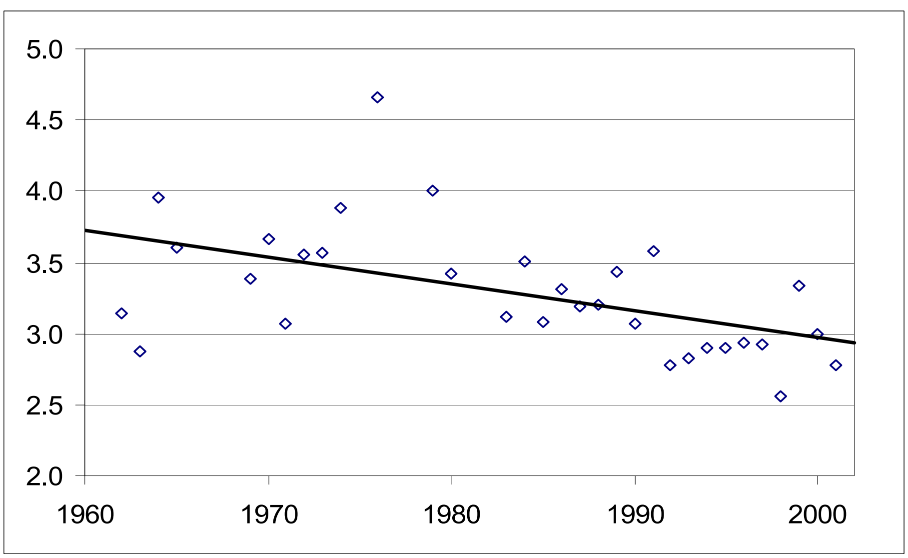
Graphs on trends in 10-day average reference crop evapotranspiration (ET_0) at Bogra



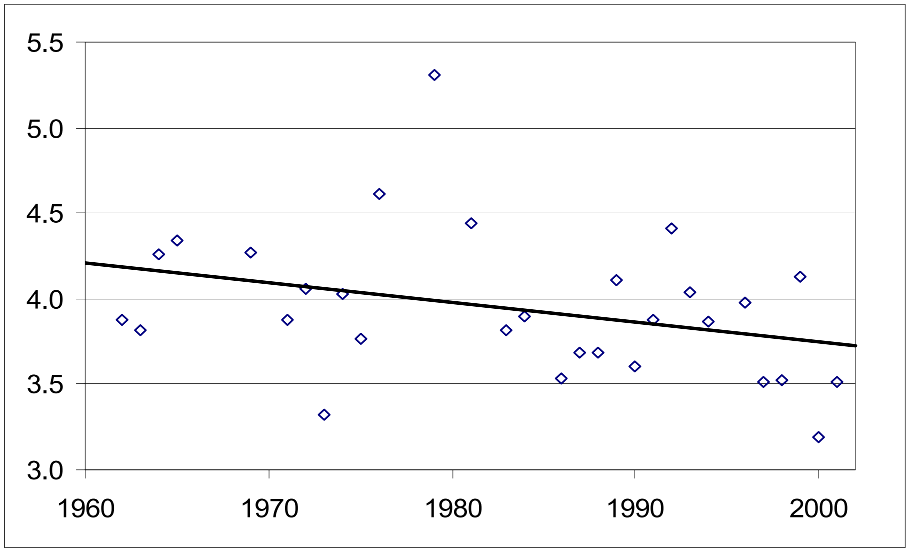
Annex IV: Trends in 10-day average reference crop evapotranspiration (ET_0) in Jan I, Jan II and Jan III (from top to bottom) (horizontal axis is year & vertical axis is ET_0 in mm/day)

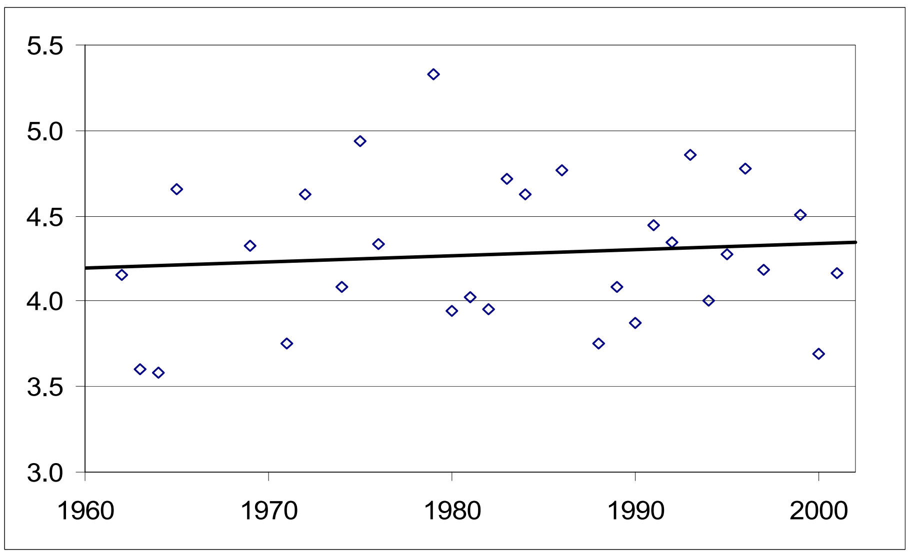


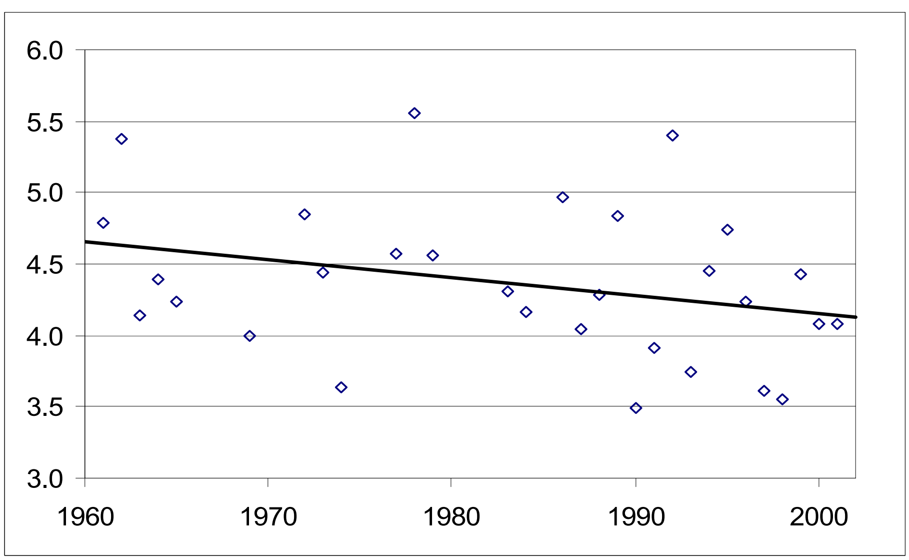




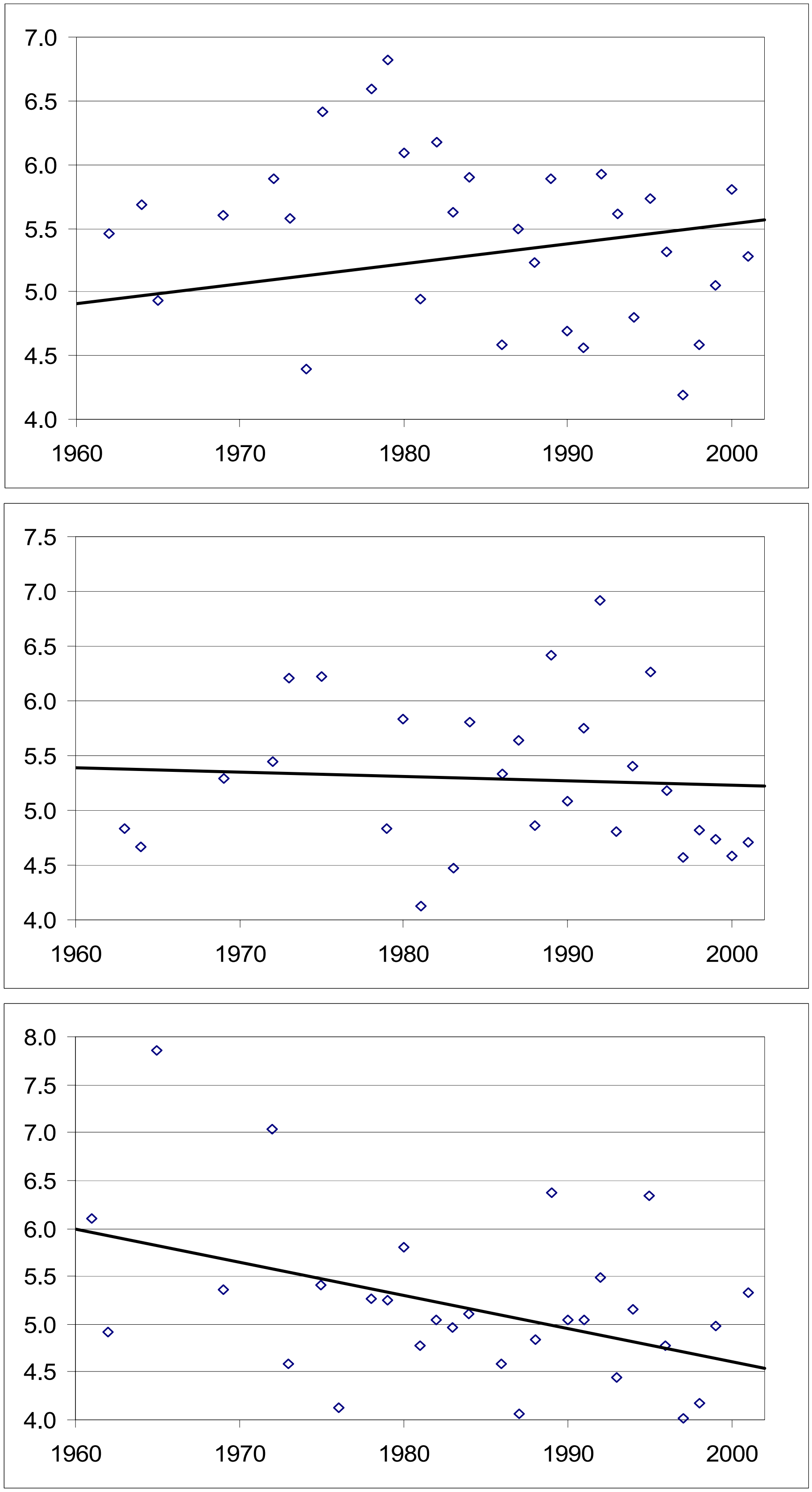
Annex IV: (continued) for Feb I, Feb II and Feb III (from top to bottom) (horizontal axis is year & vertical axis is ET_0 in mm/day)



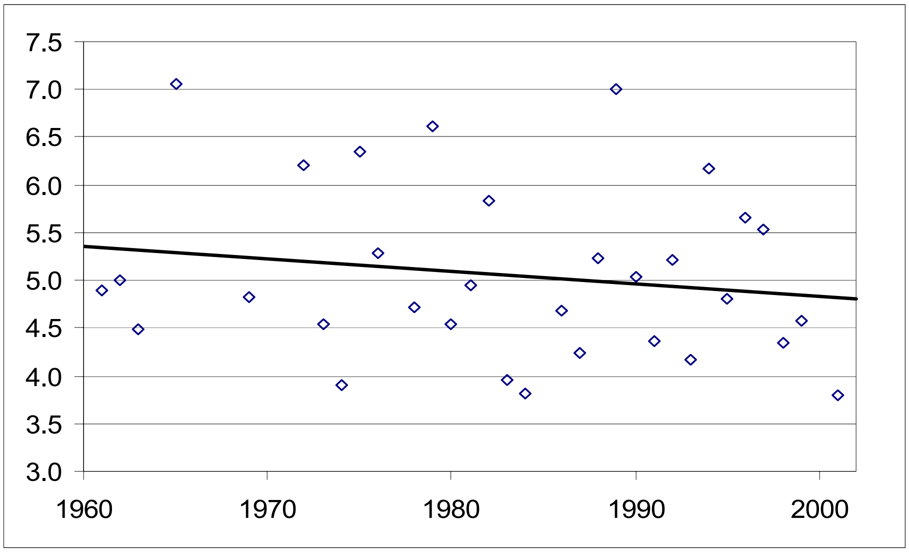


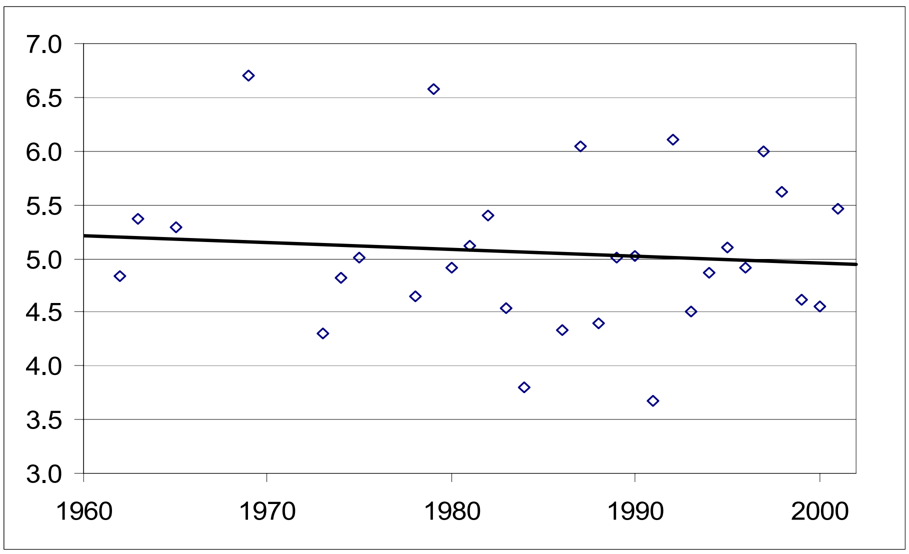


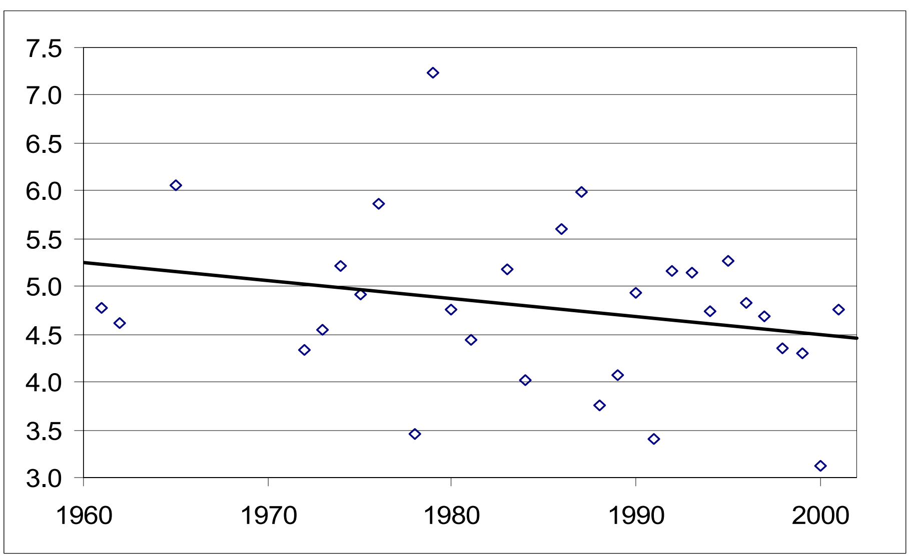
Annex IV: (continued) for Mar I, Mar II and Mar III ((from top to bottom) (horizontal axis is year & vertical axis is ET_0 in mm/day)



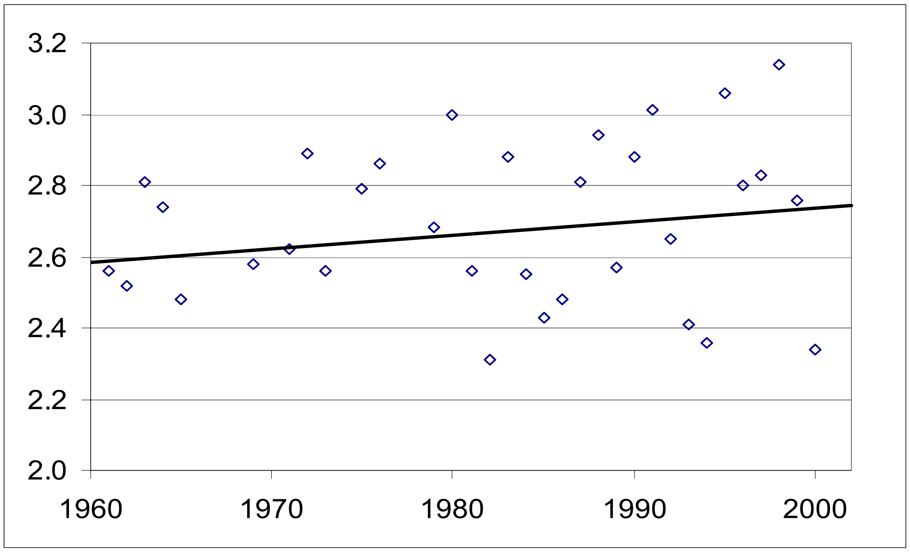
Annex IV: (continued) for Apr I, Apr II and Apr III (from top to bottom) (horizontal axis is year & vertical axis is ET_0 in mm/day)

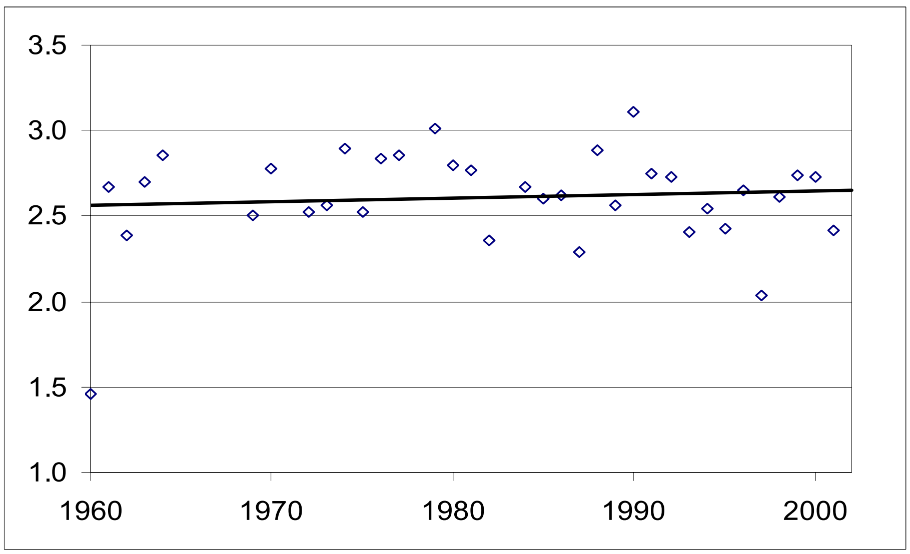


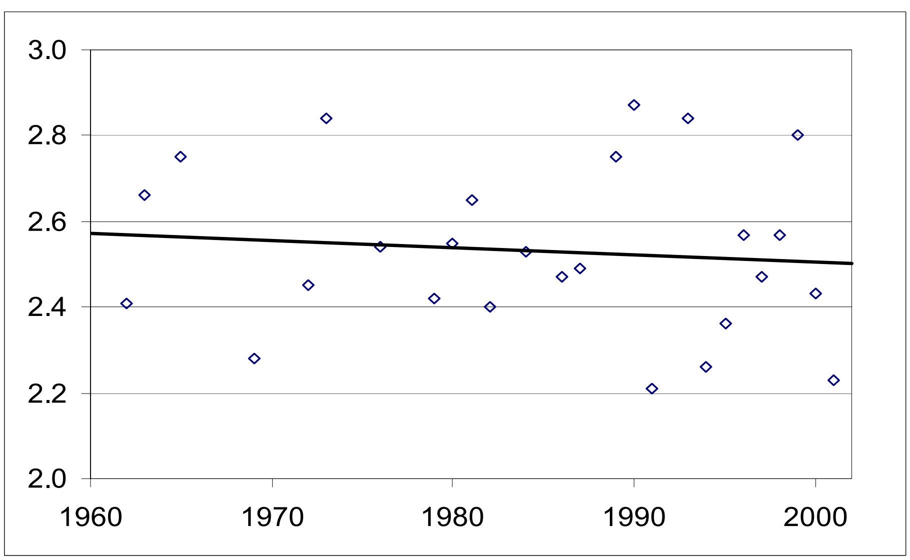




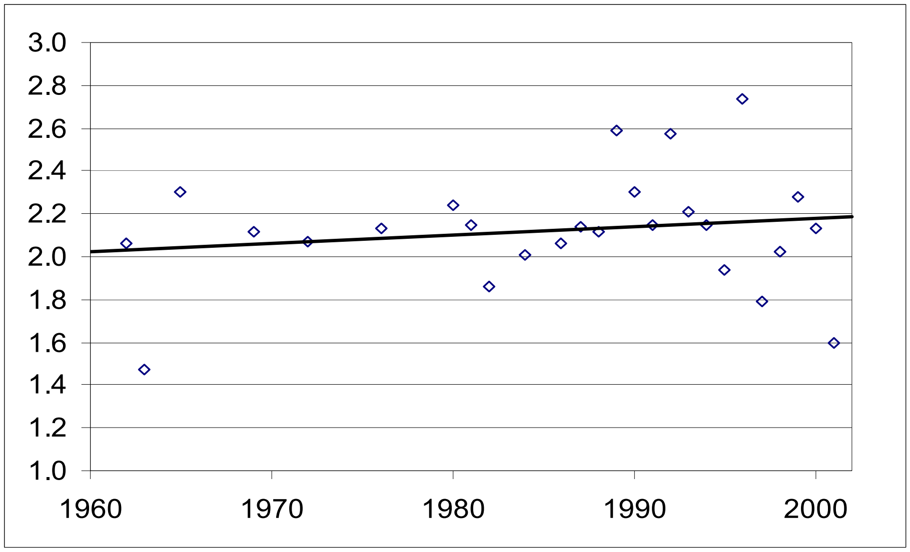
Annex IV: (continued) for May I, May II and May III (from top to bottom) (horizontal axis is year & vertical axis is ET_0 in mm/day)y)

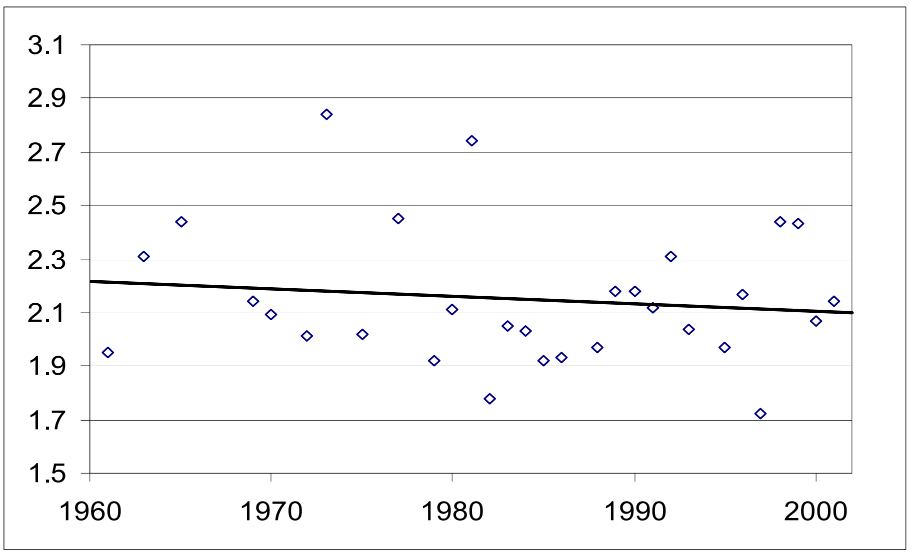


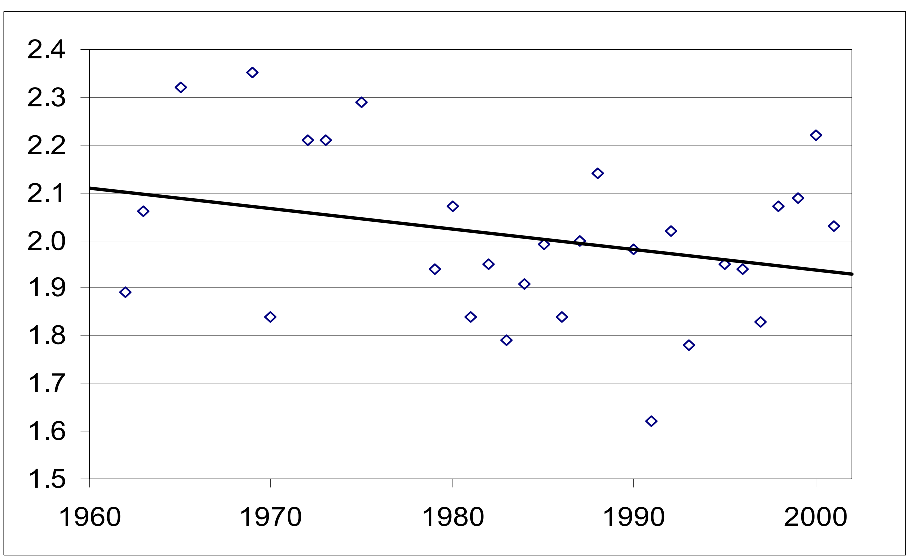




Annex IV: (continued) for Nov I, Nov II and Nov III (from top to bottom) (horizontal axis is year & vertical axis is ET_0 in mm/day)







Annex IV: (continued) for Dec I, Dec II and Dec III (from top to bottom) (horizontal axis is year & vertical axis is ET_0 in mm/day)

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