Changing Climate of Bangladesh

METreport

No. 04/2024
ISSN 2387-4201

Changing Climate of Bangladesh

Trends and changes detected in weather observations from 1980 to 2023 in Bangladesh.

Md. Bazlur Rashid, Afruza Sultana, S M Quamrul Hassan,
Elinah Kuya, Kajsa Parding and Hans Olav Hygen

Effects of Climate Change:
Increased heatwaves in the monsoon season

Abstract

The global climate is changing, and Bangladesh is not spared. In 2016, Bangladesh Meteorological Department (BMD) in collaboration with the Norwegian Meteorological Institute published a report on the current status of the climate of Bangladesh. This report goes beyond the baseline of today's climate and explores detected changes in the Bangladeshi climate through the weather observations in Bangladesh.

In this report, a homogeneity test of the Bangladeshi observations is performed, and shows that data from about 1980 has an acceptable level of homogeneity. Based on this, trends have been calculated for maximum and minimum temperature, daily temperature range, precipitation amount and frequency, and sunshine hours and cloudiness. The major picture is that in Bangladesh all of these elements show clear signals of change consistent with the global pattern of climate change.

More details of the effects of the changing climate on heatwaves and cold outbreaks have been analysed. This analysis shows a tendency to later onset of the heat, and, more worryingly, a tendency of increased heatwaves in the monsoon season. A similar analysis of heavy to very heavy rainfall does not reveal any clear shift.

Contents

①

②

③

④

⑤

①

Introduction

Photo: Hans Olav Hygen/MET Norway

Introduction

The global climate is changing (IPCC, 2021), and Bangladesh is also affected by these changes. Figure 1 depicts the development of the temperature in Bangladesh, and it clearly shows a warming of around 1°C since pre-industrial times. As will be shown in this report, this increase in temperature has been accompanied by alarming effects on the local climatic conditions, such as an increase in the number of heatwaves

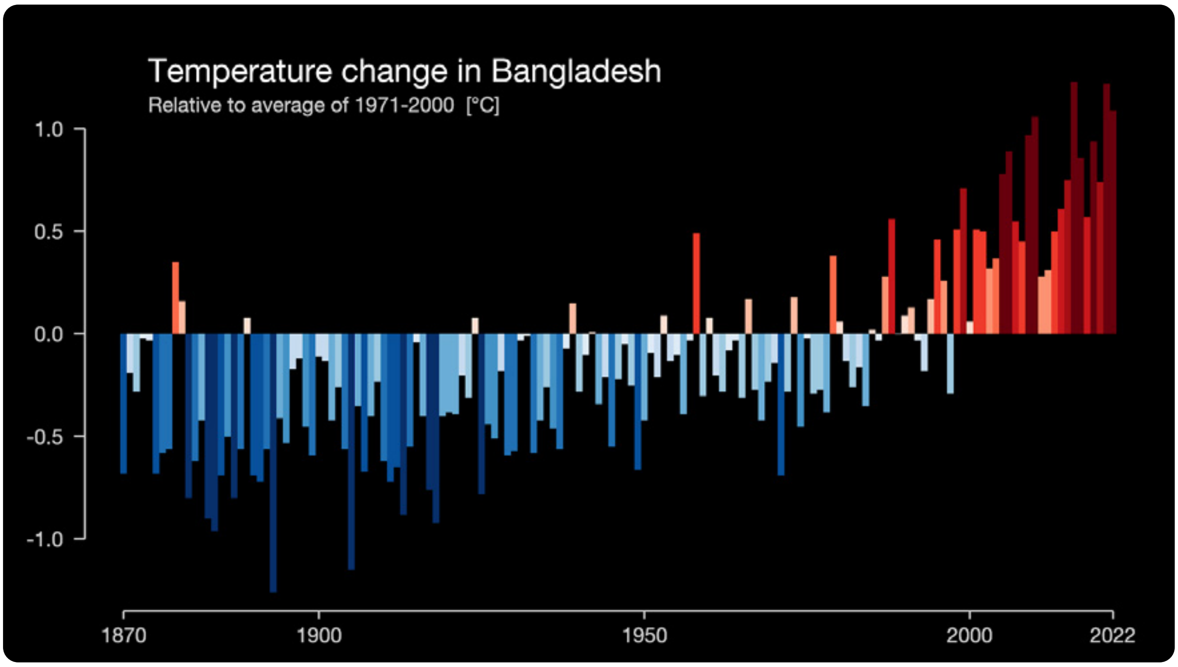


Figure 1.1: The temperature development of Bangladesh from 1871 to today. Data from Berkley, graphics from https://showyourstripes.info/c/asia/bangladesh/all

1.1 Background

Since its origins in 1971, Bangladesh Meteorological Department (BMD) has observed and archived the weather. The roots of BMD stretch further back in time, and its comprehensive archive of observations goes back to 1948. In 2016, the report “Climate of Bangladesh” was co-published with MET Norway (Khatun et al., 2016), describing the state of the Bangladeshi climate. The threat of climate change has become no less distinct in the years since, and an understanding of how the climate is changing and its effect on Bangladesh is even more necessary. This report aims to answer some of these questions by analysing observations of the weather of Bangladesh.

1.1.1 Observational sites in Bangladesh

Bangladesh has a well-established network of meteorological observatories (table 1.1), some going back more than 100 years. Due to historical events, especially the Indian liberation in 1947, the archive of BMD only contains data from 1948 and onward. Key elements like maximum temperature, minimum temperature, precipitation, sunshine hours, and cloud cover are available electronically while there still are significant amounts of data only stored on paper. All stations are manned stations, with a recent addition of Automatic Weather Stations (AWS).

Dimla Weather Station in Nilphamari district

Photo: Lene Østvand/MET Norway

Observational sites in Bangladesh

Local ID	WMO ID	Name	Division	Lat. (°N)-	Long. (°E)-	Altitude (m)	Est. (year)
11111	**41923**	**Dhaka**	**Dhaka**	**23.78**	**90.38**	**8.5**	**1949**
41909	41909	Tangail	Dhaka	24.25	89.93	10.2	1983
10609	**41886**	**Mymensingh**	**Dhaka**	**24.73**	**90.42**	**18.0**	**1883**
11505	41929	Faridpur	Dhaka	23.60	89.85	8.1	1883
11513	41939	Madaripur	Dhaka	23.17	90.18	7.0	1976
41977	41977	Chattogram Ambagan	Chattogram	22.35	91.82	33.2	1937
11921	**41978**	**Chattogram Patenga**	**Chattogram**	**22.22**	**91.80**	**5.5**	**1937**
11927	41992	Cox's Bazar	Chattogram	21.45	91.97	2.1	1908
11316	41941	Chandpur	Chattogram	23.23	90.70	4.9	1964
11313	41933	Cumilla	Chattogram	23.43	91.18	7.5	1883
11805	41943	Feni	Chattogram	23.03	91.42	6.4	1973
11814	41963	Hatiya	Chattogram	22.45	91.10	2.4	1965
11925	41989	Kutubdia	Chattogram	21.82	91.85	2.7	1977
11809	41953	Maijdee Court	Chattogram	22.87	91.10	4.9	1883
12007	41966	Rangamati	Chattogram	22.63	92.15	68.9	1957
11916	41964	Sandwip	Chattogram	22.48	91.43	2.1	1966
11912	41965	Sitakunda	Chattogram	22.63	91.70	7.3	1977
11929	41998	Teknaf	Chattogram	20.87	92.30	5.0	1976
11604	**41947**	**Khulna**	**Khulna**	**22.78**	**89.53**	**2.1**	**1921**
11407	41936	Jashore	Khulna	23.20	89.33	6.1	1867
11610	41946	Satkhira	Khulna	22.72	89.08	4.0	1877
41926	41926	Chuadanga	Khulna	23.65	88.82	11.6	1986
41958	41958	Mongla	Khulna	22.47	89.60	1.8	1988
11704	**41950**	**Barishal**	**Barishal**	**22.72**	**90.37**	**2.1**	**1883**
12103	41960	Patuakhali	Barishal	22.33	90.33	1.5	1973
11706	41951	Bhola	Barishal	22.68	90.65	4.3	1965
12110	41984	Khepupara	Barishal	21.98	90.23	1.8	1973
10320	**41895**	**Rajshahi**	**Rajshahi**	**24.37**	**88.70**	**19.5**	**1883**
10408	41883	Bogura	Rajshahi	24.85	89.37	17.9	1884
10910	41907	Ishurdi	Rajshahi	24.15	89.03	12.9	1963
10208	**41859**	**Rangpur**	**Rangpur**	**25.73**	**89.27**	**32.6**	**1883**
10120	41863	Dinajpur	Rangpur	25.65	88.68	37.6	1883
41858	41858	Sayedpur	Rangpur	25.75	88.92	39.6	1980
10705	**41891**	**Sylhet**	**Sylhet**	**24.90**	**91.88**	**33.5**	**1952**
10724	41915	Srimangal	Sylhet	24.30	91.73	22.0	1905

Table 1.1: Observational sites in Bangladesh. Divisional stations are highlighted with bold font. The table includes the local and World Meteorological Organization (WMO) ID number of the stations, their name and division, and the latitude, longitude, altitude and year established.

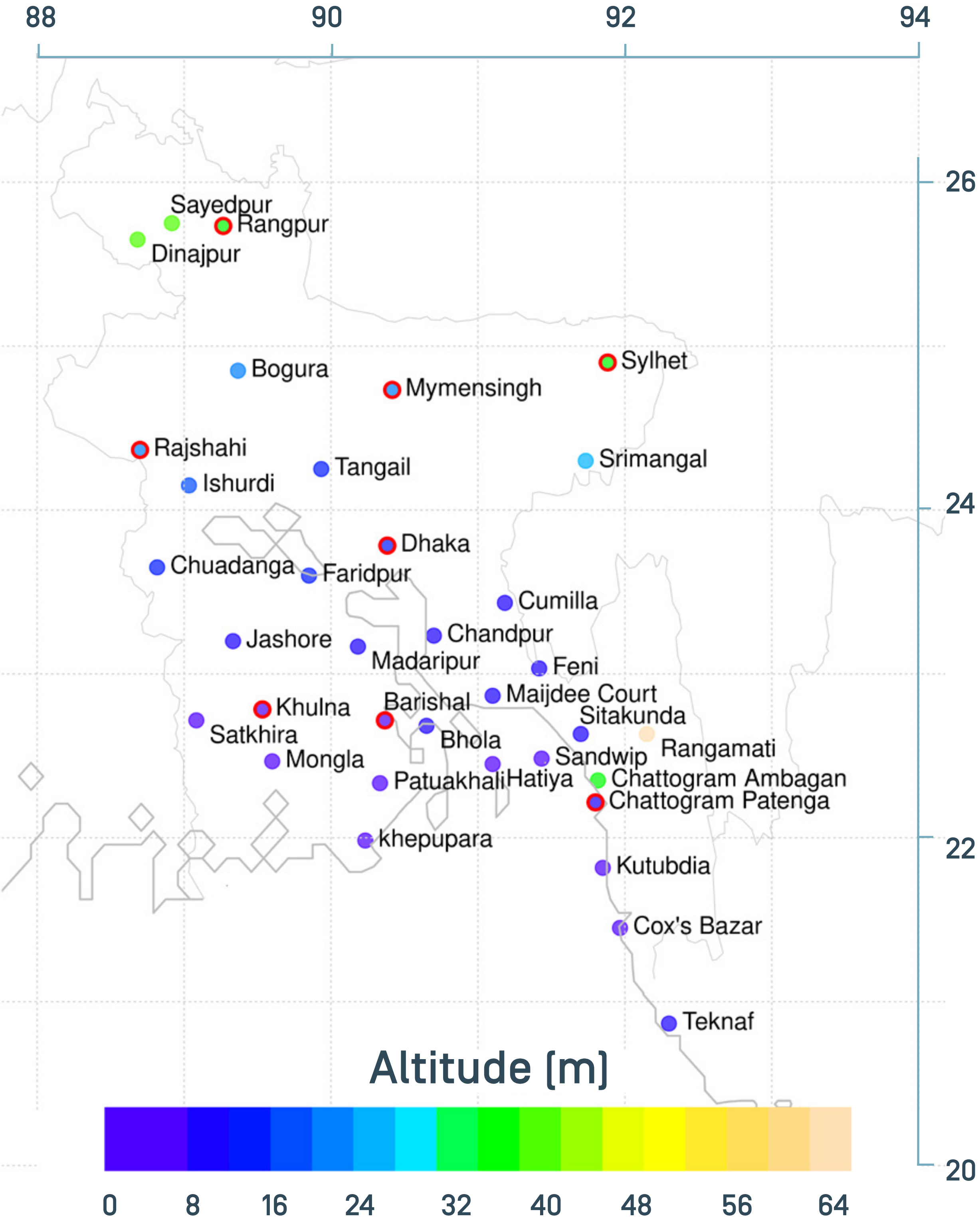


Figure 1.2. Map of observational stations in Bangladesh. The colour scale represents the altitude at the stations. Divisional stations are marked with red outlines.

②

Homogeneity of observations in Bangladesh

Photo: Gunnar Noer/MET Norway

Homogeneity of observations in Bangladesh

High-quality, reliable and homogeneous datasets have been widely acknowledged as essential for comprehensive analysis of long term climate change and variability studies (Peterson et al., 1998, Aguilar et al., 2003). Long-term climatological time series are regarded as homogeneous if the variations within the time series are only a result of variations in weather and climate, i.e the measurements have been consistently done using the same practices, with the same undamaged instruments at the same place and time and in the same environment. However, many climatic observations have been altered by several external changes which makes the data divergent from the actual climate variation in the study region. Such changes include substitutions or alterations of instruments, observers, observation methods and practices, the station's geographical location and in the environment surrounding the station (Peterson et al., 1998). These external changes may introduce sudden shifts (homogeneity breaks) to the time series. Some changes, e.g urban development, lead to gradual biases over time from the real macro-climatic characteristics. These shifts and biases are often comparable to that of climate change and may lead to misinterpretation of climate analysis results (Menne and Williams, 2009). It is therefore of great importance to analyse and correct for such external influences to achieve a homogeneous climatic time series before making a climate assessment. Homogenisation is the process of adjusting the data to minimise the effect of spurious factors and ensure the consistency and quality of the data.

Poorly observed datasets, which lack observation history and are inhomogeneous, often lead to misinterpretation and poor understanding of historical climate characteristics, and hence unreliable future climate projections as well as a root cause of climate uncertainty. Past homogeneity tests of observed temperature series around the world have revealed a widespread presence of serious inhomogeneities, and hence homogenisation become a basic requirement for climatological studies (Menne and Williams, 2009; Mamara et al., 2014; Kuya et al., 2020; Joelsson et al., 2022).

Some prerequisites to developing a homogenised time series were, however, not present in the Bangladesh temperature data. We therefore limit this study to evaluate the homogeneity of the BMD temperature series and its reliability of climate monitoring studies.

2.1 Data and methods

2.1.1 Temperature dataset

The temperature series used in the study are dry bulb temperature observations obtained from the Bangladesh Meteorological Department (BMD). The dry bulb temperature is the ambient air temperature measured by a thermometer that is not affected by humidity. The first step in climate analysis is to assess the homogeneity of such series. The analysis covered the period 1961-2021. Most of the temperature series did not cover the entire study period and had several missing values especially between 1961-1980, some of which are due to the various stages of the Bangladesh liberation wars. Data back to 1961 was, however, used because it is better to homogenise with a longer time series. Homogenisation also allows the imputation of missing data while correcting breaks and outliers. The study considered series with at least 80% data coverage to be included in the analysis following the guide to Climatological practices (WMO, 2011) recommendations. However, to have a spatial representation of Bangladesh, some series with more than 20% but less than 30% of missing values were included in the study. The resulting dataset consisted of 29 series for the period 1961-2020, shown in Table 2.1 and Figure 1.2.

Analysed series no.	**Name**	**Lat**	**Lon**	**Altitude**	**Analysed period**	**% missing data since 1961**
41923	Dhaka	23.8	90.4	8.5	1961-2021	2.0
41886	Mymensingh	24.7	90.4	18.0	1961-2021	2.5
41929	Faridpur	23.6	89.9	8.1	1961-2021	0.8
41939	Madaripur	23.2	90.2	7.0	1961-2021	28.6
41978	Chattogram	22.3	91.8	5.5	1961-2021	9.6
41964	Sandwip	22.5	91.4	2.1	1961-2021	13.1
41965	Sitakunda	22.6	91.7	7.3	1961-2021	26.8
41966	Rangamati	22.5	92.2	68.9	1961-2021	4.8
41933	Comilla	23.4	91.2	7.5	1961-2021	7.2
41941	Chandpur	23.3	90.7	4.9	1961-2021	15.6
41953	M.Court	22.9	91.1	4.9	1961-2021	5.5
41943	Feni	23.0	91.4	6.4	1961-2021	22.1
41963	Hatiya	22.4	91.1	2.4	1961-2021	13.4
41992	Coxs Bazar	21.5	92.0	2.1	1961-2021	0.8
41998	Teknaf	20.9	92.3	5.0	1961-2021	28.0
41891	Sylhet	24.9	91.9	33.5	1961-2021	2.6
41915	Srimangal	24.3	91.7	39.6	1961-2021	4.0
41895	Rajshahi	24.4	88.7	19.5	1961-2021	5.2
41907	Ishurdi	24.1	89.1	12.9	1961-2021	1.6
41883	Bogra	24.9	89.4	17.9	1961-2021	10.0
41859	Rangpur	25.7	89.2	32.6	1961-2021	4.5
41863	Dinajpur	25.7	88.7	37.6	1961-2021	14.2
41947	Khulna	22.8	89.5	2.1	1961-2021	8.2
41946	Satkhira	22.7	89.1	4.0	1961-2021	4.0
41936	Jessore	23.2	89.2	6.1	1961-2021	9.2
41950	Barisal	22.8	90.4	2.1	1961-2021	0.8
41960	Patuakhali	22.3	90.3	1.5	1961-2021	25.1

Table 2.1: List of stations analysed with percentage of missing data. (Note that the station called Chattogram here is referred to as Chattogram_Patenga in Table 1.1 and Figure 1.2.)

Photo: Hans Olav Hygen/MET Norway

Homogenisation approach and application

The homogenisation software HOMER (Mestre et al., 2013) was used in this study. The software Climatol (Guijarro, 2018, 2019) was also used for comparison. Both HOMER and Climatol are relative homogenisation methods, meaning that the analysis relies on neighbouring stations (reference stations). HOMER, as described by Kuya et al. (2020), is an iterative semi-automatic method that takes advantage of metadata when accepting and rejecting detected breaks. It has three break detection functions in its homogenisation process: Pairwise detection, joint detection and ACMANT detection.

Climatol, on the other hand, provides automatic quality control (outlier correction), homogenisation (break detection and correction) and missing data attribution. Version 3.1.1 of the Climatol R package was used for comparison and is described in Kuya et al. (2021).

The success of break-point detection is dependent on the correlation strength between the candidate series and its reference series, as well as the number of reference series (cf. Kuya et al., 2020). A robust cross-correlation coefficient, with certain distance restriction, ensures that the candidate and reference series adequately represent similar climate signals. It should, however, be noted that common periods of missing values in selected series and their potential reference series can potentially influence the selection of reference series (Costa and Soares, 2008).

The homogenisation approach (HOMER) in this study employed additive correction with a minimum correlation of 0.6 for the selection of the network of neighbour series (reference series). A minimum number of six reference series in the network was set for each candidate series. This means that all candidate series had at least six reference stations regardless of the correlation coefficient. The study's lowest correlation coefficient was 0.5, indicating that the data series were relatively well correlated with their reference series. The number of reference series was limited to six in order to reduce the number of less correlated series, especially in cases where none of the neighbours exhibited correlations greater than or equal to 0.6. The series were tested on an annual basis in the pairwise detection, as well as on a seasonal basis.

While HOMER has a built-in quality control function to identify anomalous series and detect outliers, these were not performed in this analysis. Additionally, the detected break points were not checked against the documented metadata to validate if there were actually inhomogeneities. These are major limitations to this analysis, as quality control, metadata and station history are main components of homogenisation. A comprehensive homogenisation process is therefore recommended in future analyses.

Results

Results for homogeneity testing found all of the 29 Bangladesh dry bulb temperature series as inhomogeneous. All series were found to have at least one or more (up to six) homogeneity breaks. HOMER detected 82 breaks while Climatol identified 85. It is worth noting that most of these breaks were “outlier breaks", i.e., breaks occurring within a short time period of each other (a year or two apart or sometimes within the same year). This type of break comes about mostly from outlying values in the series. The data quality control revealed more than 100 outlier values based on Climatol analysis. This shows the benefits of quality control, such that legitimate outliers are removed before the homogenisation process. Use of metadata can also disqualify some of the detected breaks. A large part, 49% and 41% of the detected breaks in HOMER and Climatol respectively, occurred before 1980.

Considering the case of Rajshahi series, HOMER’s pairwise detection results are given in Fig 2.2, where we note homogenisation breaks in 1968, 1978, 1994/95 and a potential break in 2016. In the end, corrections were made in 1967, 1978 and 2017 (see Fig 2.3). This implies that there was somewhat good agreement in the amplitudes of the changes in pairwise comparison and those in the automatic joint-detection and the ACMANT

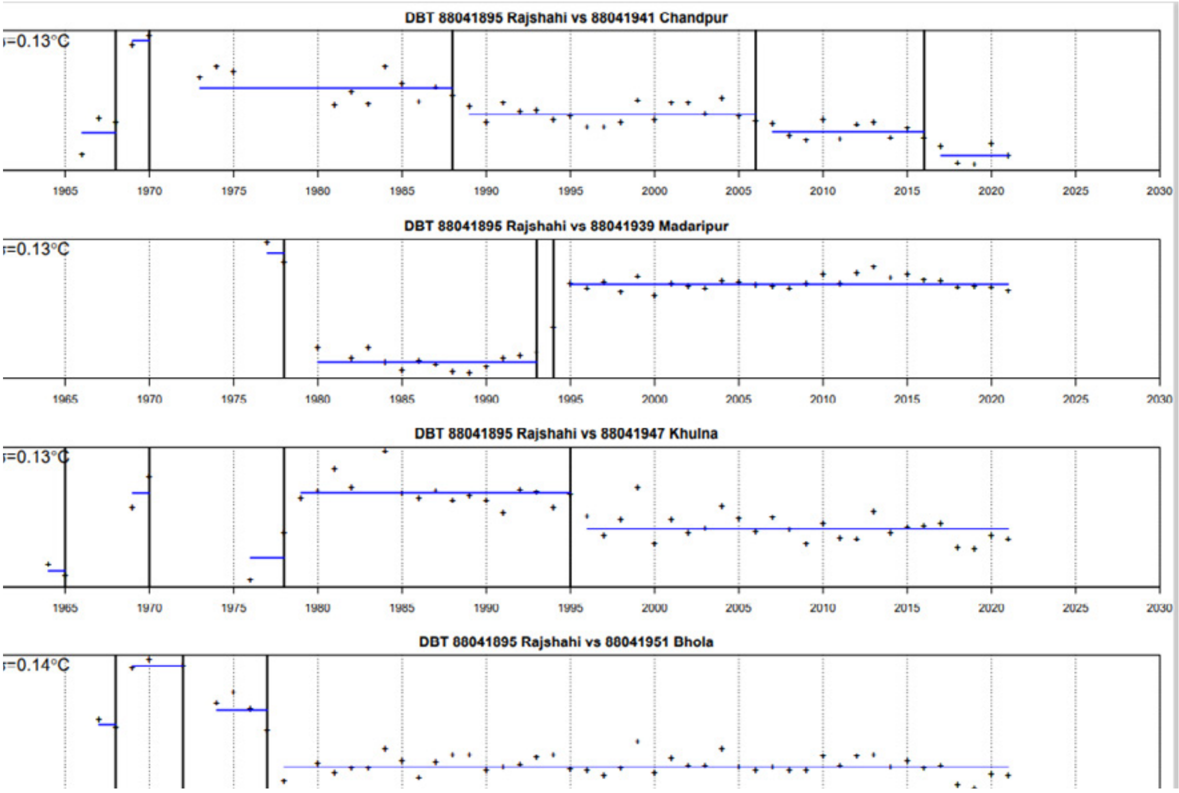
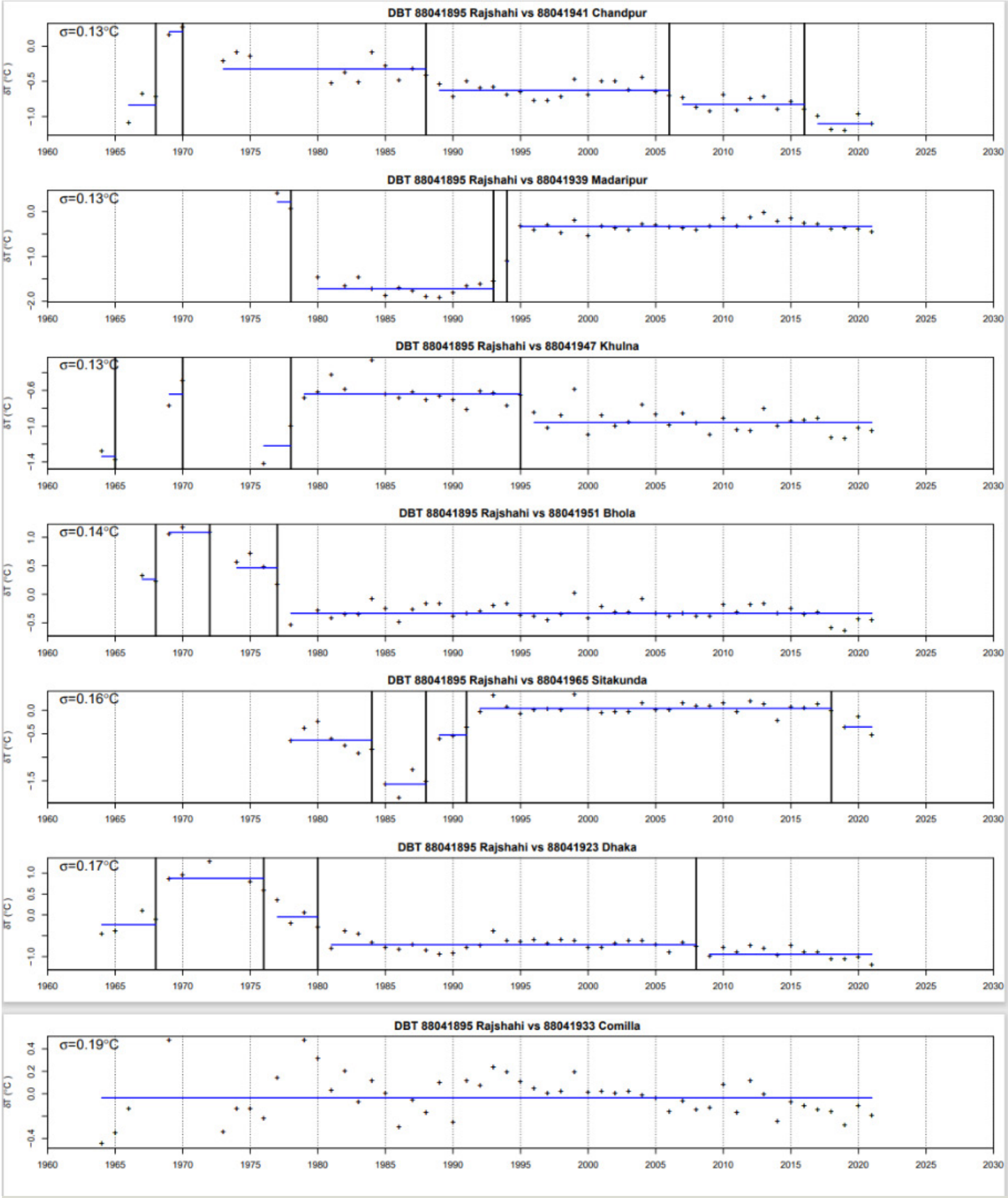


Fig. 2.1: Number of breaks per year for the Bangladeshi temperature series detected by HOMER (blue) and Climatol (red)

detection phase (cf. Kuya et al., 2020 to understand these steps). Thus, even in the absence of metadata, there is sufficient statistical evidence to the correction of the breaks made to Rajshahi series.

The raw and corrected Rajshahi series after final correction are provided in Figure. 2.4. Note how, after correction and reconstitution of missing data in Rajshahi series, the overall temperature trend has changed. Figure 2.4 shows an annual decrease in the average temperature for Rajshahi throughout the study period for the non-homogenised series while an annual increase is seen in the homogenised series. Eleven of the 29 series tested showed a general decrease of temperature throughout the study period before homogenisation. However, only one series (Dinajpur) maintained a decreasing trend after homogenisation. This demonstrates the importance of homogenisation for accurate interpretation of climate characteristics.



Figuere 2.2: Pairwise comparison between the annual mean temperature at the Rajshahi station and its nearest neighbours. Vertical black lines denote the year of a probable break. Comparisons are sorted according to increasing values of σ, the noise standard deviation, which is included in the upper left corner of each plot. (DBT stands for Dry Bulb Temperature, which is the ambient air temperature, elsewhere referred to as temperature).

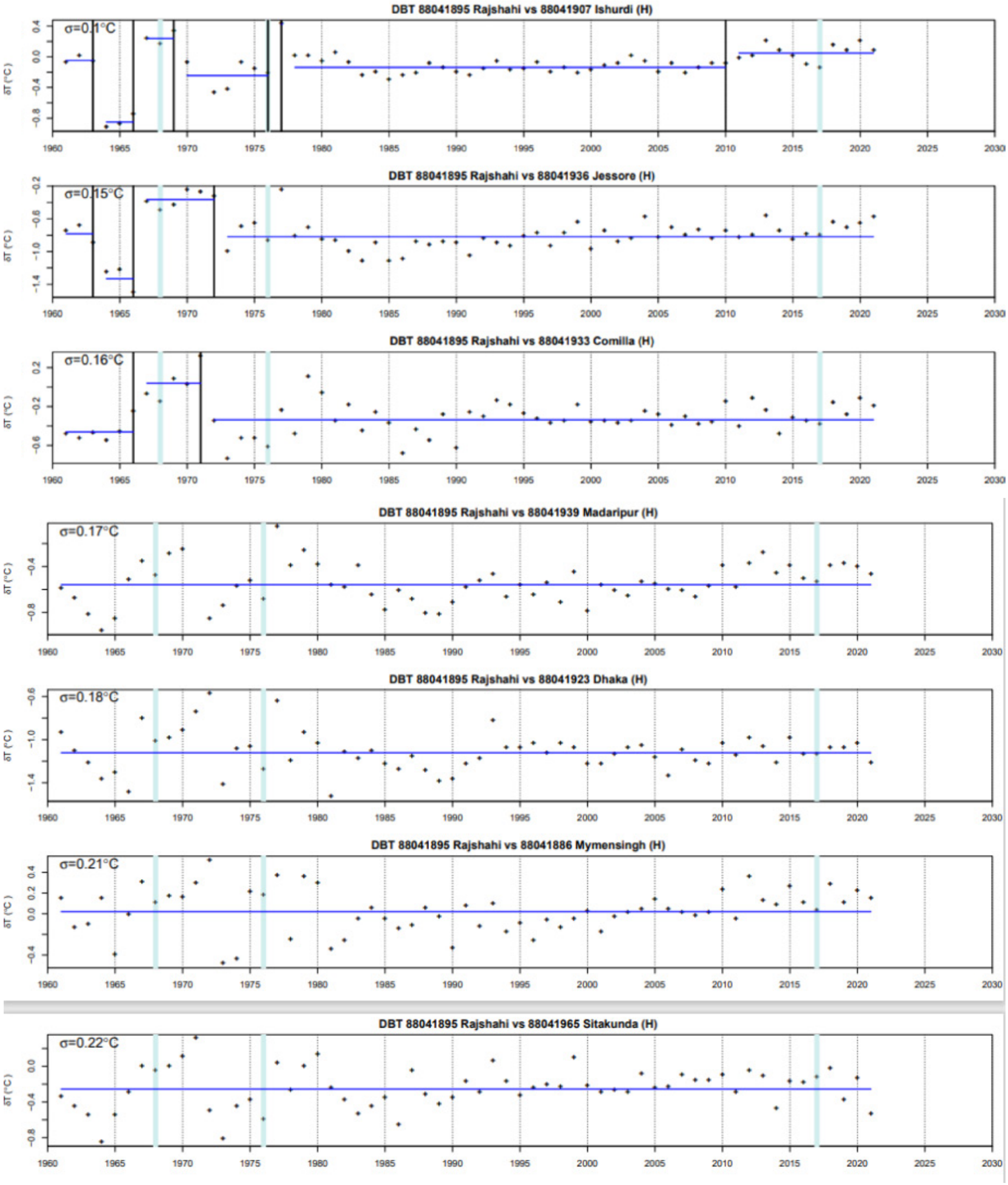


Figure 2.3: Pairwise comparison between the corrected annual mean temperature series of Rajshahi and its neighbours. Light blue vertical lines denote the breaks that have been adjusted. Comparisons are sorted according to increasing values of σ (noise standard deviation, upper left corner of each plot).

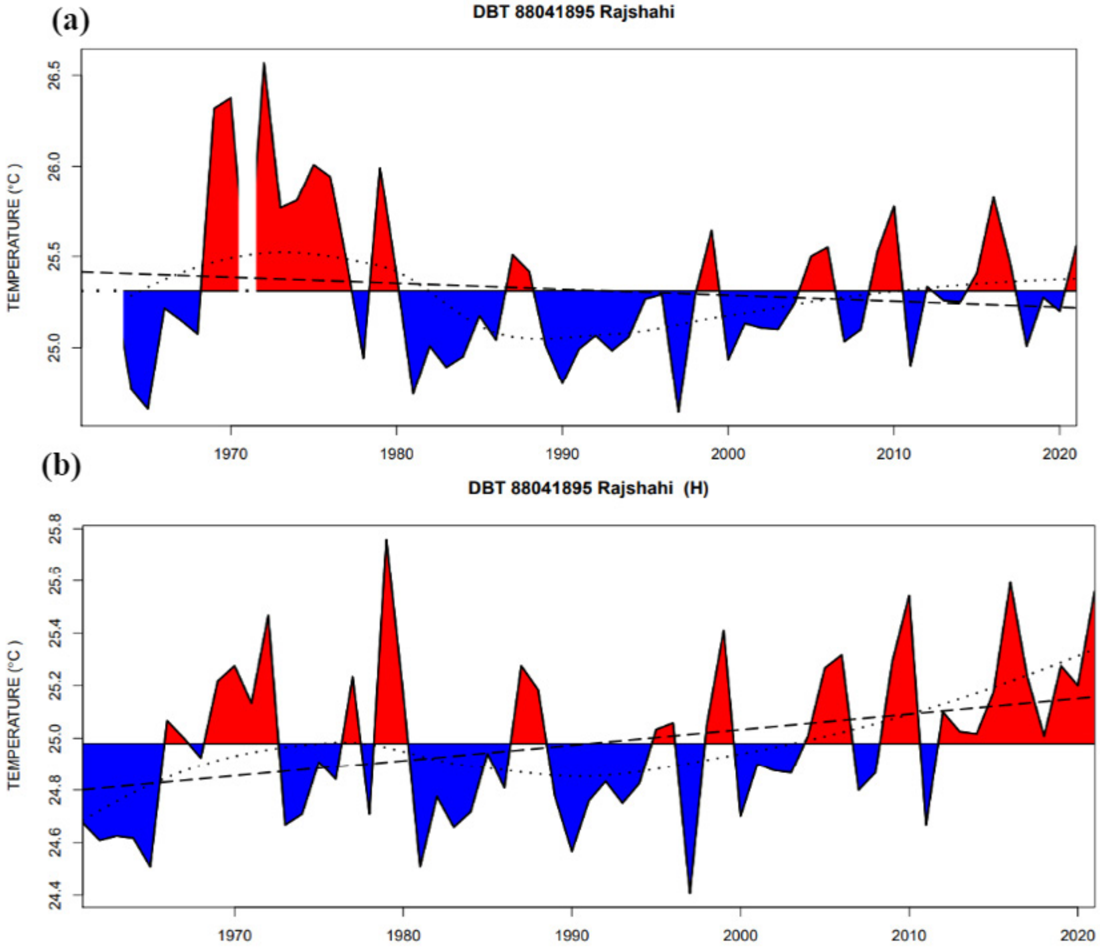


Figure 2.4: Raw (a) and homogenised (b) Dry Bulb Temperature (DBT) at Rajshahi time series.

Impacts of homogenisation

The influence of homogenisation on selected temperature series in Bangladesh are shown in Figure 2.5. It shows the 5-year Gaussian density function 'normal' average for the annual monsoon (June, July, August and September) and winter (December, January, February) anomalies. They were calculated for the raw (non-homogenised) and homogenised temperature series with respect to the new standard climate normal 1991-2020 reference period. A wider range of anomalies is seen in the raw series especially before 1990 than the homogenised series. The results confirm that homogenisation contributes to better spatial coherence of time series.

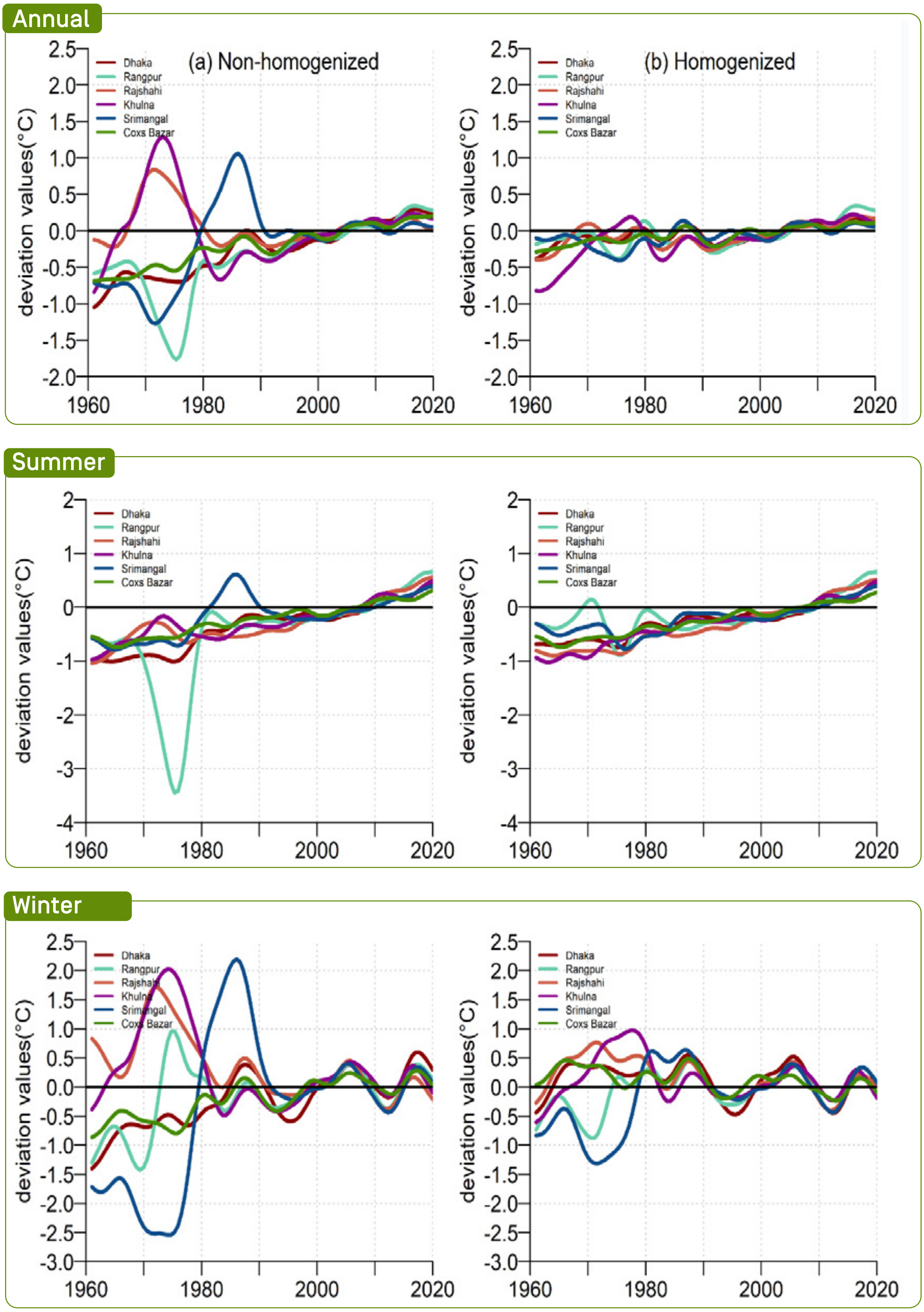


Figure 2.5: Deviation of the annual (top), summer (middle) and winter (bottom) for selected series with respect to 1991-2000 mean before (a) and after homogenisation (b). The anomaly series has been filtered using a 5-year Gaussian density function.

Summary and Conclusions

The homogeneity test produced a 61 year long homogenous dataset for 29 monthly temperature series in Bangladesh, during the period 1961–2021. HOMER and Climatol homogenisation methods were used to assess homogeneity of the temperature series. All series were found with homogeneity breaks ranging from 1 to 6 per series. All these breaks were corrected. While it is practice to follow given guidelines for inhomogeneity testing, including quality control and use of metadata, some steps were overlooked/ignored due to unavailability of station history. Nevertheless, in HOMER for example, in most cases, there was good agreement in the amplitudes of the changes in the three different detection algorithms, thereby giving sufficient statistical evidence to the correction of the breaks. However, a comprehensive homogenisation process is recommended for Bangladeshi temperature series. Most of the inhomogeneity breaks were detected before 1980 (50%), where the data quality was also of great concern. Raw observed temperature data after 1981 should however still be used with caution.

The homogeneity testing demonstrated the importance of homogenisation for accurate interpretation of climate characteristics. In the end, homogenisation showed how greatly Bangladesh temperature series could be improved in quality. The quality and temporal coherence of the dataset has been greatly improved. The reliability of the homogenised dataset in explaining the large-scale climate variations in Bangladesh, however, is subject to a comprehensive homogenisation, where all the detected breaks can be justified.

③

Trends in climate of Bangladesh

Photo: Gunnar Noer/MET Norway

Trends in climate of Bangladesh

As stated above, the global climate is getting warmer (IPCC 2021), and the climate of Bangladesh is no exception. The following chapter describes an investigation of the trends in temperature, precipitation, sunshine hours and cloudiness. Based on the homogeneity analysis in chapter two, the estimates of climate change in Bangladesh are restricted to the period from 1980 to 2023. Data from months with more than five days of missing observations were excluded. Raw temperature data were used rather than the homogenised time series, as the homogenised data were not available on a daily time resolution. This use of raw data gives an extra uncertainty, but one should keep in mind that almost half of the detected inhomogeneities in the temperature data were detected during the 20 year period 1961-1980, and that there is a lower frequency of inhomogeneities in the later period, 1981-2020. One should also bear in mind that the detected breaks have a tendency to contribute to an underestimation of the past warming.

All the following analysis are performed on the seasonal level:

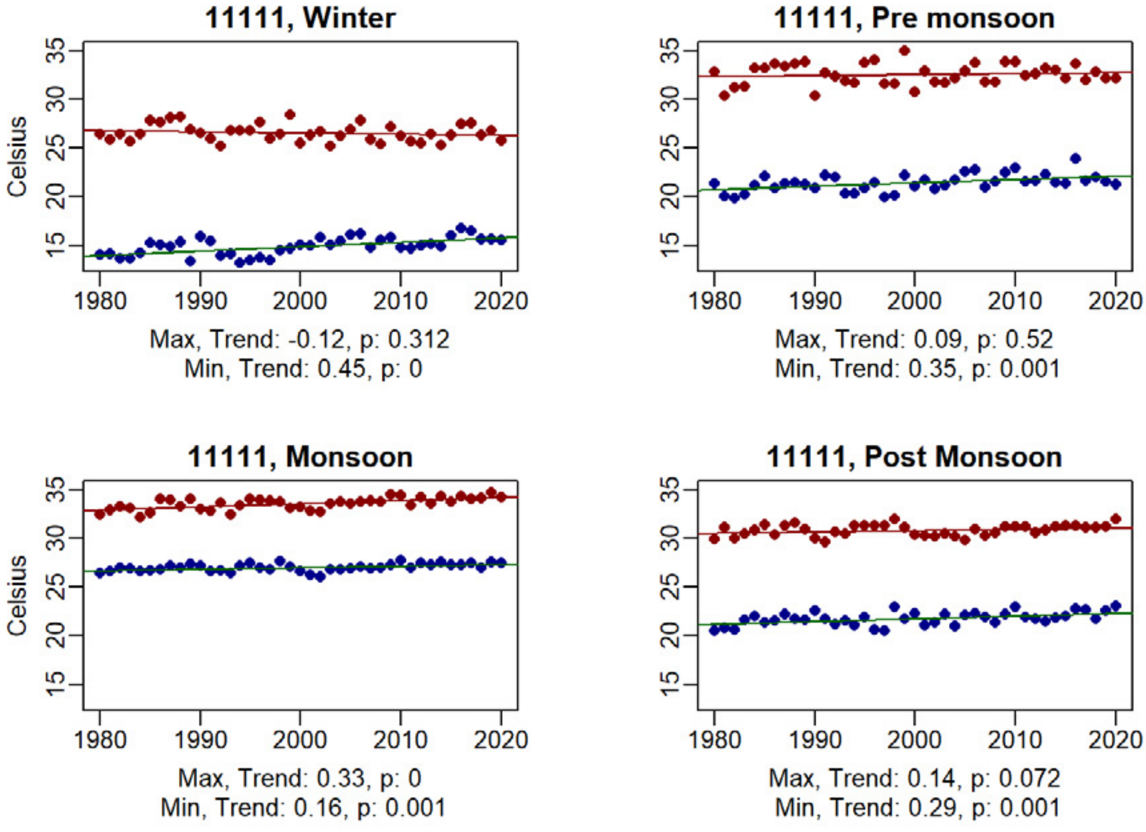
- **Winter:** December, January, February
- **Pre-monsoon:** March, April, May
- **Monsoon:** June, July, August, September
- **Post-monsoon:** October and November

3.1 Trends in temperature

The trends in temperature, daily maximum and daily minimum, were analysed for all stations for the period 1980-2020. The temperature of Bangladesh shows clear signs of change towards a warmer climate. There are regional and seasonal variations and a clear difference between the development of the daily maximum and minimum was detected (Figure 3.1 and Figures 3.3 - 3.5), which is also apparent in the analyses of the daily temperature range (Figures 3.2 and 3.6). All seasons showed clear signs of warmer weather, but there was one striking difference: For most stations, the maximum winter temperature did not show the same development in the inland region, either increasing less than the minimum temperature or decreasing slightly, resulting in a reduction of the diurnal temperature range.

In Dhaka (Figure 3.1), the daily minimum temperature increased significantly in all seasons, while the maximum temperature increased significantly only in the monsoon season and showed no significant trend in the other seasons. These changes in maximum and minimum temperatures also affect the Daily Temperature Range (DTR), which decreased significantly in winter (Figure 3.2). Corresponding figures for all 35 stations are included in the Appendix, and results of the trend analysis are summarised in table 3.1 for selected divisional stations.

The trends in the temperature and DTR shows two distinct modes (Figure 3.6). In the



11111, Winter

Max, Trend: -0.12, p: 0.312
Min, Trend: 0.45, p: 0

11111, Pre monsoon

Max, Trend: 0.09, p: 0.52
Min, Trend: 0.35, p: 0.001

11111, Monsoon

Max, Trend: 0.33, p: 0
Min, Trend: 0.16, p: 0.001

11111, Post Monsoon

Max, Trend: 0.14, p: 0.072
Min, Trend: 0.29, p: 0.001

Figure 3.1: Maximum and minimum temperature at the observational station 11111 (Dhaka). The trends are in degrees Celsius per decade.

monsoon season, the minimum and maximum temperature increased uniformly in the whole country (Figure 3.4 c and 3.5 c), but the maximum temperature increased more rapidly than the minimum temperature, thus increasing the DTR. This may be due to decreasing cloudiness in the monsoon, which would contribute to warmer days and colder nights. In the winter, the DTR decreased in the urbanised inland and increased in the coastal regions (Figure 3.6 a). The maximum temperature increased in the coastal region, but not inland, while the minimum temperature showed almost an opposite pattern. This might be connected to local and regional pollution in the inland stations, which may inhibit daytime warming by blocking incoming solar radiation. The pre- and post-monsoon trend patterns of minimum and maximum temperature and DTR fall somewhere in between, but the pre-monsoon patterns of change are more similar to the winter, and the post-monsoon more reminiscent of the monsoon season.

Analysis of the mean 2m temperature from the ERA5 reanalysis data set from the period 1980-2023 showed a warming of between 0.2 - 0.4 oC per decade (statistically significant, p-values < 0.05) in the whole country in the pre-monsoon, monsoon, and post-monsoon seasons, while there were no statistically significant trends in the region in winter (Figure 3.7). This confirms the picture described by the surface based observations, of a suppressed warming in the winter season.

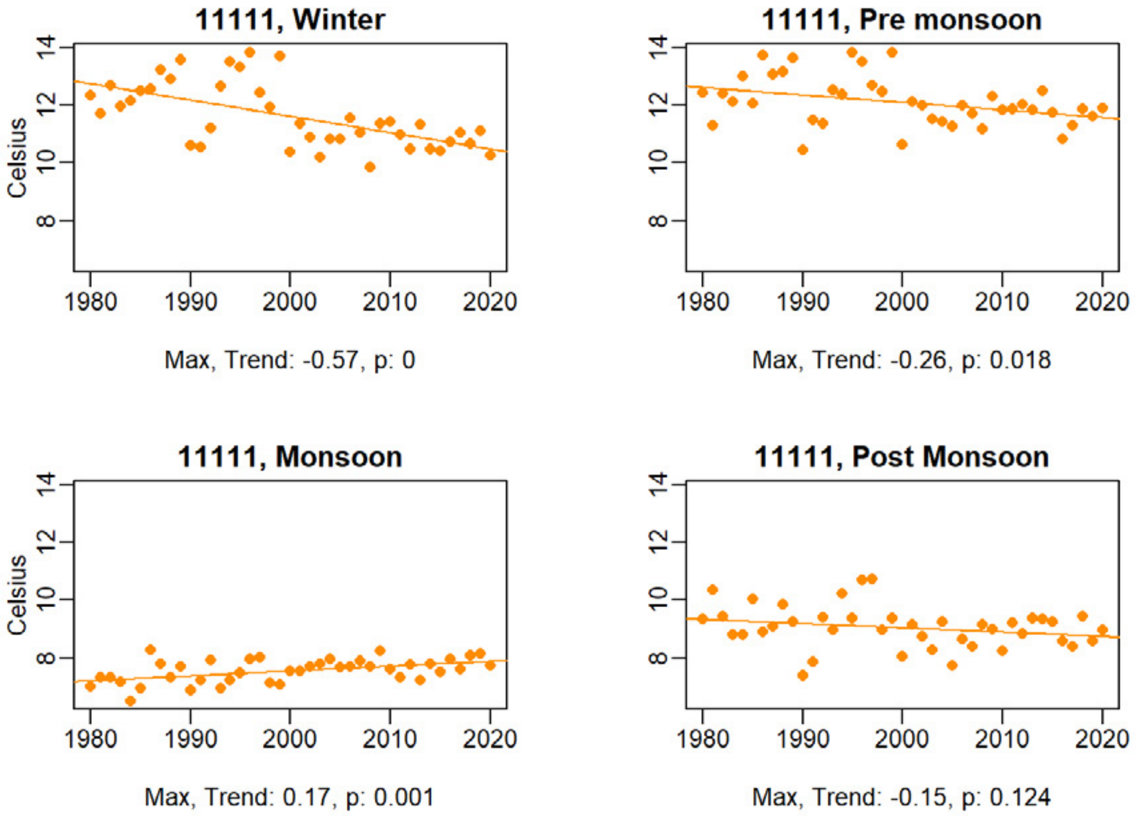


Figure 3.2: Trends in daily temperature range at Dhaka (11111).

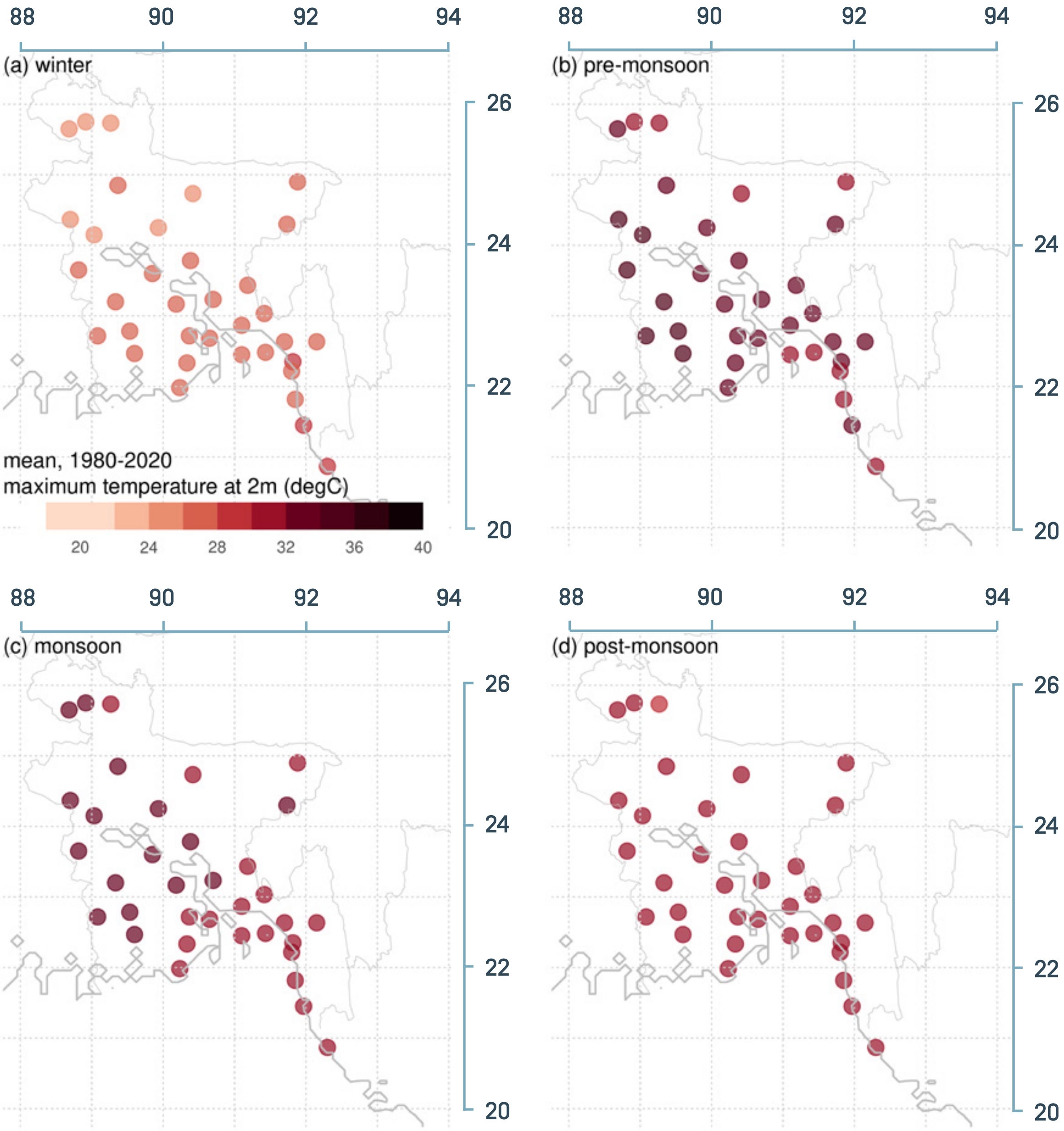


Figure 3.3: Seasonal mean values of the daily maximum temperature (°C) based on observations from stations in Bangladesh in the period 1981-2020, for the (a) winter, (b) pre-monsoon, (c) monsoon, and (d) post-monsoon seasons.

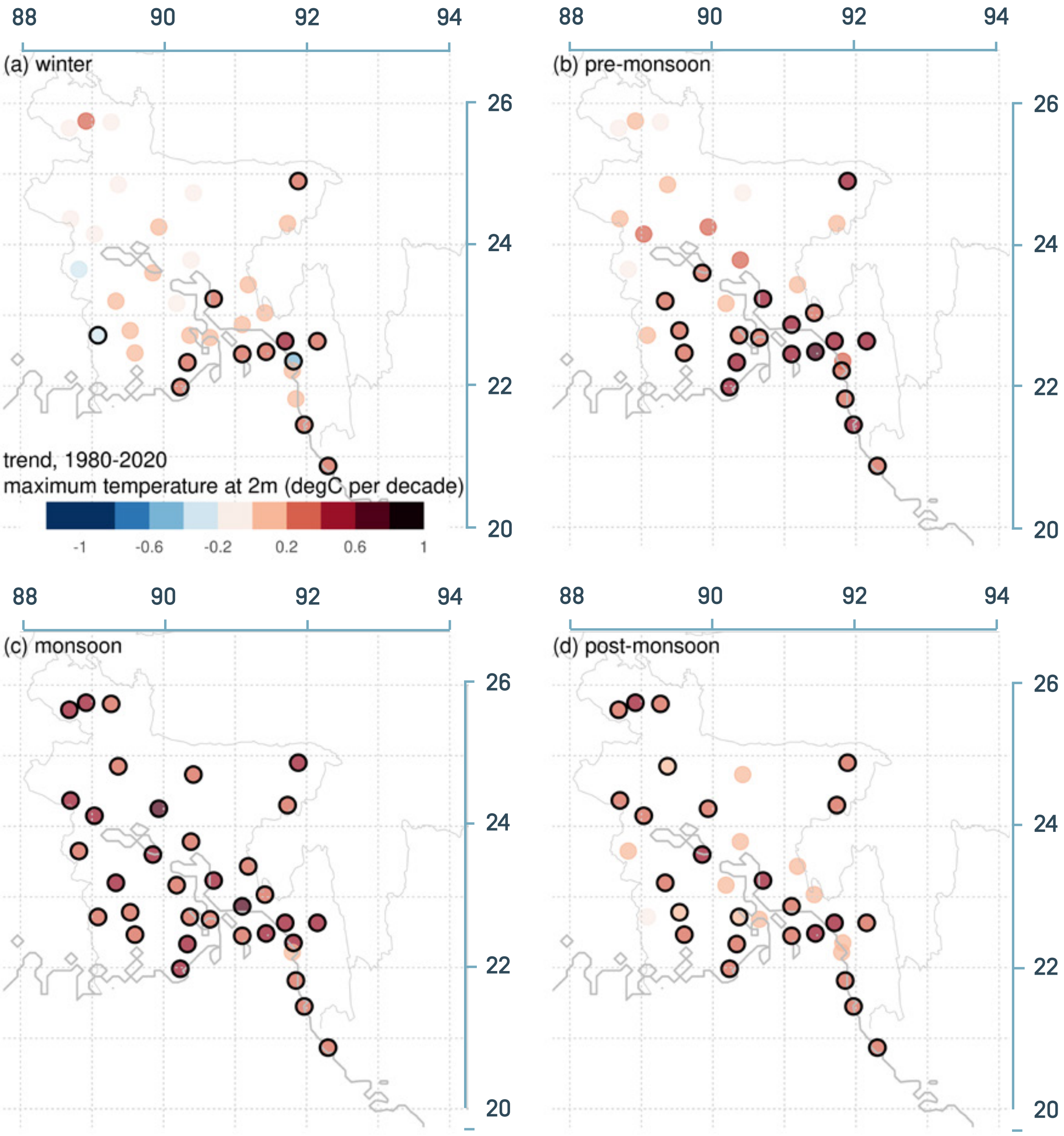


Figure 3.4: Trends in the daily maximum temperature in the period 1980-2020 (°C/decade). Stations with significant trends (p<0.05) are marked with black outlines.

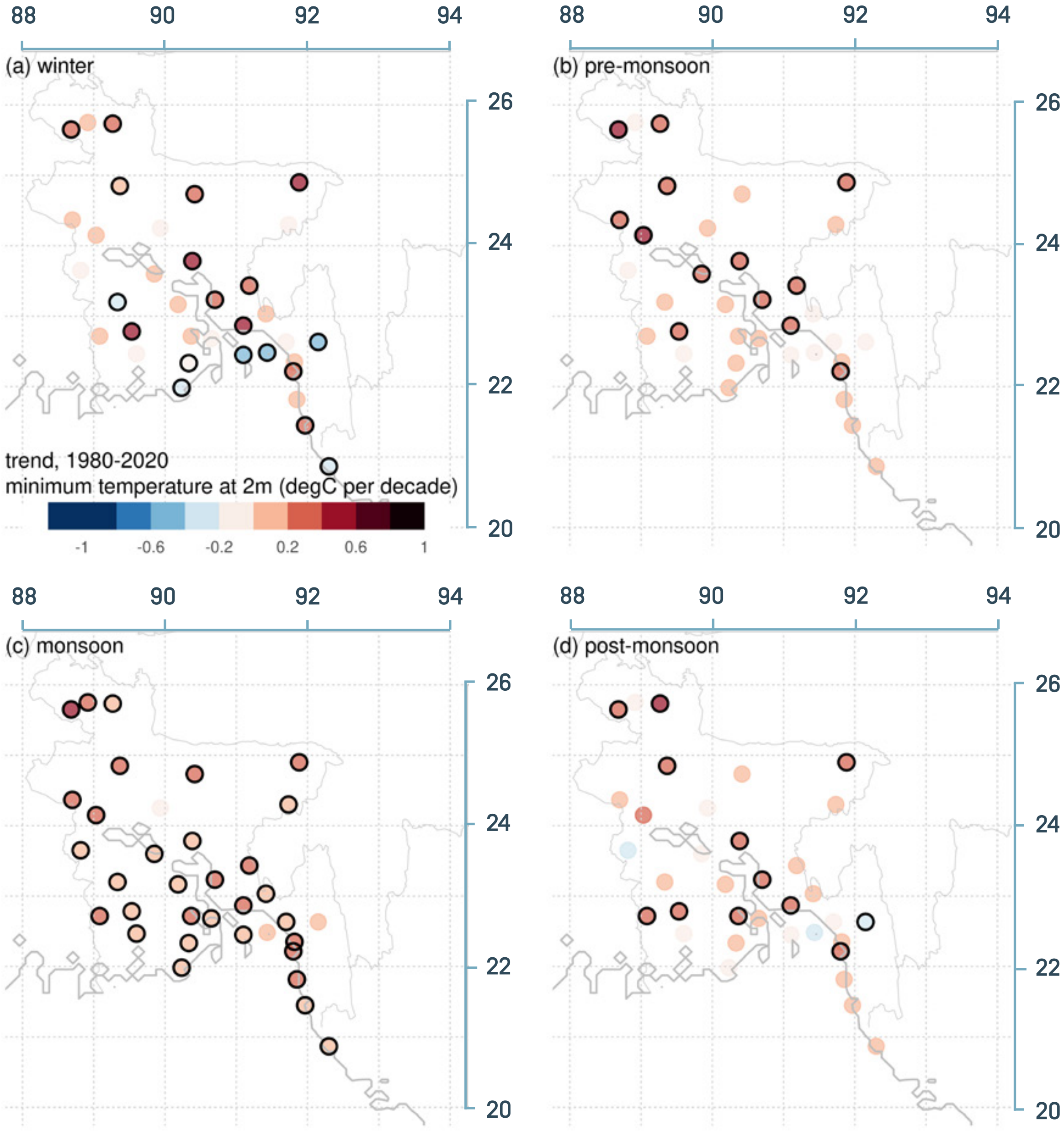


Figure 3.5:Trends in the daily minimum temperature in the period 1980-2020 (°C/decade). Stations with significant trends ($p<0.05$) are marked with black outlines.

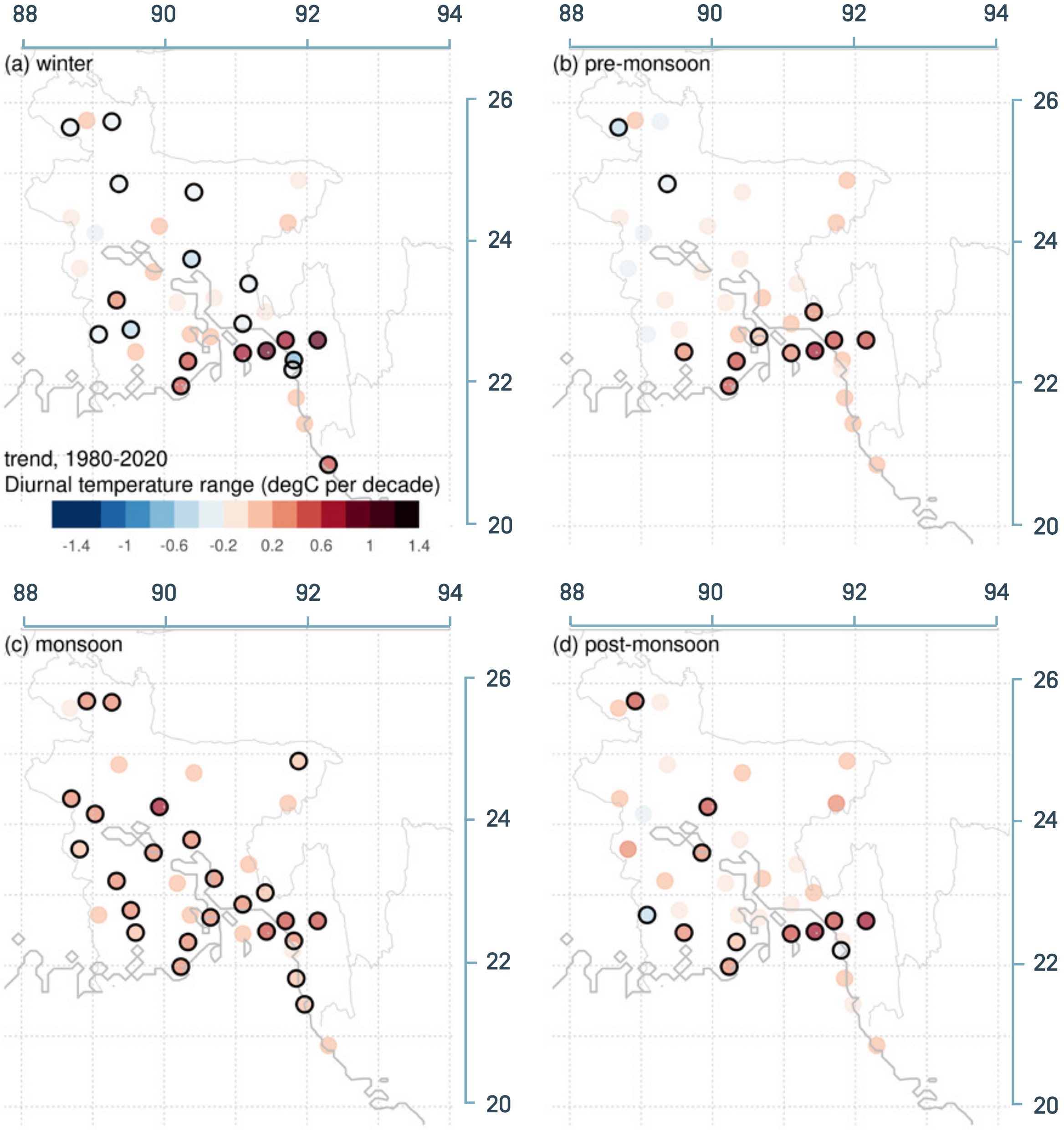


Figure 3.6:Trend in diurnal temperature range (DTR), based on temperature observations from stations in Bangladesh in the period 1980-2020 (°C/decade). Stations with significant trends ($p<0.05$) are marked with black outlines.0 (°C/decade).

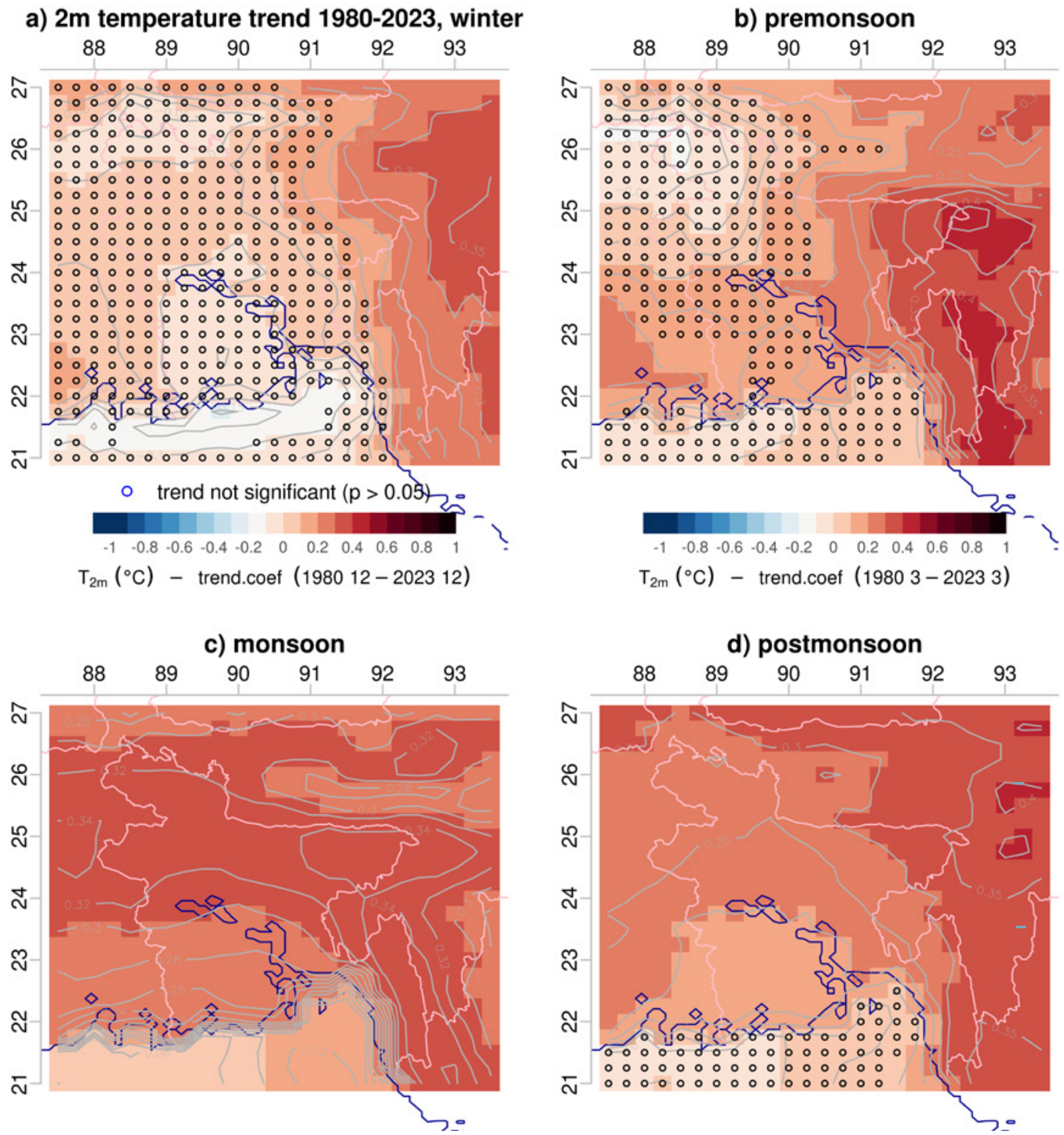


Figure 3.7: Trends of the mean temperature (°C/decade) based on ERA5 reanalysis data for the period 1980-2023. Black circles indicate that the trends are not statistically significant (p-values > 0.05).

Division	Temperature [°C/dec]	Winter	Pre-monsoon	Monsoon	Post-monsoon
Dhaka	Maximum	**-0.1**	**0.1**	**0.3**	**0.1**
	Minimum	**0.5**	**0.4**	**0.2**	**0.3**
	DTR	**-0.6**	**0.3**	**0.2**	-0.2
Rangpur	Maximum	-0.01	-0.1	**0.3**	**0.3**
	Minimum	**0.3**	**0.4**	**0.1**	**0.4**
	DTR	**-0.3**	**-0.5**	**0.2**	-0.1
Rajshahi	Maximum	-0.2	-0.03	**0.5**	**0.2**
	Minimum	-0.1	**0.3**	**0.2**	**0.1**
	DTR	**-0.3**	**-0.3**	**0.2**	0.1
Mymensingh	Maximum	-0.2	-0.1	**0.3**	0.1
	Minimum	0.2	0.2	**0.2**	0.1
	DTR	**-0.4**	**-0.3**	0.1	0.1
Sylhet	Maximum	**0.4**	**0.5**	**0.5**	**0.4**
	Minimum	0.4	0.4	0.3	0.4
	DTR	**-0.03**	**0.2**	0.2	**-0.03**
Chattogram	Maximum	**0.1**	0.3	0.2	**0.1**
	Minimum	0.3	0.4	0.3	0.3
	DTR	**-0.2**	**-0.1**	-0.1	-0.2
Barishal	Maximum	**0.1**	0.2	0.4	0.2
	Minimum	**0.1**	**0.1**	0.3	0.2
	DTR	**0.00**	**0.1**	**0.1**	**-0.03**
Khulna	Maximum	0.00	**0.2**	0.4	0.3
	Minimum	0.4	0.4	0.2	0.2
	DTR	-0.4	**-0.2**	0.2	**0.02**

Table 3.1: Trends (°C/decade) in maximum and minimum temperature at divisional stations. Significant trends ($p \leq 0.05$) are marked in bold font.

3.2 Trends in precipitation

The main season for precipitation in Bangladesh is the monsoon. For example, in the capital of Dhaka the non monsoon months generate a few hundred millimetres of precipitation, while the monsoon generates almost 1500 millimetres (Figure 3.8). Bangladesh is an agricultural country and dependent on enough water through the incoming rivers and rainfall. On the other side, Bangladesh, basically being a giant river delta, is prone to flooding. This duality of flooding and need for water is making Bangladesh particularly vulnerable to changes in precipitation patterns. Since Bangladesh receives the most precipitation in the monsoon season, this season is of most interest.

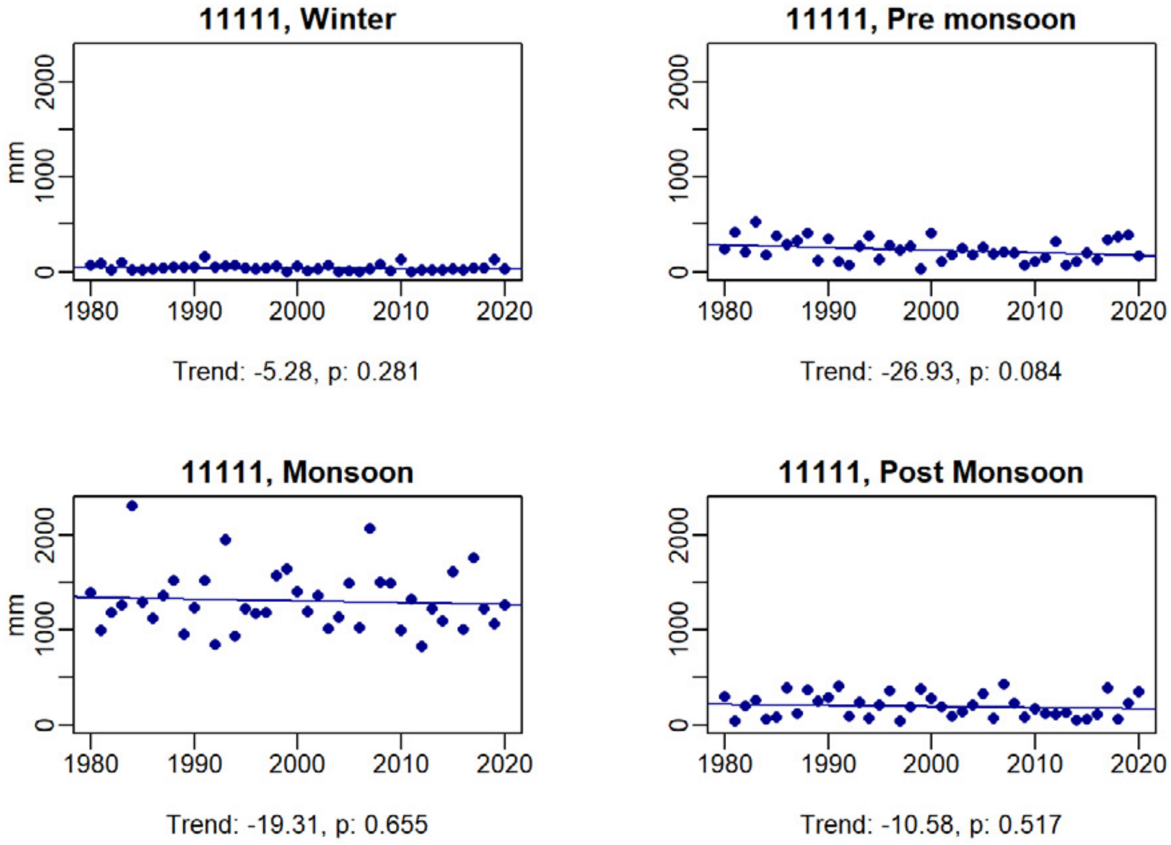


Figure 3.8: Time series of seasonal precipitation sum at Dhaka (mm/season). The estimated linear trend and p-value are included below the plots.

In Dhaka (station id 11111), the average precipitation amount in the period 1980-2020 did not change significantly in any season (Figure 3.8, corresponding time series figures for the other stations can be found in the Appendix). However, there is moderate evidence ($p < 0.05$) of a decrease of around -2.7 days per decade in the number of rainy days (> 1 mm precipitation) in the monsoon season (Figure 3.9).

Looking at the observational records of precipitation from the whole country, there were no widespread changes in the total precipitation amount in any season (Figure 3.10). The frequency of rainfall events (the fraction days with > 1 mm of precipitation) showed a weak increase in many stations in the eastern region Chattogram during the monsoon season and a reduction only in two stations (Dhaka and Rajshahi) (see Figure 3.11). The precipitation intensity (defined as the mean precipitation on days with > 1 mm of rainfall) showed little change in the period 1980-2020, except for a small reduction (around -1 to -3 mm/decade) in the pre-monsoon season in the central and southern parts of Bangladesh (Figure 3.12).

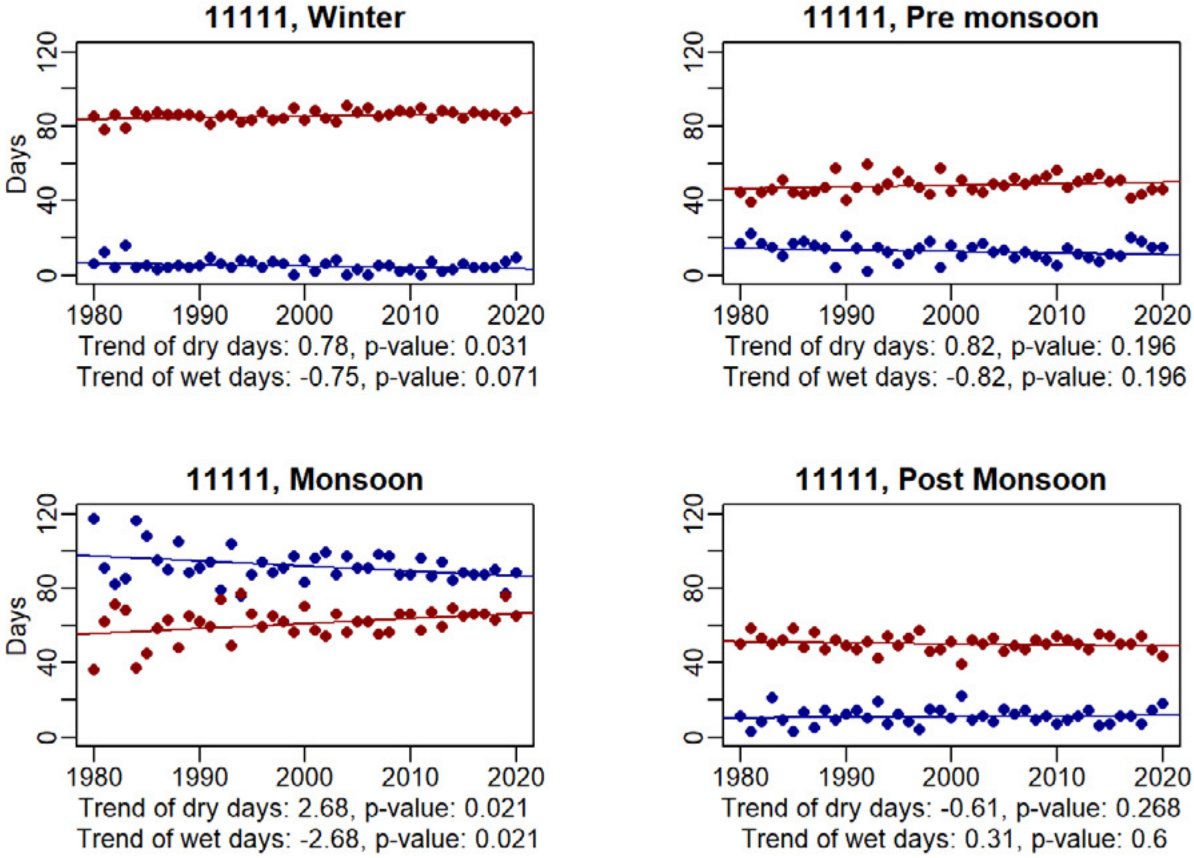


Figure 3.9: Trends in number of dry days and wet days at Dhaka (11111).

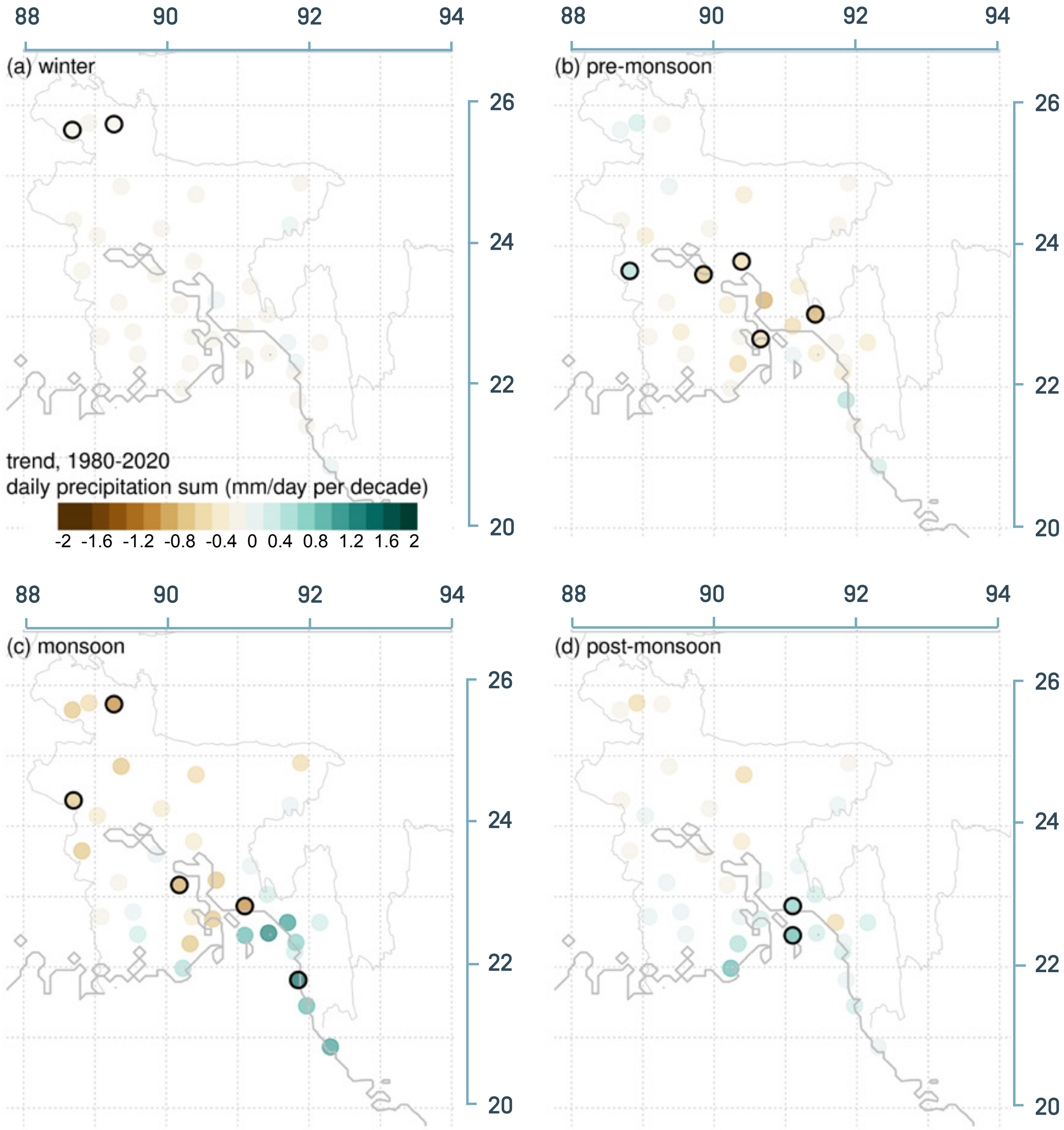


Figure 3.10. Trend in seasonal mean daily precipitation sum (mm/day per decade), based on precipitation observations from stations in Bangladesh in the period 1980-2020. Stations with significant trends ($p<0.05$) are marked with black outlines.

The precipitation intensity (defined as the mean precipitation on days with > 1 mm of rainfall) shows little change in the period 1980-2020, except for a small reduction (around -1 to -3 mm/decade) in the pre-monsoon season in the central and southern parts of Bangladesh (Figure 3.13).

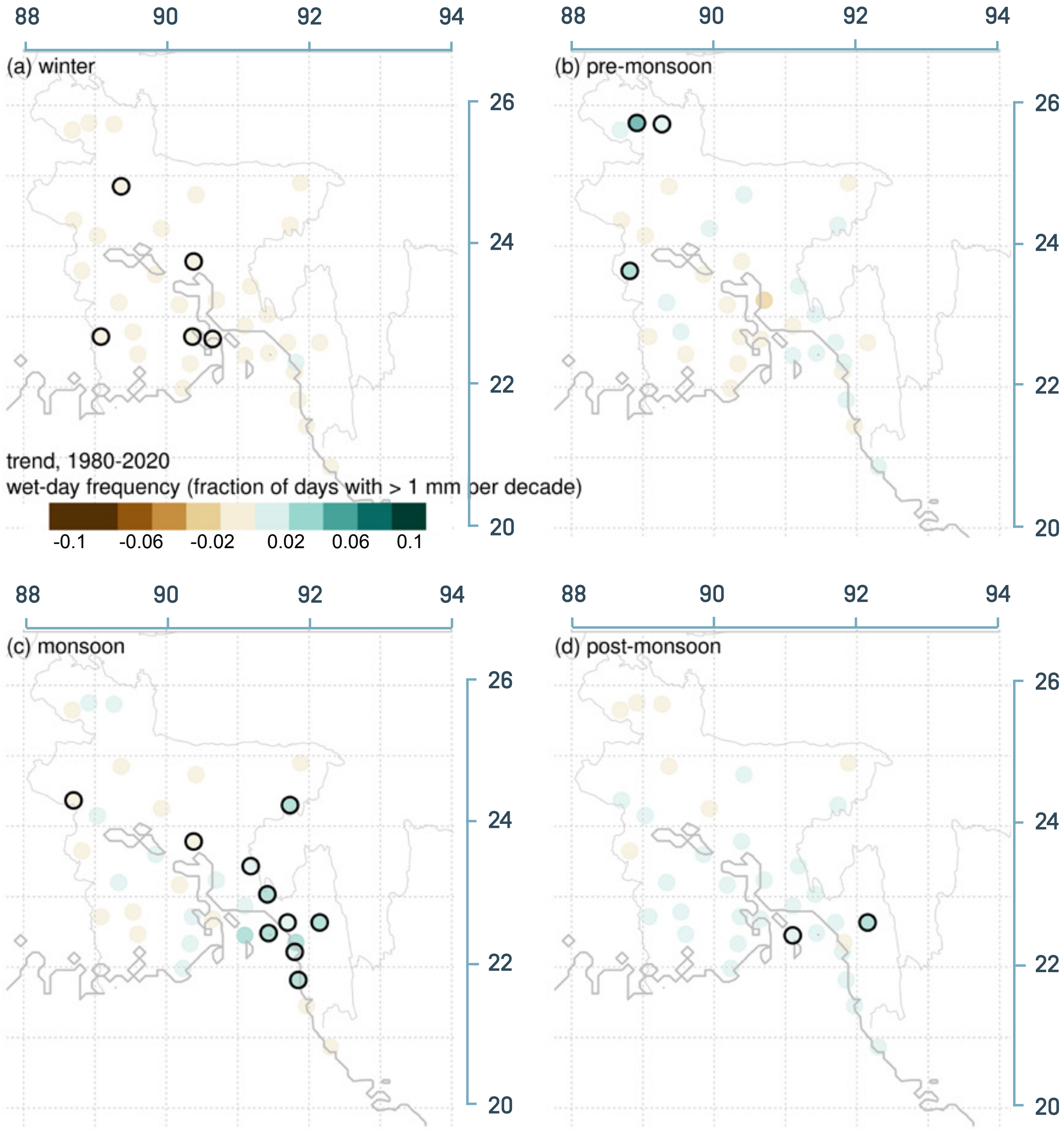
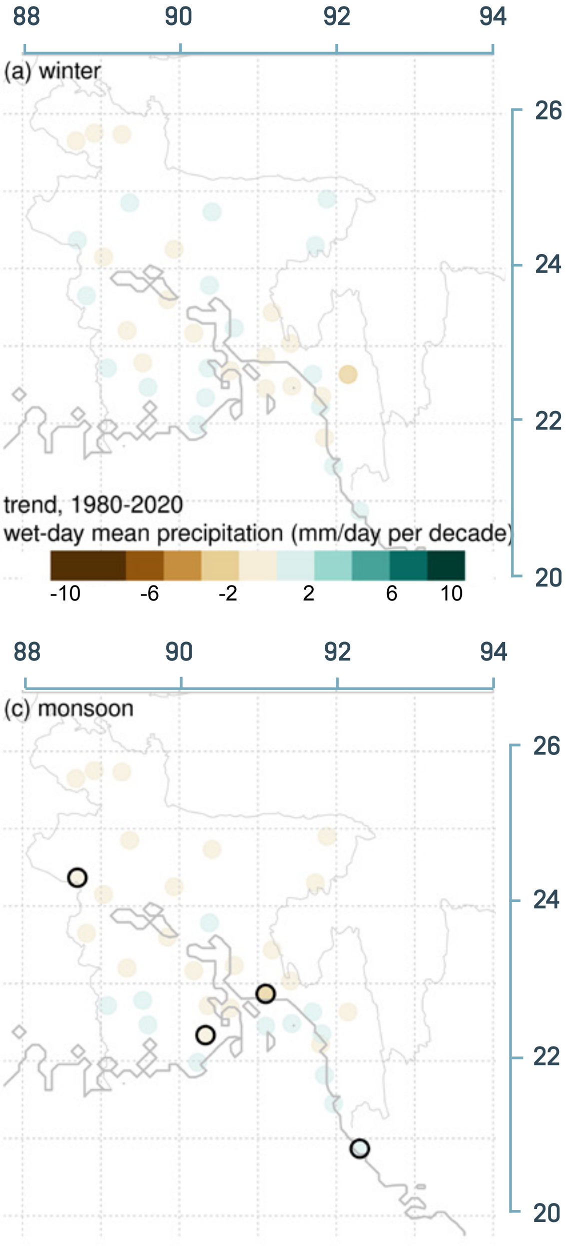


Figure 3.11: Trends in the seasonal precipitation frequency (fraction of days in a season that have > 1 mm of precipitation) based on observations from stations in Bangladesh in the period 1980-2020. Stations with significant trends ($p<0.05$) are marked with black outlines.

Trend analyses of the ERA5 reanalysis total precipitation for the period 1980-2023 supported the conclusion that there were no strong or widespread changes in the rainfall in Bangladesh in any season (Figure 3.13). In the pre-monsoon season, the ERA5 precipitation trend analysis indicated a significant decrease in eastern Bangladesh, but the surface based observations did not display the same pattern of change (Figure 3.10).



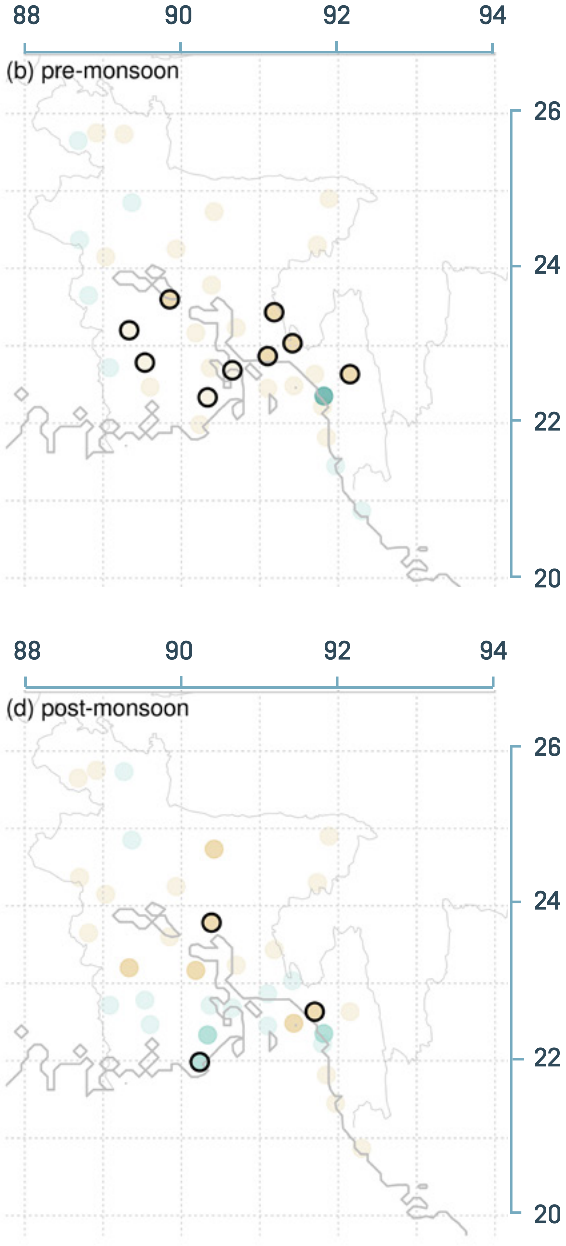


Figure 3.12: Trends in the mean precipitation intensity (the average precipitation sum on days with > 1mm) based on observations from stations in Bangladesh in the period 1980-2020. Stations with significant trends (p<0.05) are marked with black outlines.

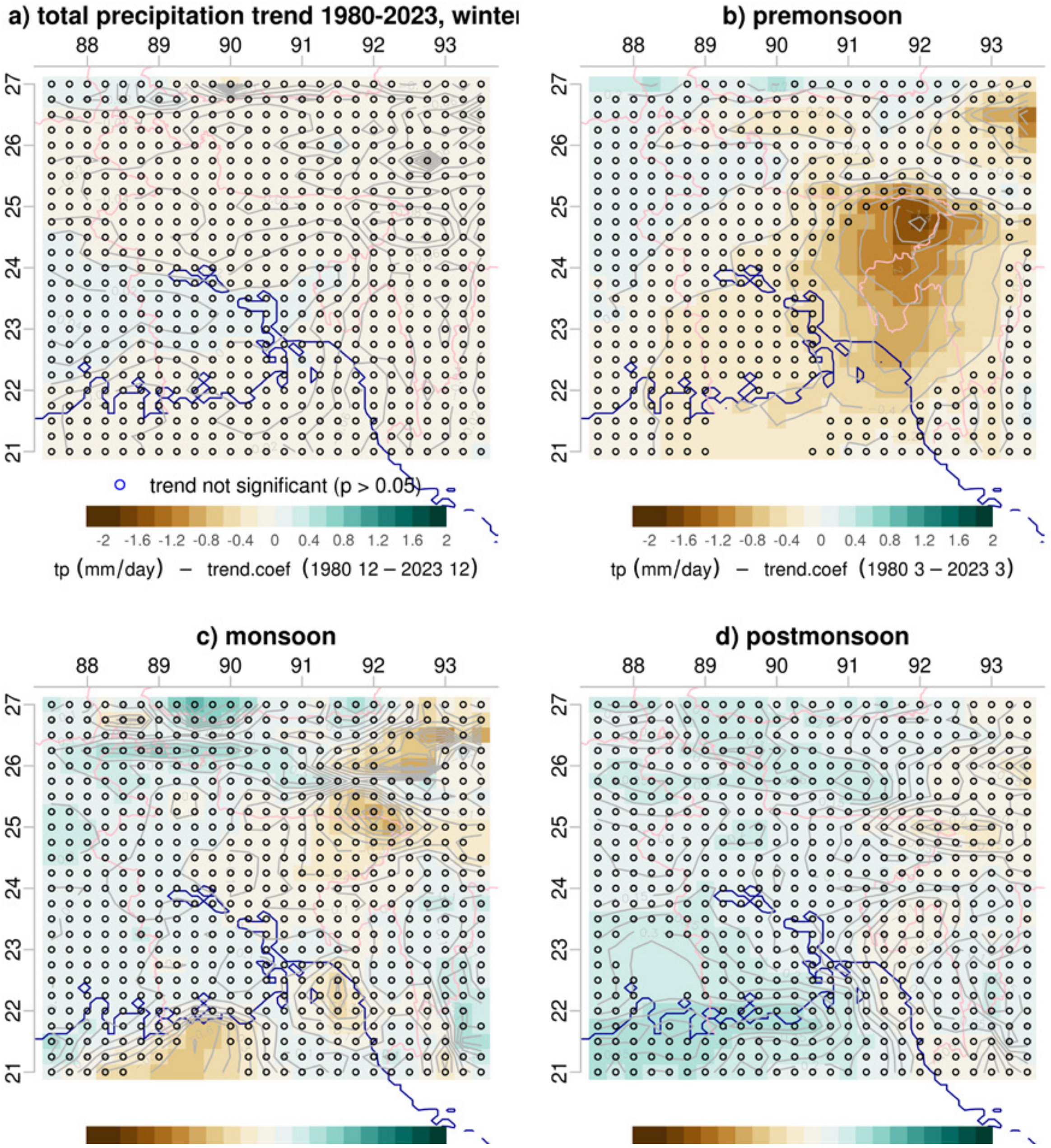


Figure 3.13. Trends of the mean total precipitation (mm/day per decade) based on ERA5 reanalysis data for the period 1980-2023. Black circles indicate that the trends are not statistically significant (p-values > 0.05).

Division	Precipitation	Winter	Pre-monsoon	Monsoon	Post-monsoon
Dhaka	Amount	-5.3	-26.9	-19.3	-10.6
	Wet days	-0.8	-0.8	**-2.7**	0.3
	Dry days	**0.8**	0.8	**2.7**	-0.6
Rangpur	Amount	**-6.5**	12.8	-105.1	-1.4
	Wet days	-0.3	1.1	-0.9	-0.6
	Dry days	0.3	**-1.4**	0.9	0.6
Rajshahi	Amount	-7.9	2.9	-53.9	-6.01
	Wet days	-0.4	-0.9	**-2.7**	0.1
	Dry days	0.6	0.1	**2.5**	-0.1
Mymensingh	Amount	-5.9	0.3	-58.3	-27.6
	Wet days	-0.3	0.3	-1.9	0.1
	Dry days	0.5	-0.3	1.9	-0.1
Sylhet	Amount	-2.3	-7.1	-8.6	-1.8
	Wet days	-0.6	-1.1	0.1	-0.1
	Dry days	**0.8**	1.1	-0.1	0.1
Chattogram	Amount	-6.1	**-40.0**	30.1	15.4
	Wet days	-0.3	-1.1	**2.1**	0.2
	Dry days	0.5	1.1	**-2.1**	-0.4
Barishal	Amount	-5.2	-21.0	-35.2	8.0
	Wet days	**-0.9**	-0.9	-0.03	0.4
	Dry days	**0.9**	0.9	0.03	-0.4
Khulna	Amount	-7.8	**-31.4**	22.5	7.01
	Wet days	-0.4	-0.01	-1.2	0.2
	Dry days	0.6	0.01	1.2	-0.2

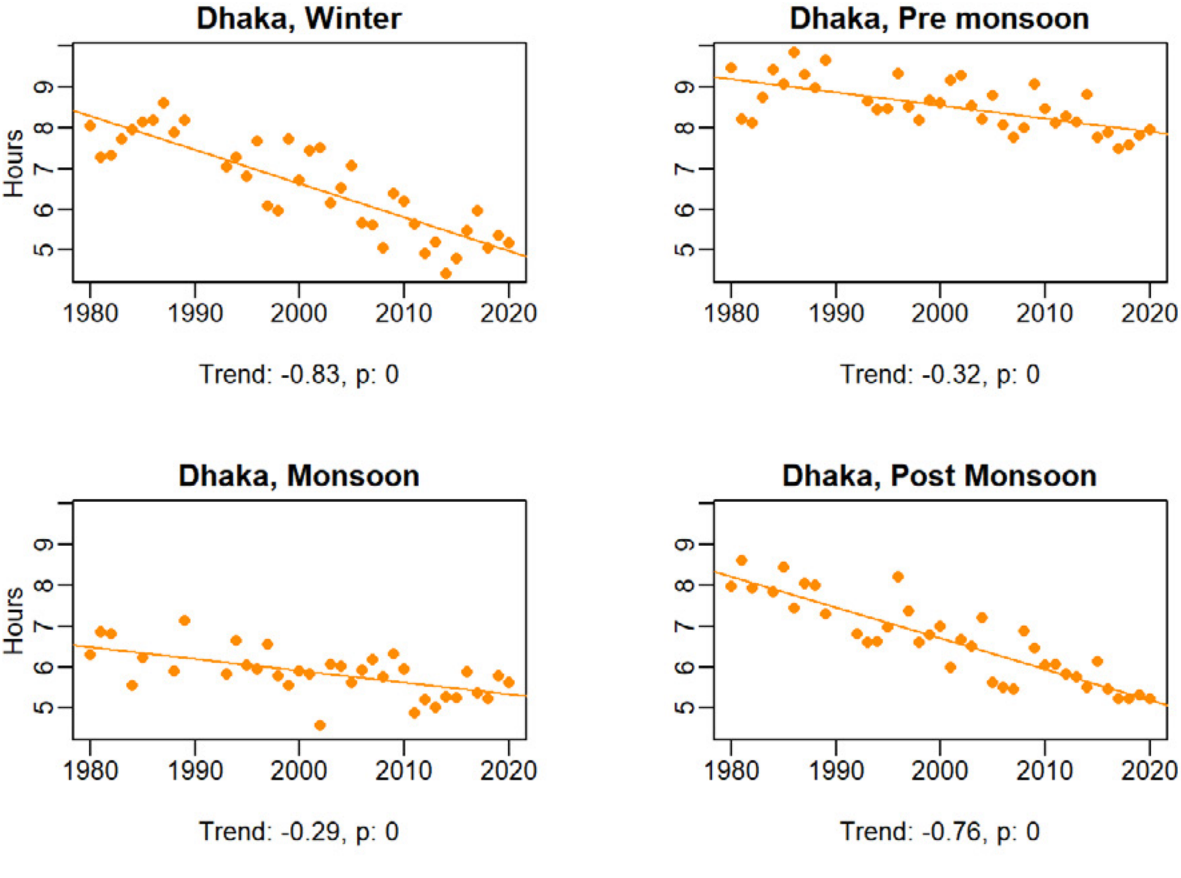
Table 3.2: Trends in precipitation amount (mm/decade), wet and dry days (number of days/decade) at divisional stations. Significant trends ($p \leqslant 0.05$) are marked with bold font.

3.3 Trends in sunshine and cloudiness

The detected changes in temperature are caused by a combination of changes in the global climate and local drivers like sunshine hours and cloudiness. In the following chapter, the trends in these two elements will be explored.

3.3.1 Sunshine hours

Sunshine hours were collected at all observation sites with a Campbell–Stokes recorder, and manually calculated based on the paper measurements. Sunshine hours decreased significantly ($p < 0.05$) in Dhaka during all seasons (Figure 3.14), but the trends were stronger in winter (-0.83 hours/ydecade) and pre-monsoon (-0.76 hours/decade) than in monsoon (-0.32 hours/decade) and post-monsoon (-0.29 hours/decade). Corrsepsonding figures for all 34 stations are included in the Appendix.



Dhaka, Winter

Trend: -0.83, p: 0

Dhaka, Pre monsoon

Trend: -0.32, p: 0

Dhaka, Monsoon

Trend: -0.29, p: 0

Dhaka, Post Monsoon

Trend: -0.76, p: 0

Figure 3.14: Trends in sunshine hours (hours/decade) at Dhaka.

Sunshine hour measuring

Photo: Hans Olav Hygen/MET Norway

Sunshine hours have decreased significantly at almost all stations in the winter season and increased significantly only at Chattogram station (Figure 3.15). The pre- and post monsoon seasons show similar patterns of change, with decreased sunshine hours in major parts of the country, but weakly positive trends at a few coastal stations. In the monsoon season, there were fewer stations with statistically significant changes, and only three stations showed a significant decrease (Bagura, Dhaka and Jashore).

Division	Winter	Pre-monsoon	Monsoon	Post-monsoon
Dhaka	**-0.8**	**-0.3**	**-0.3**	**-0.8**
Rangpur	**-0.9**	**-0.6**	**-0.2**	**-0.4**
Rajshahi	**-0.8**	**-0.4**	-0.2	**-0.3**
Mymensingh	**-0.8**	**-0.3**	-0.1	**-0.2**
Sylhet	**-0.5**	**-0.3**	-0.12	**-0.3**
Chattogram	**-0.5**	**-0.3**	0.1	**-0.4**
Barishal	**-0.5**	**-0.3**	-0.04	**-0.3**
Khulna	**-0.1**	**-0.2**	0.01	**-0.3**

Table 3.3: Trends in sunshine hours (hours/decade) at divisional stations. Series with significant trends (p-values of less than or equal 0.05) marked in bold font.

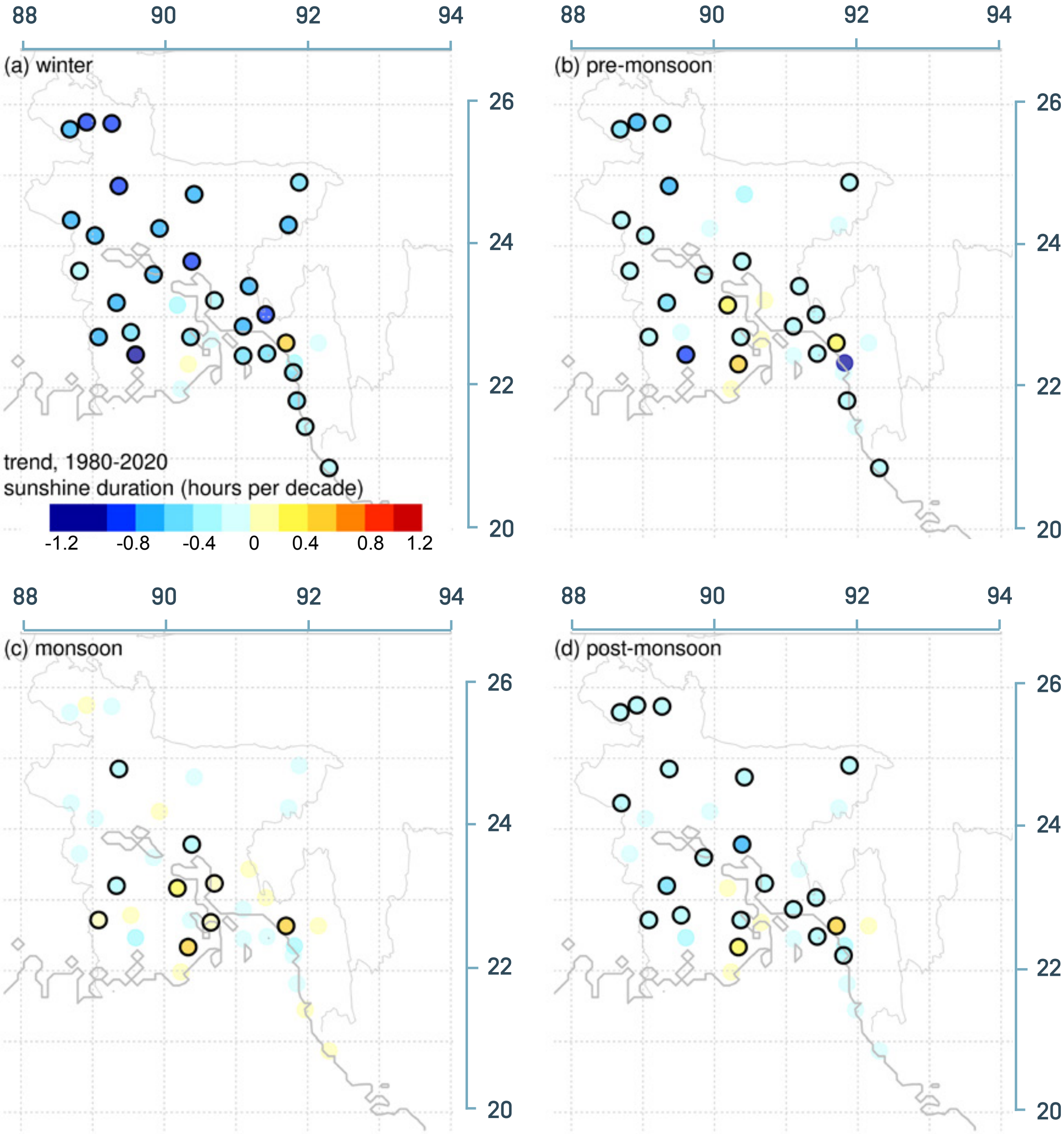


Figure 3.15: Trends of sunshine hours in the period 1980-2020 (hours per decade). Stations with significant trends ($p<0.05$) are marked with black outlines.

3.3.2 Cloud cover

The cloud cover was manually observed up to 8 times a day at the set times of 0 UTC, 3 UTC, 6 UTC, 9 UTC, 12 UTC, 15 UTC, 18 UTC, and 21 UTC, and classified in okta according to training and experience of observers. The cloud cover scale goes from 1 okta (one eighth of the sky covered in clouds) to 8 oktas (overcast). The fact that the observations were manual gives an extra dimension of uncertainty due to the inherently subjective nature of the cloud cover classification and variations in the observers at different times and locations. Even though the accuracy of the cloud cover data is probably lower than that of other data types, a trend analysis of the observations near noon (6 UTC) in Figure 3.17 and the average daily cloudiness is provided in Figure 3.18. The overall picture shows little change in cloudiness, and probably less than the uncertainties of the data, even though the trends in the observation at some stations might seem significant based on e.g. p-value.

No significant trends were detected in cloud cover at Dhaka (Figure 3.16). In the winter and pre-monsoon seasons, there was weak decreasing tendency and a slight increase during the monsoon and post-monsoon seasons, but again these were not statistically significant trends (p > 0.05).

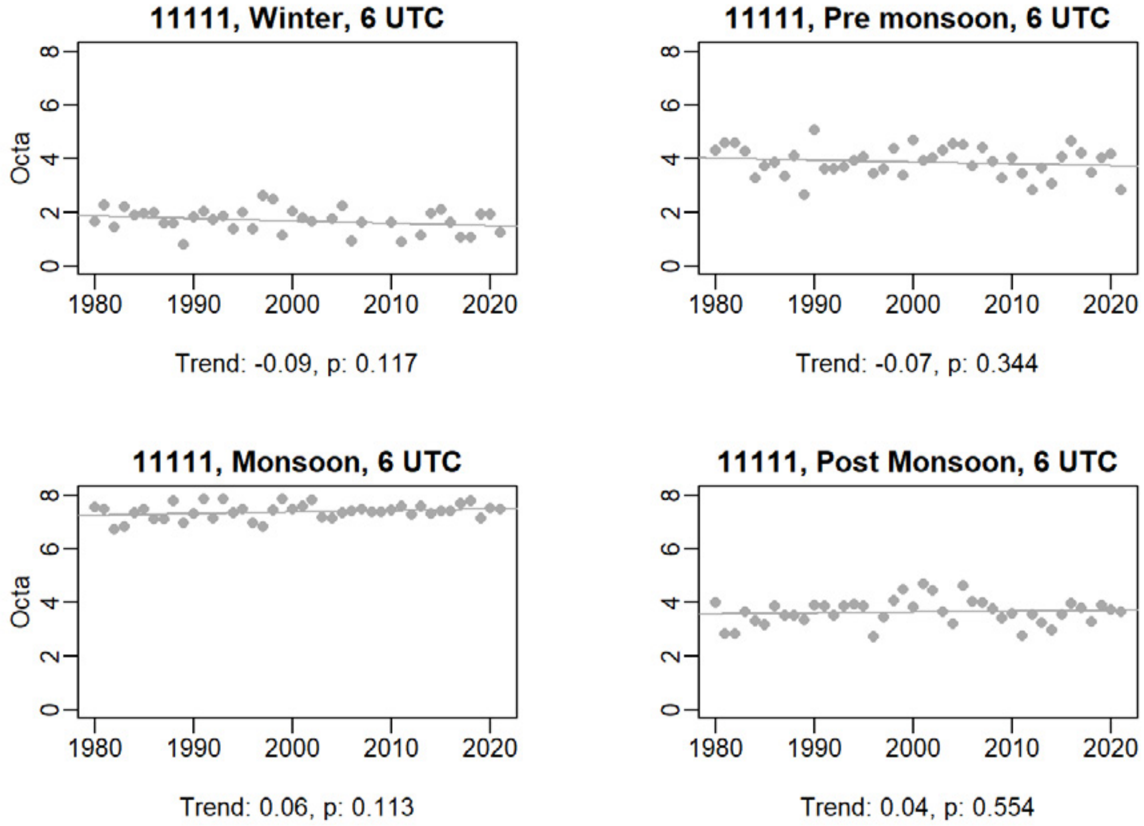


Figure 3.16: Trends in amount of cloud cover (oktas/decade) at Dhaka (11111)

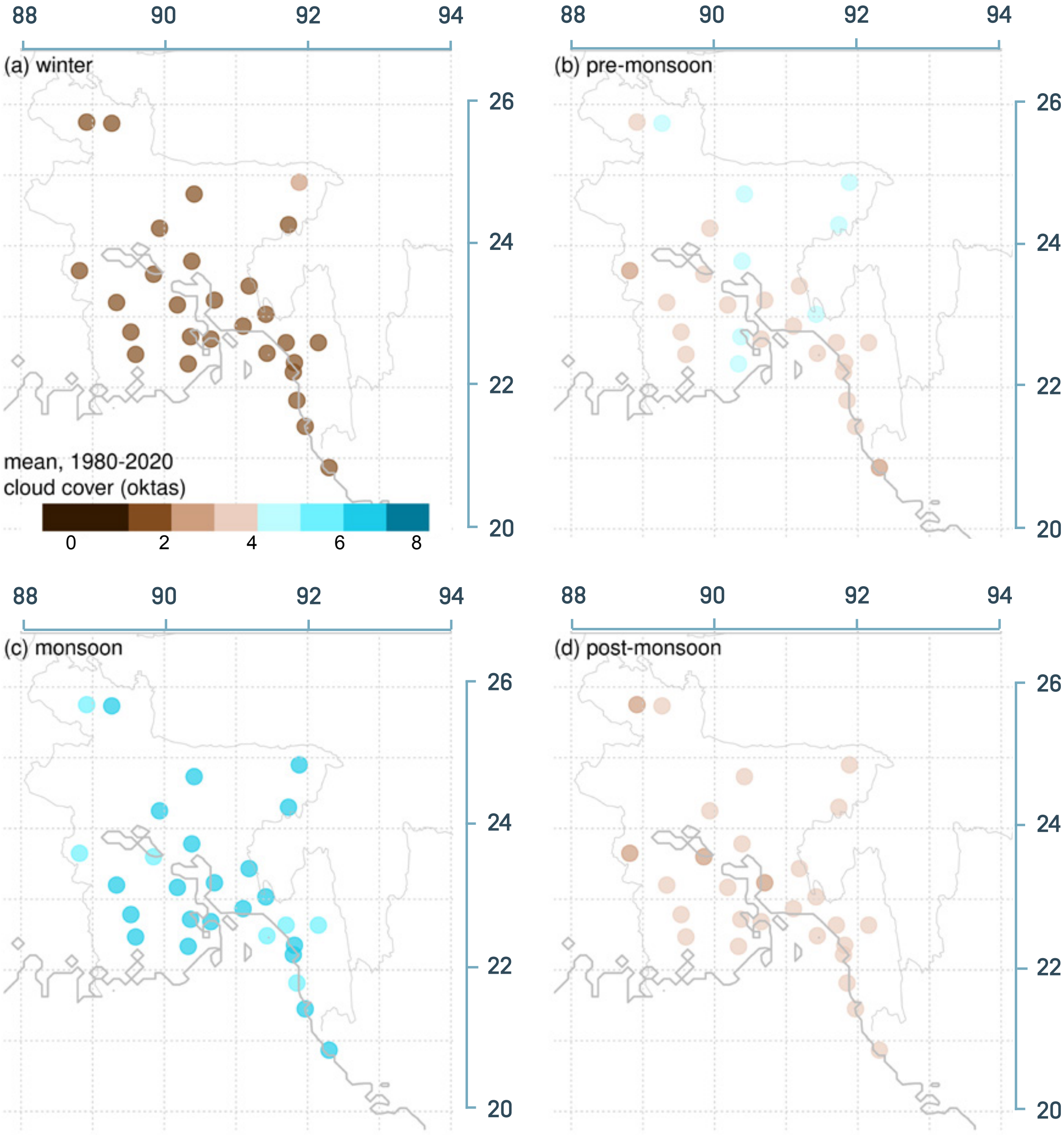


Figure 3.17: Seasonal mean values of the cloud cover at 6 UTC (noon local time) based on observations from stations in Bangladesh in the period 1980-2020.

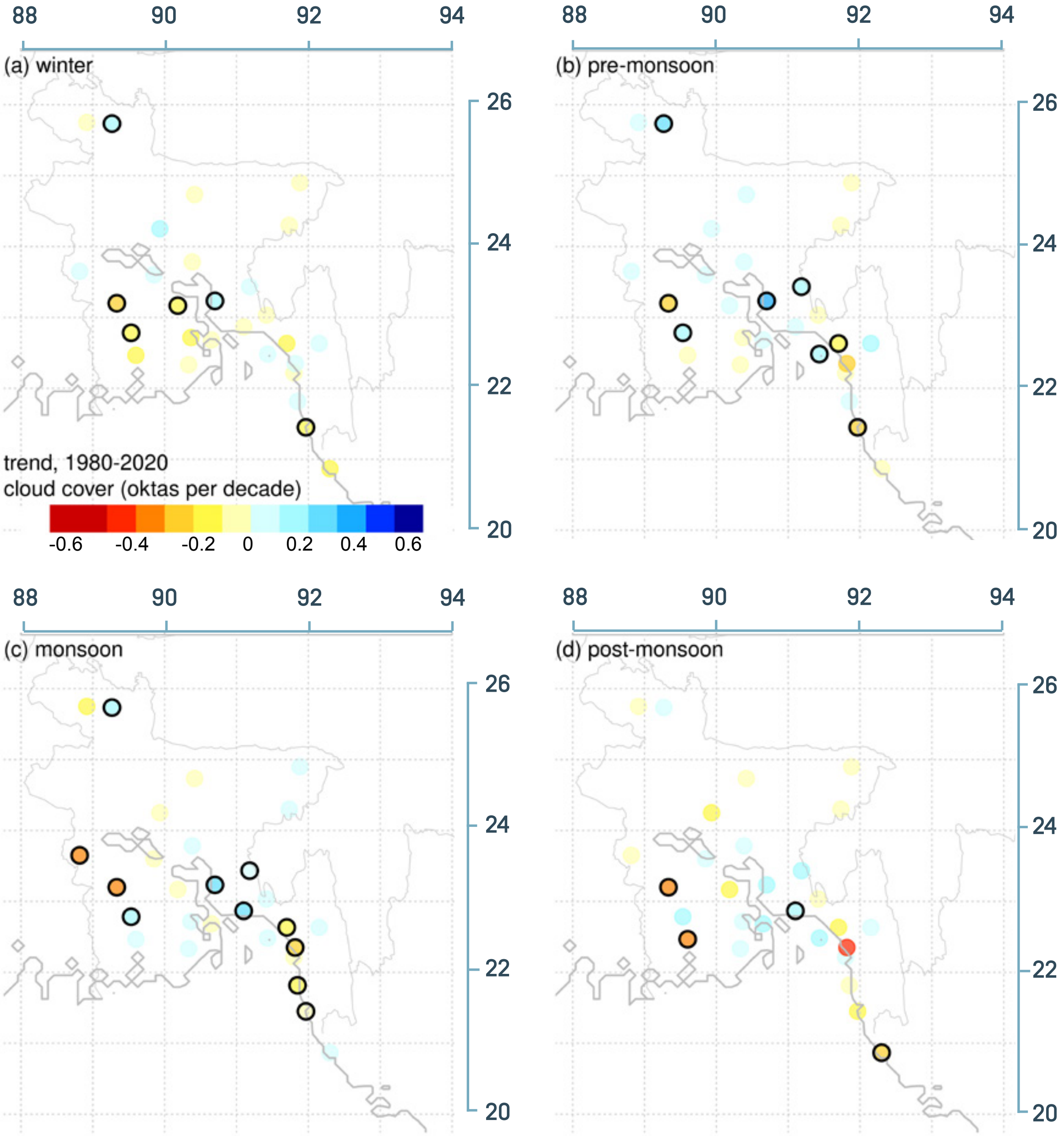


Figure 3.18: Trends of the cloud cover in the period 1980-2020 (oktas per decade). Stations with significant trends ($p<0.05$) are marked with black outlines.

Photo: Riashat Rafat/Unsplash

Division	Winter	Pre-monsoon	Monsoon	Post-monsoon
Dhaka	-0.1	-0.1	0.1	0.04
Rangpur	**0.2**	0.1	**0.2**	0.1
Rajshahi	**0.1**	0.01	0.00	0.01
Mymensingh	0.00	-0.03	0.00	-0.1
Sylhet	-0.1	**-0.2**	0.1	-0.1
Chattogram	-0.1	-0.2	0.01	0.04
Barishal	-0.1	**-0.2**	0.03	-0.02
Khulna	**-0.1**	-0.02	**0.1**	0.1

Table 3.4: Trends in cloud cover (oktas/decade) at divisional stations. Series with significant trends ($p \leqslant 0.05$)) are marked in bold font.

④

Impacts of changes in Bangladesh's climate

Photo: Rashed Kabir/Unsplash

Hans Olav Hygen/MET Norway

Impacts of changes in Bangladesh’s climate

The changes in climate conditions shown above manifest not only as changes in average conditions, but even more strongly as changes in extremes. This chapter is dedicated to study some of these impacts, specifically on heatwaves and cold outbreaks (4.1), and extreme precipitation (4.2). In chapter 4.3 an analysis of the Monsoon is presented. The overall result is a sharp increase in the heatwaves, especially in the monsoon season, and a decrease in cold outbreaks.

4.1 Heatwaves and cold outbreaks

Heatwaves and cold outbreaks are periods of unusually hot and cold weather, respectively, with the specific thresholds varying depending on the regional climate. In Bangladesh, heatwaves are defined as days with a maximum temperature equal to or above 36°C (Khatun et al., 2016), and cold outbreaks as days with a minimum temperature equal to or less than 10°C The temperature observations from Bangladesh showed a clear climate signal, with fewer cold outbreaks and more heatwaves in recent decades, and an especially alarming upswing in the heatwave frequency in the monsoon period.

Dhaka

Figure 4.1 shows blue dots for days with cold outbreaks and red dots for days with heatwaves for the observation site in Dhaka for the years 1980 - 2023. The graph indicates changing seasonal patterns: a reduction in the number of cold outbreaks and shortening of the cold outbreak period, and an extension of the period of heatwaves from primarily occurring in the pre-monsoon season (in the 1980s and 1990s) to lasting well into the monsoon season (in the last decade).

In Dhaka, cold outbreaks occurred most frequently in January, and the number of events appear to have decreased after 1997. There were some cases of cold outbreaks in December and February as well, but only one after 1997 (in February 2012). This analysis suggests a reduction in cold outbreak days in the capital city.

In the 1980s an 90s the first heatwave days of the pre-monsoon season were prevalent in the second or third week of March. However, a notable shift occurred after 1997, moving the first heatwave days to the third or last week of March. In April and May, heatwave days were pervasive almost the whole time period. In the monsoon season (June - September), the number of heatwave observations in Dhaka increased in the last decade, since the early 2010's.

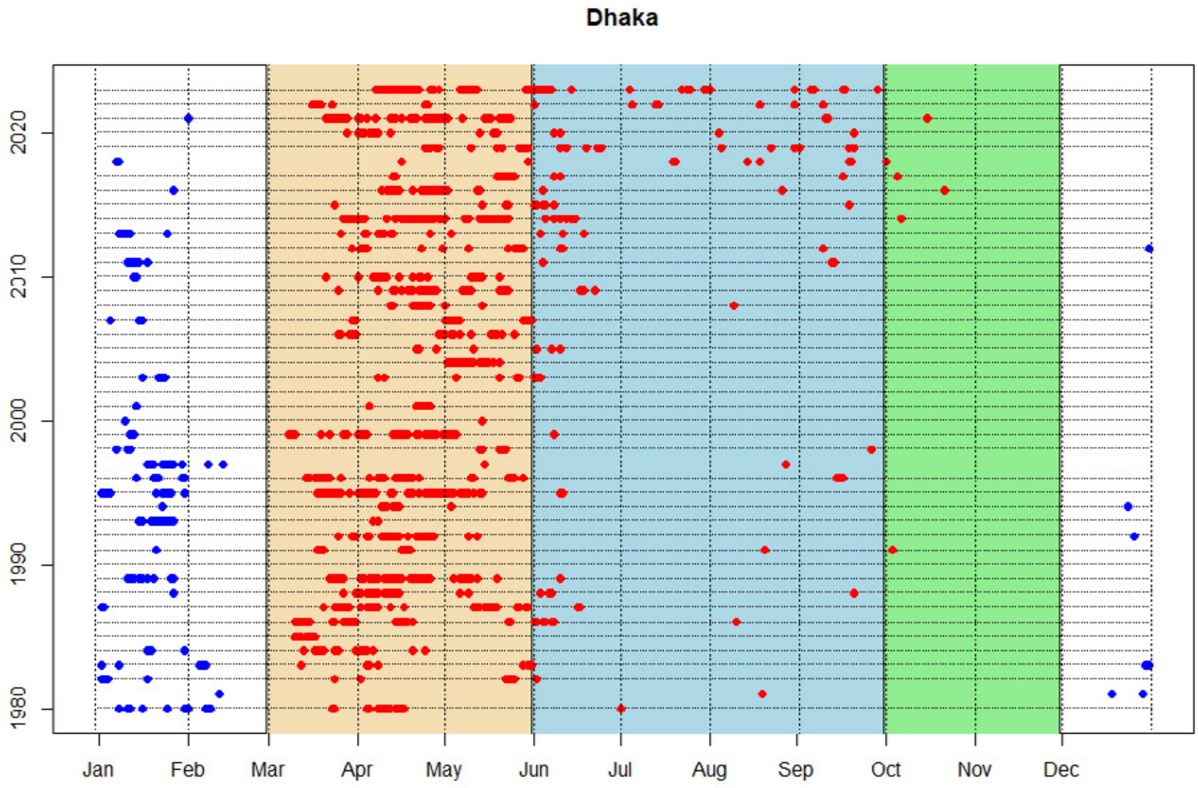


Figure 4.1: Number of cold (blue) and heatwave (red) days in Dhaka.

Rajshahi

Rajshahi is located in the northwest of Bangladesh and both heatwaves and cold spells occur frequently here. Figure 4.2 shows a large number of heatwave days from April to May throughout the observational records, but the start of the heatwave period appears to have been delayed in the last two decades, from early to late March.. The number of heatwaves also increased considerably in the monsoon season, from June to October, which is a a very alarming issue. From July to October, very few heatwave days were recorded in the 1980s and 90s, but after around 2005, the number of heatwave days increased dramatically, and in the last few years heatwaves were almost as frequent in the monsoon season as in the pre-monsoon season.

Up to 2006, the period of cold outbreaks started in the first week of December, but then decreased, indicating a delay in cold outbreak conditions. In the year 2023, there were no heatwave conditions recorded in Rajshahi in December at all. The number of cold outbreak days in December and February have decreased, but a large number of cold outbreak days were observed in January throughout the period 1980-2023.

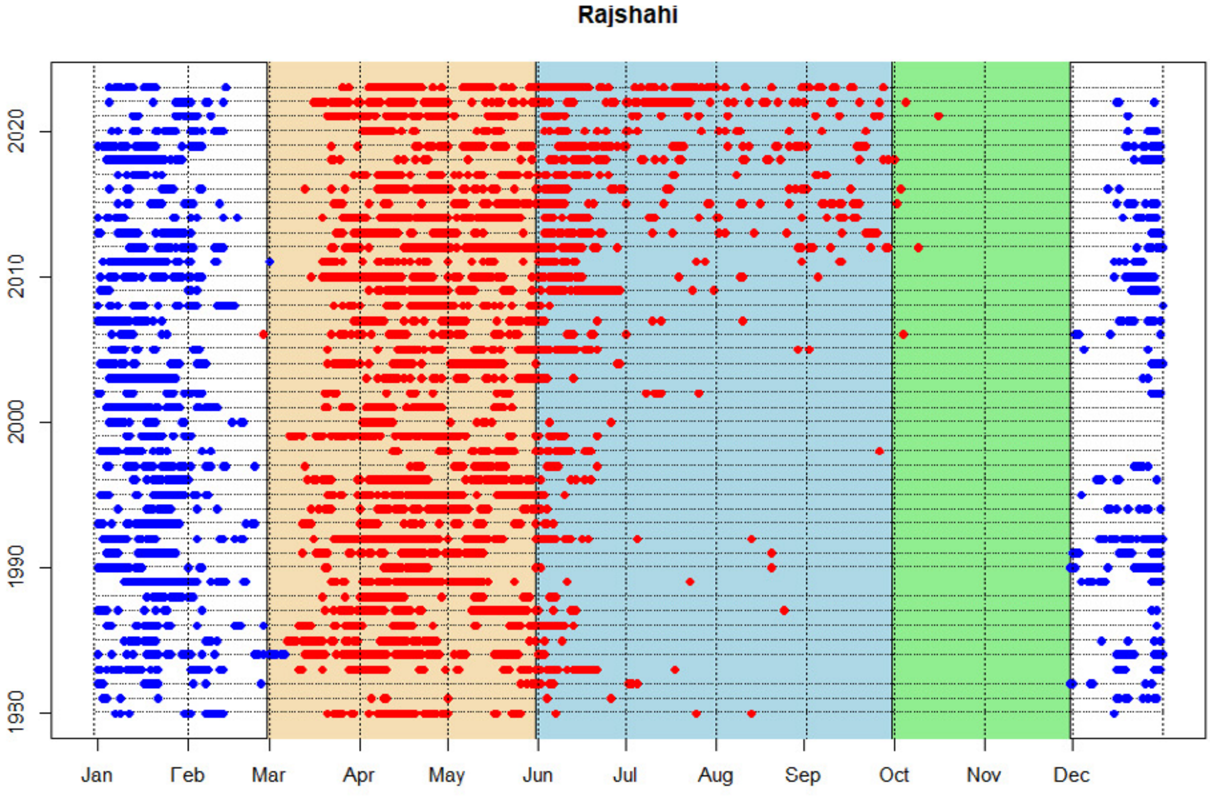


Figure 4.2: Number of cold (blue) and heatwave (red) days in Rajshahi.

Rangpur

Rangpur is also located in the northwestern part of Bangladesh and is one of the coldest parts of the country. Throughout the observational records, cold outbreaks here started in early or mid December (Figure 4.3). In 1981, there was even a cold outbreak observation in November. However, in the last few years, the period of cold outbreaks appears to have been delayed, not starting until the third or fourth week of December or even in January. In January, a large number of cold outbreak days were observed in Rangpur throughout the observational records 1980-2023. Historically, February also had frequent cold outbreaks, but in recent years the end of February has been without cold outbreaks.

The heatwave period in Rangpur appears to have gradually been delayed and prolonged. In the 1980s and 90s, the heatwave period started in late March or early April and most heatwave days occurred in April, May and the beginning of June. Since 2000, the period of heatwaves has started later and continued throughout the monsoon season, June - September, even lasting into October in some years.

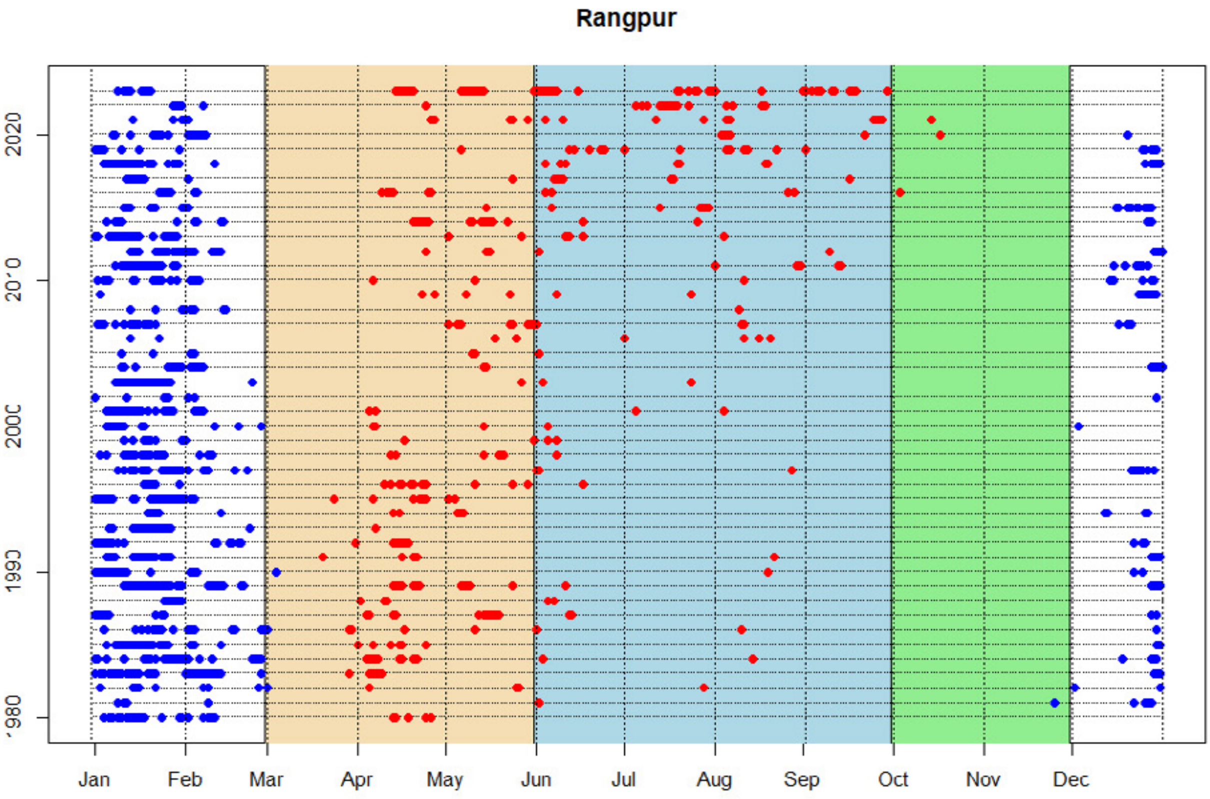


Figure 4.3: Number of cold (blue) and heatwave (red) days in Rangpur.

Khulna

At Khulna, there appears to have been a decrease in the number of cold outbreak days (Figure 4.4). Here, the main period of cold outbreaks was December and January. There have been no recorded cold outbreak days in the month of February since 1998. In the month of December, there was no obvious trend in the number of cold outbreak days, but considerable year-to-year variations and a period without any cold outbreaks during 1997-2009. In January, a good number of cold outbreak days were recorded before 2001 but there appears to have been a decrease in recent decades.

In the 1980s and 90s, the heatwave period at Khulna generally started in mid to late March, peaked in April and May, and continued with less intensity into June. Since 2005, the number of heatwave days in June increased, and from July to October, months in which very few heatwaves were observed historically , there was a notable increase in the number of hot days.

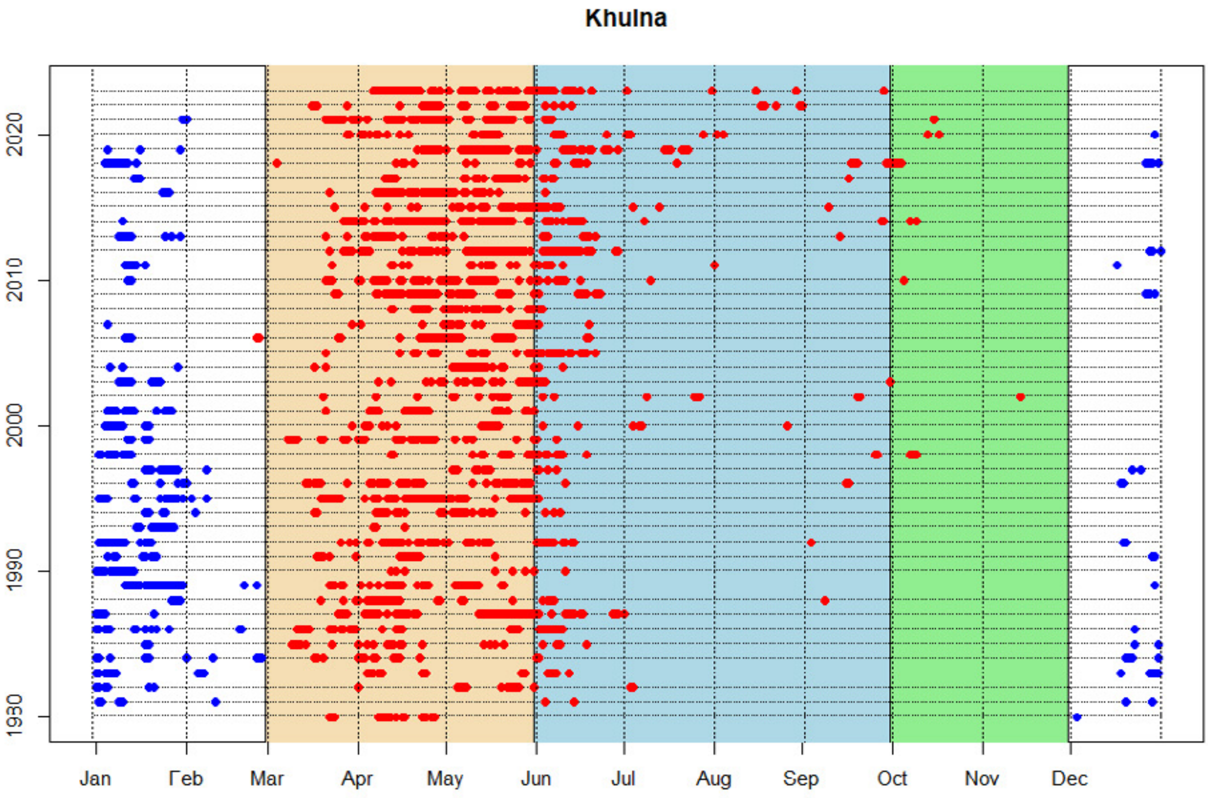


Figure 4.4: Number of cold (blue) and heatwave (red) days in Khulna.

Barishal

Barishal has a slightly different climate from Khulna due to the geographical location in southwestern Bangladesh, with fewer heatwaves but a larger number of cold outbreaks (Figure 4.5). Cold outbreaks generally begin in the third or last week of December. In January, there were many cold outbreak days throughout the whole time period, 1980-2023, but in February, they were more rare. Figure 4.5 indicates no obvious changes in the number of cold outbreaks in Barishal.

There are indications of seasonal shifts in the heatwaves of Barishal, with a later onset date and extension of the heatwave period later into the monsoon season. From 1981 to 2005, the heatwaves started during the first to third week of March, but after 2005, it was observed almost in the last week of March. There was no remarkable change in the number of heatwaves in the months of April, but an increase in May and June and in recent times some heat days were seen in July to September.

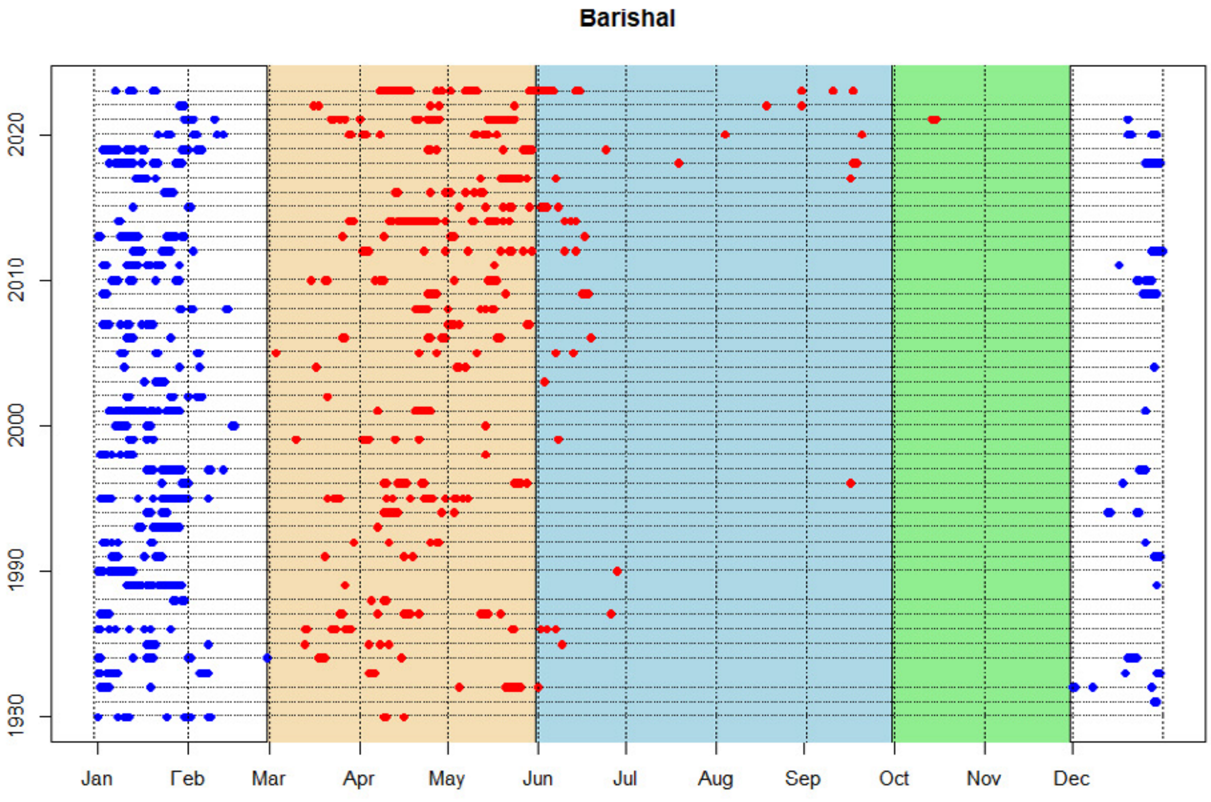


Figure 4.5: Number of cold (blue) and heatwave (red) days in Barishal.

Chattogram

The climate of Chattogram, the second largest city in Bangladesh, is tropical, influenced by the monsoon, with a dry season from November to March and a rainy season from May to October. The temperature records showed no large number of heatwaves or cold outbreaks. Additionally, there was no data for the time period 2004 - 2007 at this station (see Figure 4.6). From the available data, only one cold outbreak day was identified in December, February and March. In January, a few cold outbreak days occurred before 2001, but no cold outbreak days were detected in the last ten years at Chattogram. A limited number of heatwaves were observed from March to November and the majority of hot days were found in May.heat days can be found in the month of May.

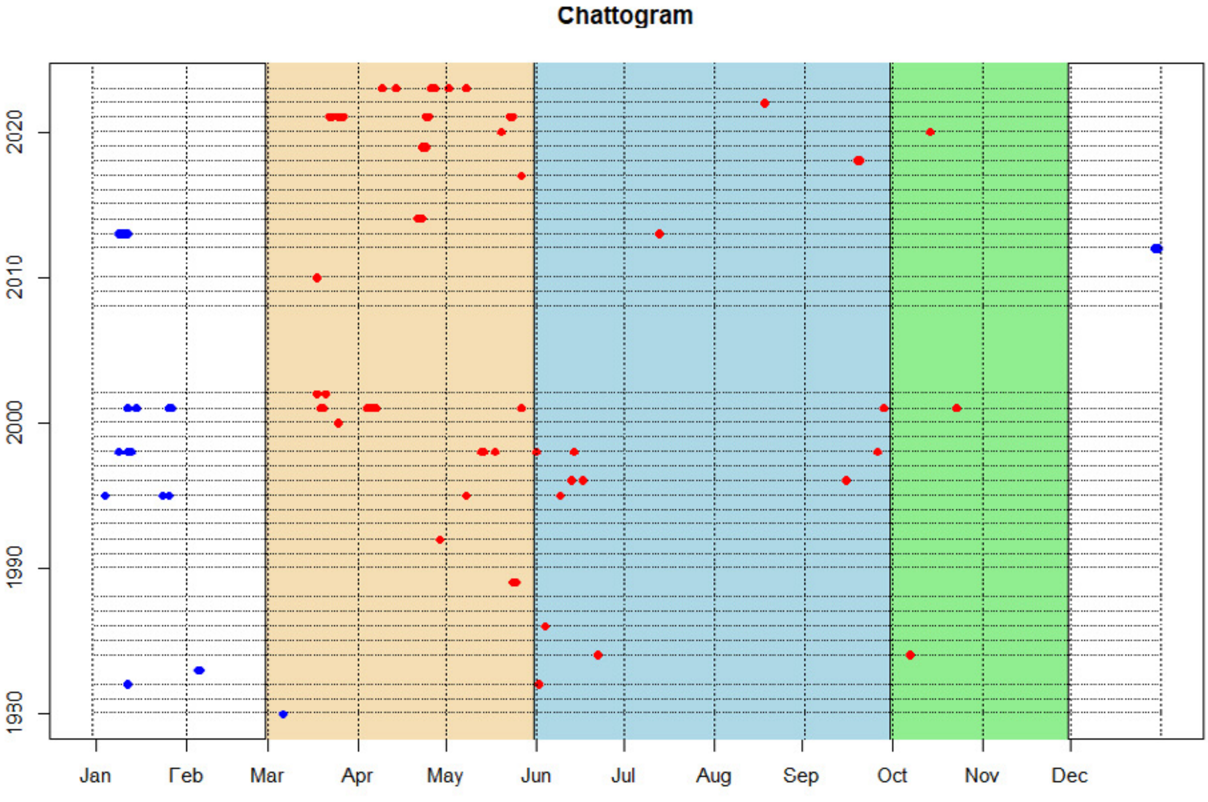


Figure 4.6: Number of cold (blue) and heatwave (red) days in Chattogram.

Sylhet

Sylhet is located in the northeastern part of Bangladesh on the Surma River. Due to the geographic location, this place has hot and wet summers and a relatively mild winter. In December, there were very few cold outbreak days and there have been no cold outbreak days at Sylhet in the last ten years (Figure 4.7). In January, Sylhet is comparatively cooler than other months but in recent years the number of cold outbreaks has decreased. In February, cold outbreaks have decreased and are no longer a common phenomenon.

The heatwave situation of Sylhet is different from other regions in Bangladesh, with a more even spread through the pre-monsoon and monsoon season compared to other sites. There seems to have been an increase in the number of heatwave days for the whole period of April to October.

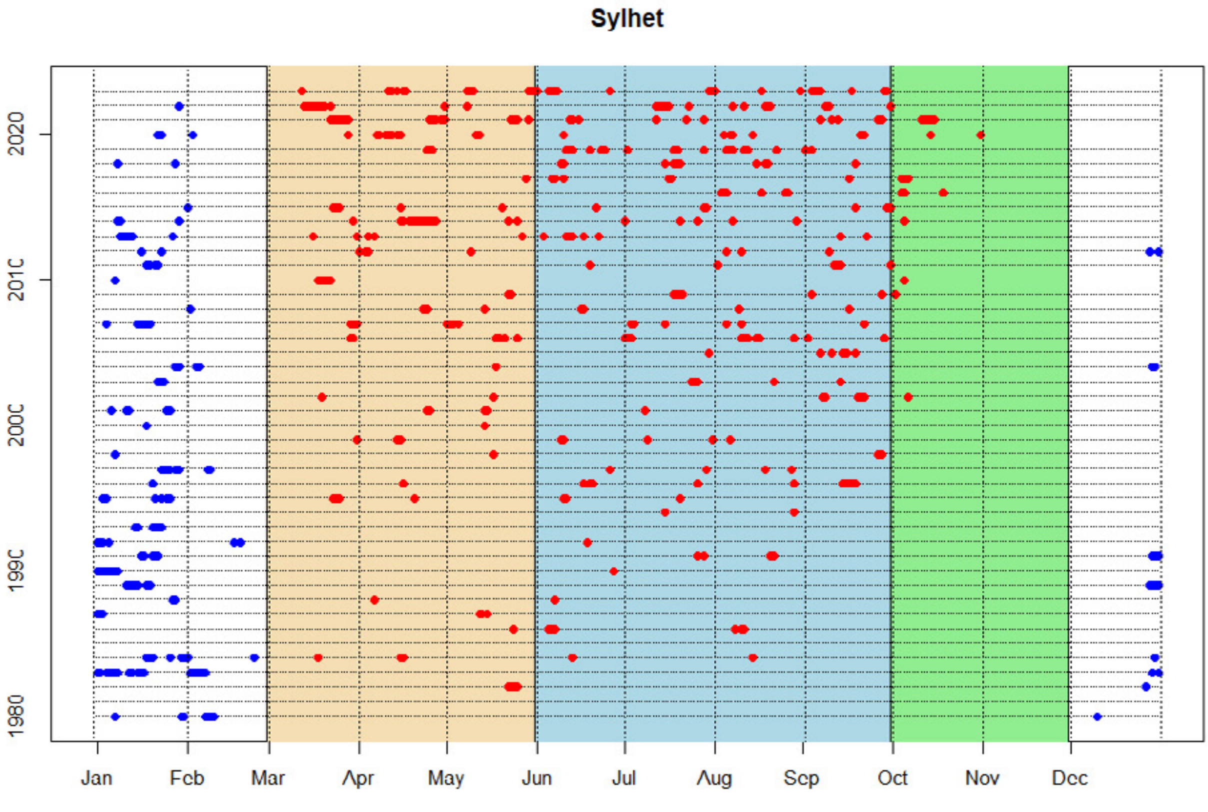


Figure 4.7: Number of cold (blue) and heatwave (red) days in Sylhet.

Mymensingh

TheThe climate of Mymensingh is a little cooler than the adjacent Dhaka region. The temperature records showed that the period of cold outbreaks started around mid December and continued up to February. In January, a large number of cold outbreak days were observed throughout the period 1980 - 2023 (Figure 4.8).

There were clear changes in the number of heatwave days in the pre-monsoon season at Mymensingh, with a shift in the onset from March or early April before 2000, to late April or May in more recent decades. The number of heatwave days also increased notably in the monsoon and early post-monsoon season, from June to October.

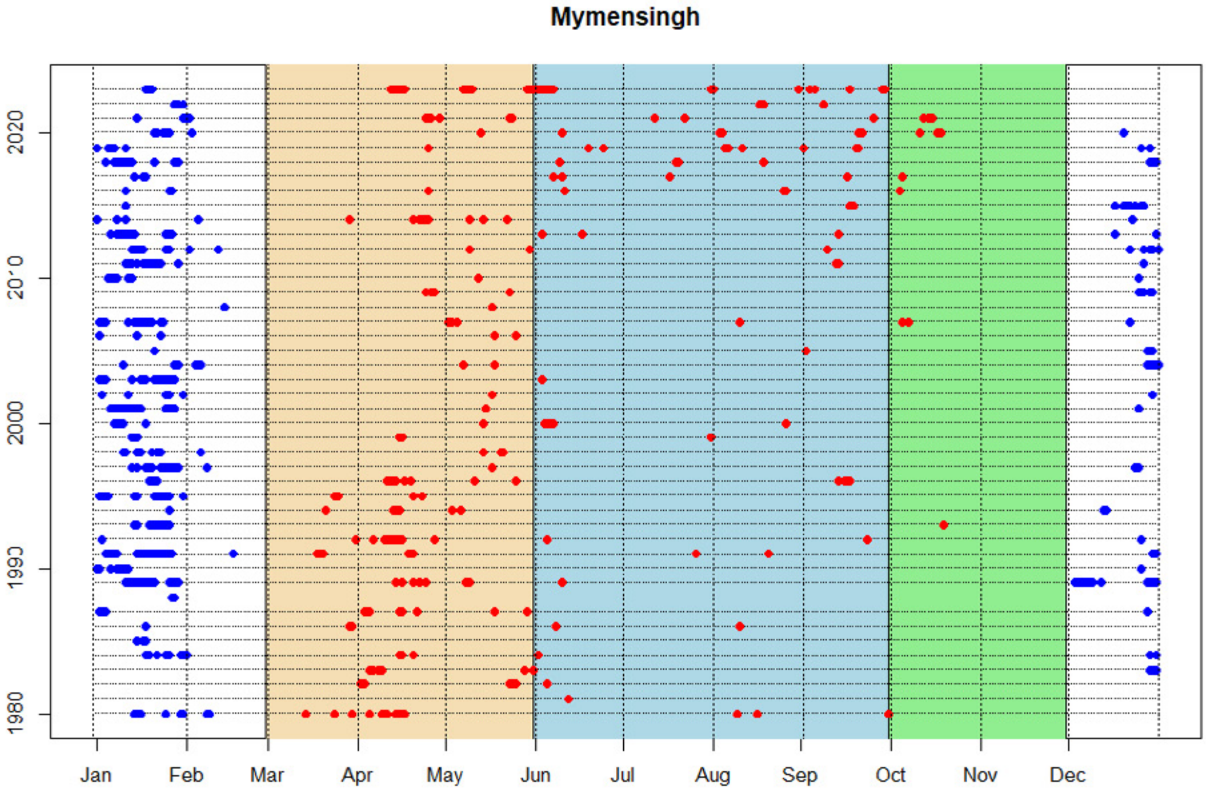


Figure 4.8: Number of cold (blue) and heatwave (red) days in Mymensingh.

National summary of heatwaves in Monsoon and Pre-monsoon

Figures 4.9 and 4.10 summarise the geographic tendencies for heatwaves in Bangladesh. Heatwaves were most frequent in the pre-monsoon season, the hottest season in Bangladesh (Figure 3.3), but also occurred in the monsoon season. The western area was more affected by the heatwaves than the rest of the country. The number of heatwave days increased the most in seasons and regions where they were uncommon in the earlier part of the observational records. In the pre-monsoon season, the number of heatwave days increased significantly at many stations near the coast, and in the monsoon season, there was a rise in heatwave days across the country.

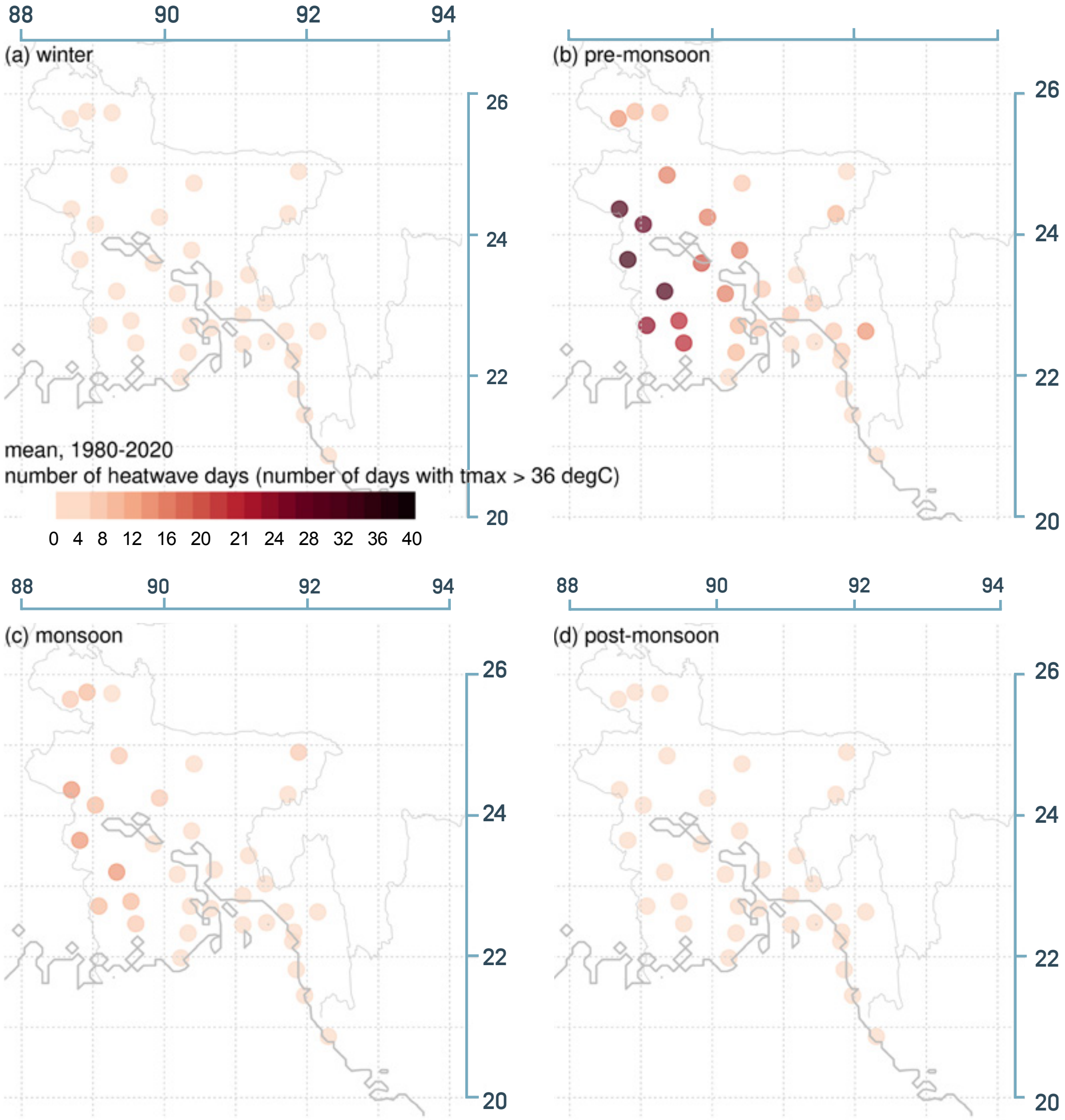


Figure 4.9: Seasonal mean values of the number of heatwave days (maximum temperature > 36°C) in Bangladesh. (The total number of days in a season varies: 122 days in the monsoon season, 61 days in the post-monsoon, and around 90 days in the winter and pre-monsoon.)

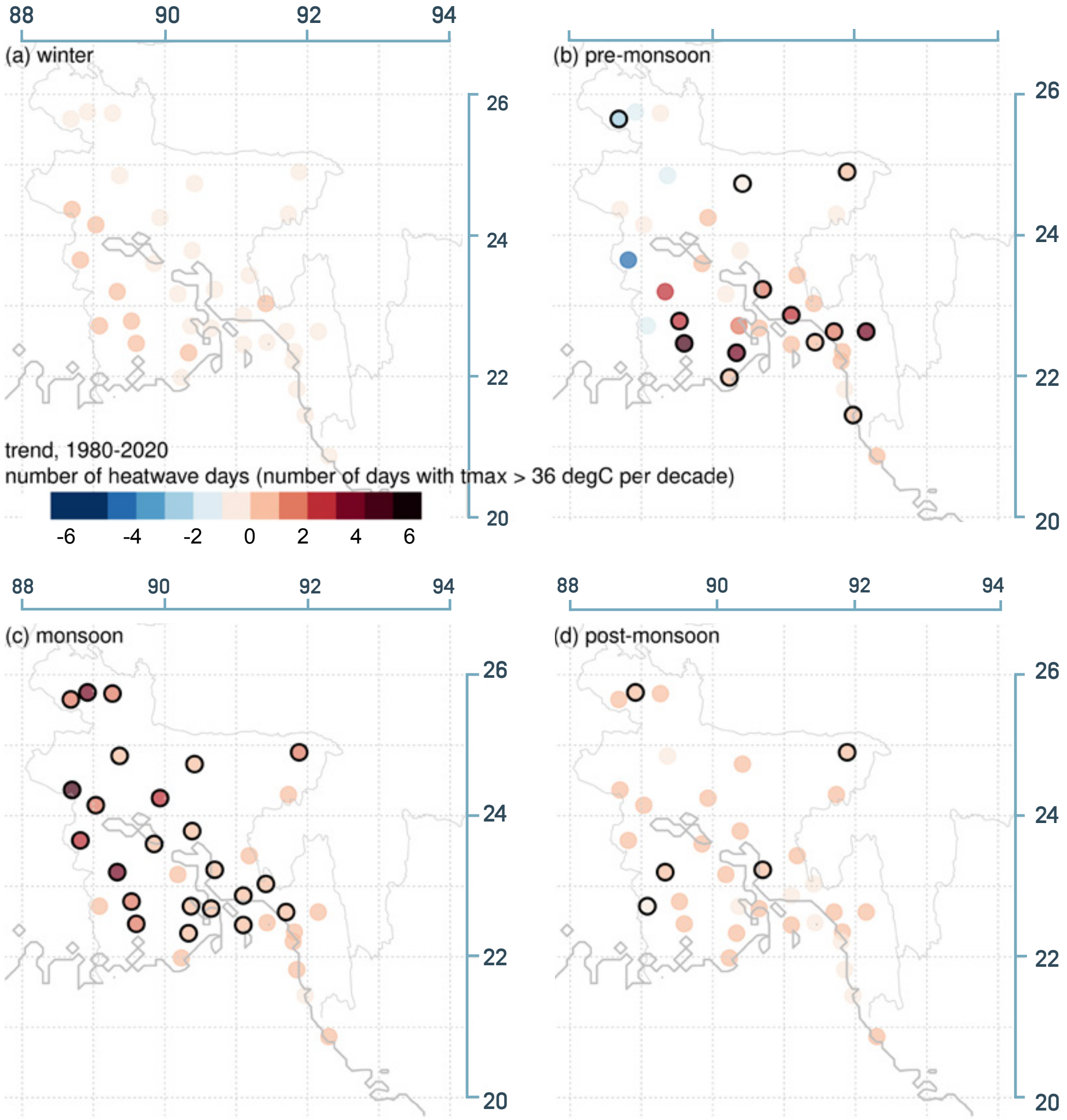


Figure 4.10: Trends in the number of heatwave days (maximum temperature > 36°C) in the period 1980-2020. Stations with significant trends (p<0.05) are marked with black outlines.

Photo: Gunnar Noer/MET Norway

Photo: Hans Olav Hygen/MET Norway

Heavy (44mm - 88mm) and Very Heavy Rainfall (>88mm) Events

The BMD has classified different rainfall categories (Khatun et al., 2016) i.e., light rain (1-10 mm), moderate rain (11-22 mm), moderately heavy rain (23-43 mm), heavy rain (44-88 mm), and very heavy rain (greater than 88 mm). In this report, heavy to very heavy rainfall observations are presented at the different meteorological stations of Bangladesh.

Dhaka

In Dhaka, heavy rainfall is rare during the winter and the records show only one very heavy rainfall event and six heavy rainfall events during the winter in the period 1980-2023 (Figure 4.11). In the pre-monsoon season (March to May), only a small number of very heavy rainfall events were observed in Dhaka, but heavy rainfall events were common in April and May. . In the monsoon season (June to September), a large number of heavy to very heavy rainfall events occurred. After 2009, there appears to have been a drop in extreme rainfall in the monsoon season (there were only five very heavy rainfall events in June, three in July, three in August, and two in September). However, no significance tests have been applied here and we therefore cannot determine whether this is a significant change or whether it falls within the scope of natural variability.

There were quite a few heavy and very heavy rainfall events in October, at the beginning of the post-monsoon season, but in November, extreme rainfall events were rare.

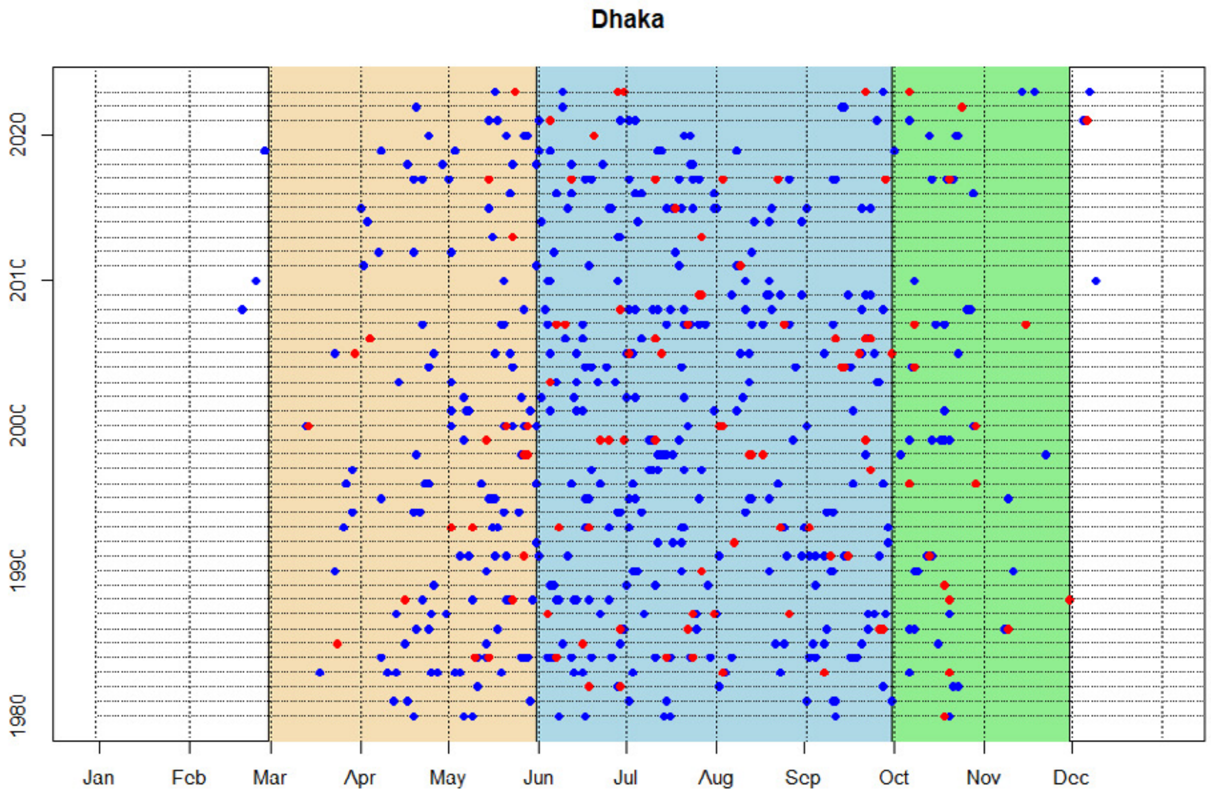


Figure 4.11: Number of heavy (blue) and very heavy (red) rainfall observations in Dhaka.

Rajshahi

The main period of extreme rainfall in Rajshahi is the monsoon season (June - October), but heavy and very heavy rainfall events are also frequent in the pre-monsoon (March - June) and post-monsoon (October - November) seasons, and even occur in the winter (December - February), although very rarely.

The winter season in Rajhshahi is relatively dry, and the records showed only seven records of heavy rainfall observations (four in December, three in February) in the period 1980-2023 (Figure 4.12). In the pre-monsoon season, there were many heavy rainfall observations in Rajshahi, but only three very heavy rainfall events which were all observed from 2007 onwards. In March, there were no heavy to very heavy rainfall records after 2005, suggesting that there may have been a delay in the period of heavy precipitation.

In the monsoon season, heavy rainfall events were frequent and a small number of very heavy rainfall events were also observed. The graph shows a decrease in the frequencies of heavy rainfall in August and September, but is unclear whether the change is statistically significant. In the post monsoon season, there were recorded events of very heavy rainfall in October but none in November.

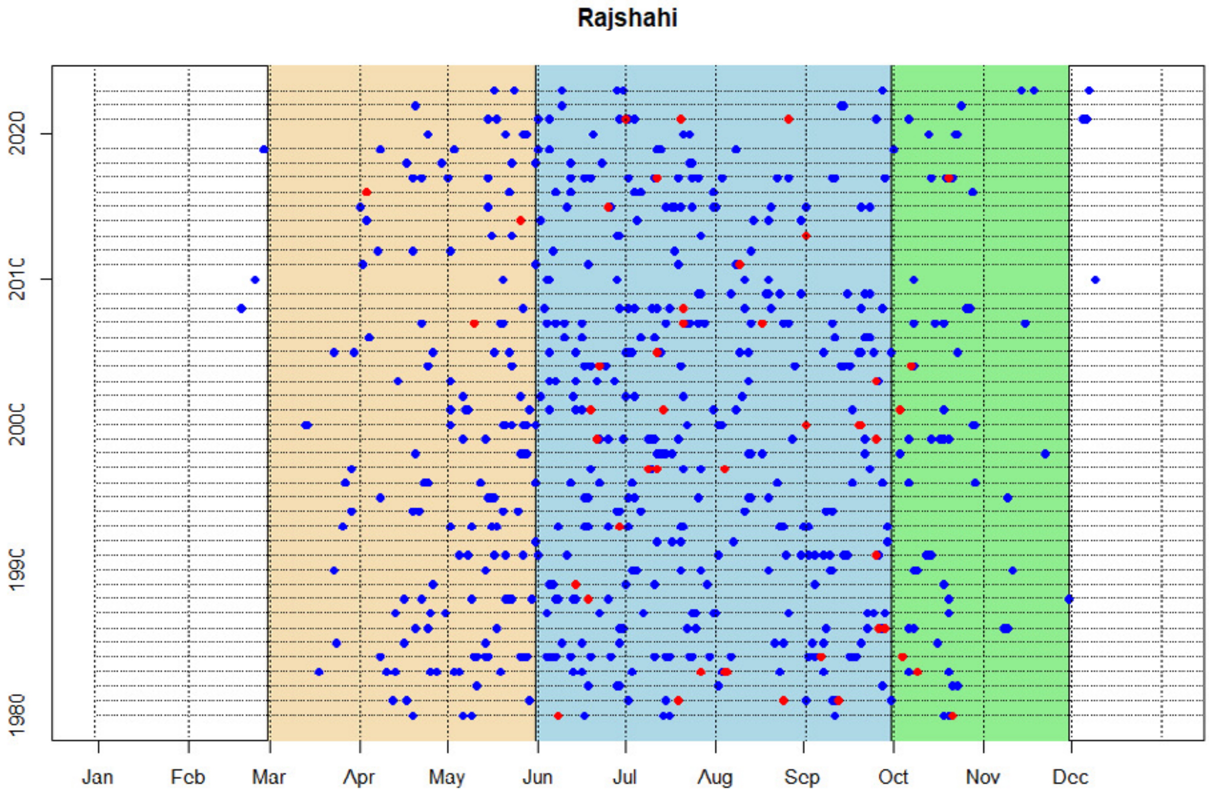


Figure 4.12: Number of heavy (blue) and very heavy (red) rainfall observations in Rajshahi.

Rangpur

At Rangpur, no occasions of very heavy rainfall have been observed during the winter season, but there were four heavy rainfall events (three in December and three in February; see Figure 4.13). In the pre-monsoon season, there were few very heavy rainfall incidents (none in March, two in April, and nine in May). The heavy rainfall frequency shows signs of a seasonal shift, with a sharp decline after 2005 in March. In the monsoon season, heavy to very heavy rainfall observations were almost uniform throughout the whole time period. In the post monsoon season, heavy rainfall observations display uniformity in October, although the occurrences of very heavy rainfall varied throughout the precipitation records. In November, no occurrences of very heavy rainfall have been recorded and only eight heavy rainfall events have been observed.

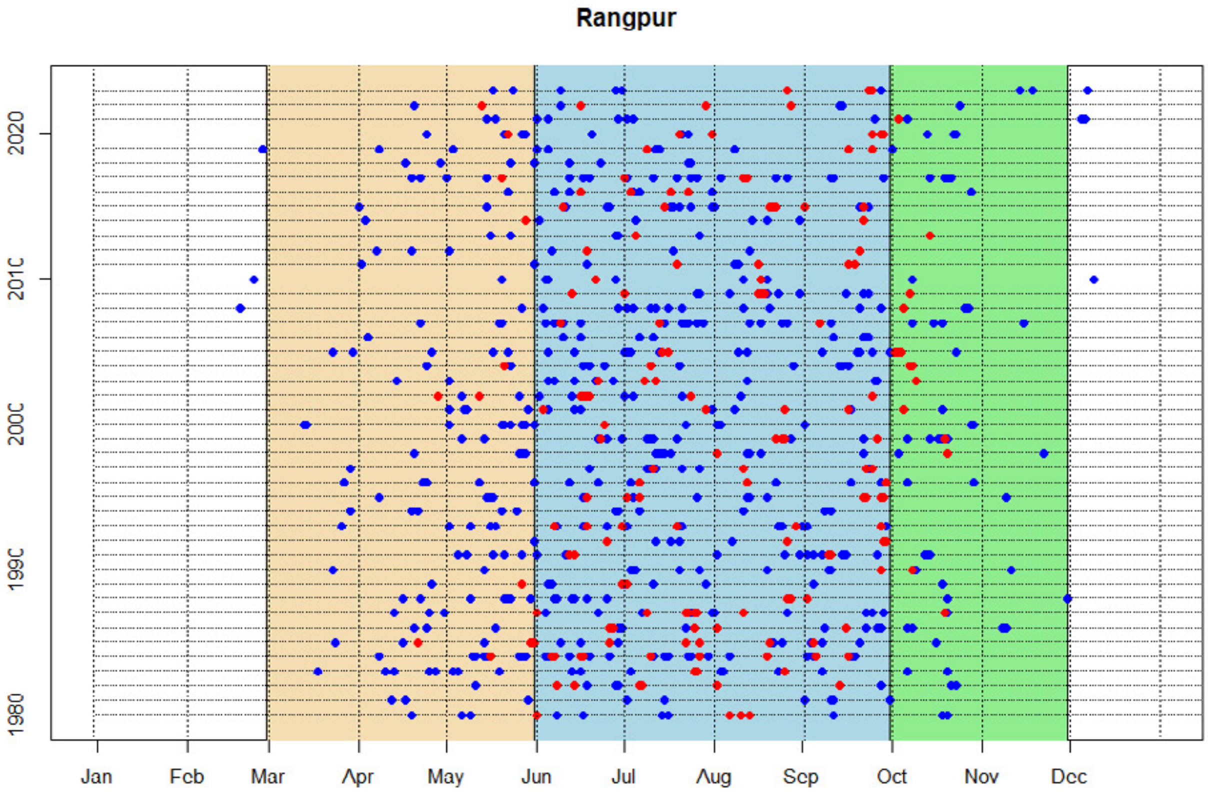


Figure 4.13: Number of heavy (blue) and very heavy (red) rainfall observations in Rangpur.

Khulna

In Khulna, very heavy rainfall has not been observed during the winter season and only six heavy rainfall occurrences (three in December and three in February), all recorded before 2008 (Figure 4.14). In the pre-monsoon season, there were few observations of very heavy rainfall. Since 1998, there have been no occasions of very heavy rainfall in the pre-monsoon season and heavy rainfall events have decreased in March. In the monsoon season, heavy to very heavy rainfall events were common throughout the time period 1980-2023. However, after 2010, the occurrence of heavy and very heavy rainfall events decreased in August and September. In the post monsoon season, heavy to very heavy rainfall events were not uniformly distributed in October and there are indications of a decrease from around 2008. In November, there were six very heavy and five heavy rainfall events.

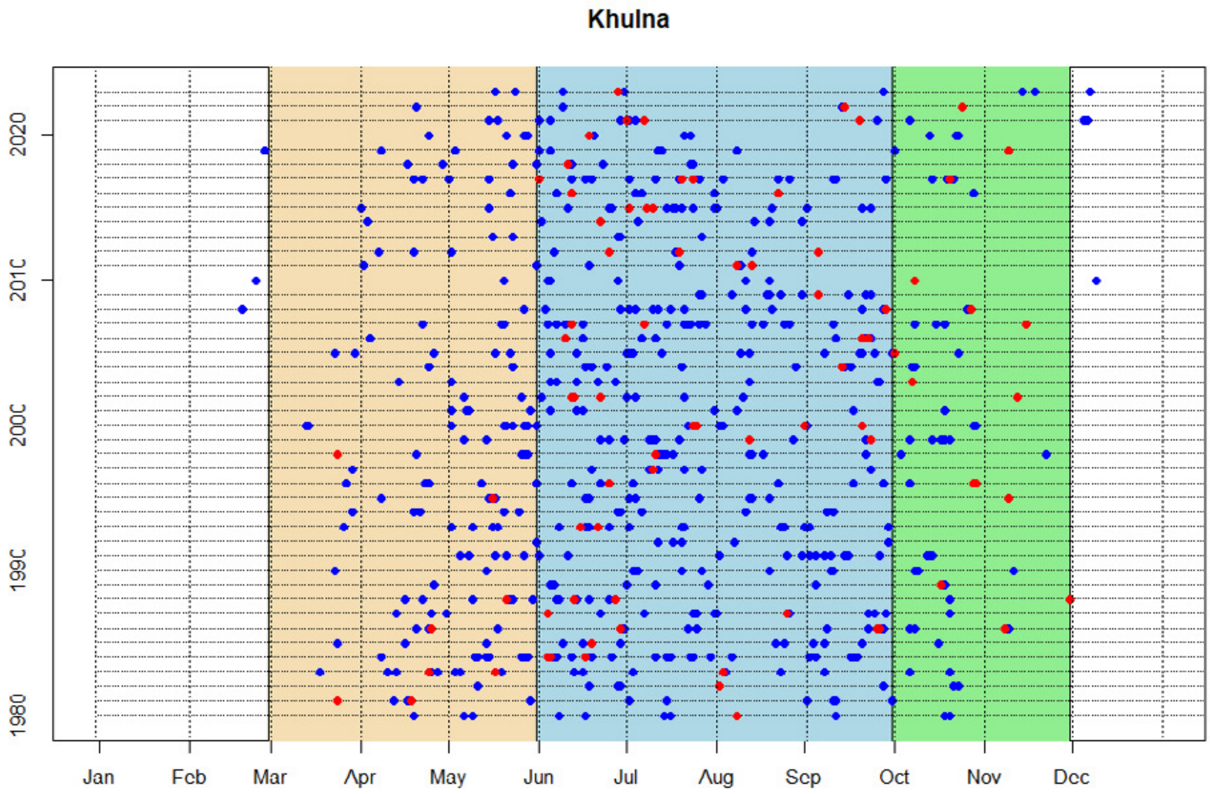


Figure 4.14: Number of heavy (blue) and very heavy (red) rainfall observations in Khulna.

Barishal

At Barishal, there were no observations of very heavy rainfall during the winter season but six heavy rainfall events (three in December and three in February; Figure 4.15). In the pre-monsoon season, there were few very heavy rainfall events: only one in March, two in April and seven in May. Heavy rainfall observations showed a seasonal shift, decreasing in March after 2005. In the monsoon season, heavy to very heavy rainfall events were frequent and occurred almost uniformly throughout the whole time period, except for a decrease in the number of heavy rainfall events in September in the last decade. In the post-monsoon season, heavy to very heavy rainfall observations occurred in October, but not every year. In November, there were few recorded events of heavy to very heavy rainfall.

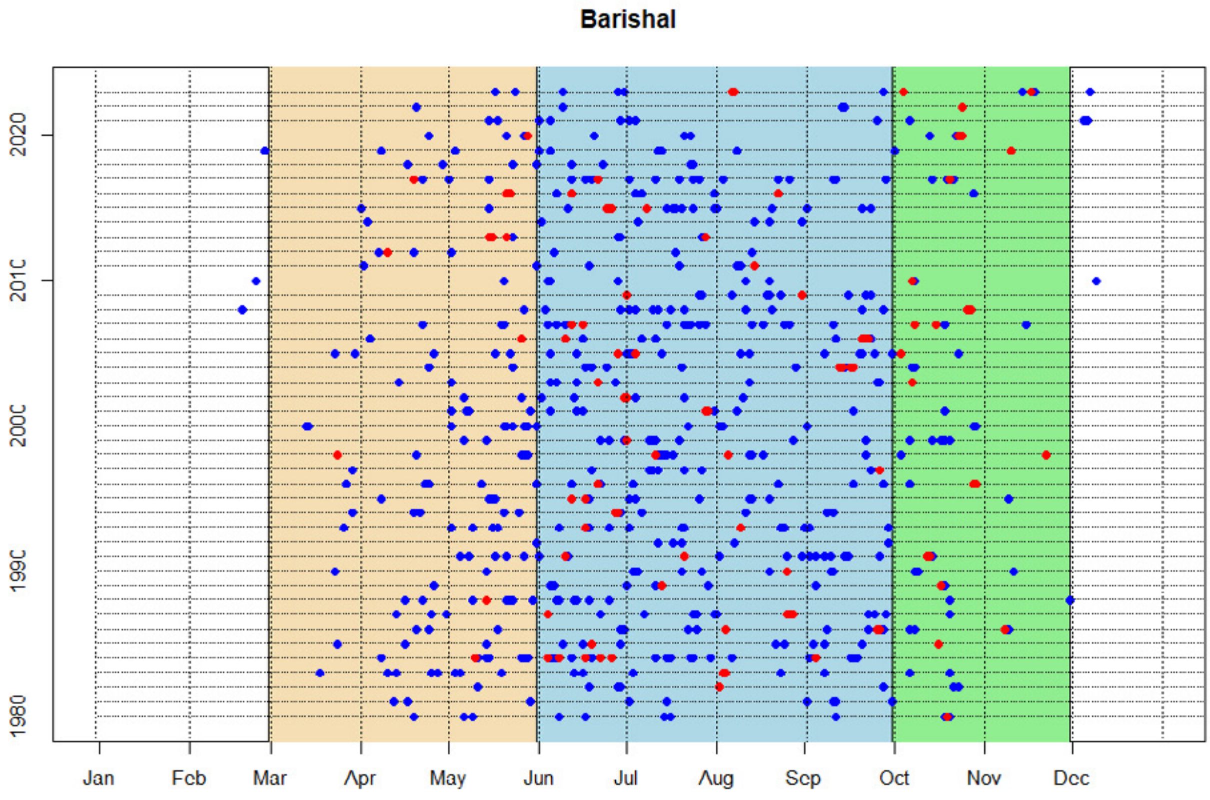


Figure 4.15: Number of heavy (blue) and very heavy (red) rainfall observations in Barishal.

Chattogram

At Chattogram station, there is no precipitation data from the period 2004 - 2007 (Figure 4.16). From the available data from 1980 to 2023, there were six heavy rainfall occurrences recorded during the winter season (three in December and three in February) and no occurrences of very heavy rainfall. In the pre-monsoon season, there were many very heavy rainfall observations in May, compared to April, and only two very heavy rainfall incidents were recorded in March. In the recent period, heavy rainfall observations decreased in March but there were no appreciable changes in heavy rainfall occurrences in April and May.

In the monsoon season, heavy to very heavy rainfall observations were stable throughout the whole time period. The highest frequency of very heavy to heavy rainfall events were found in July and June.

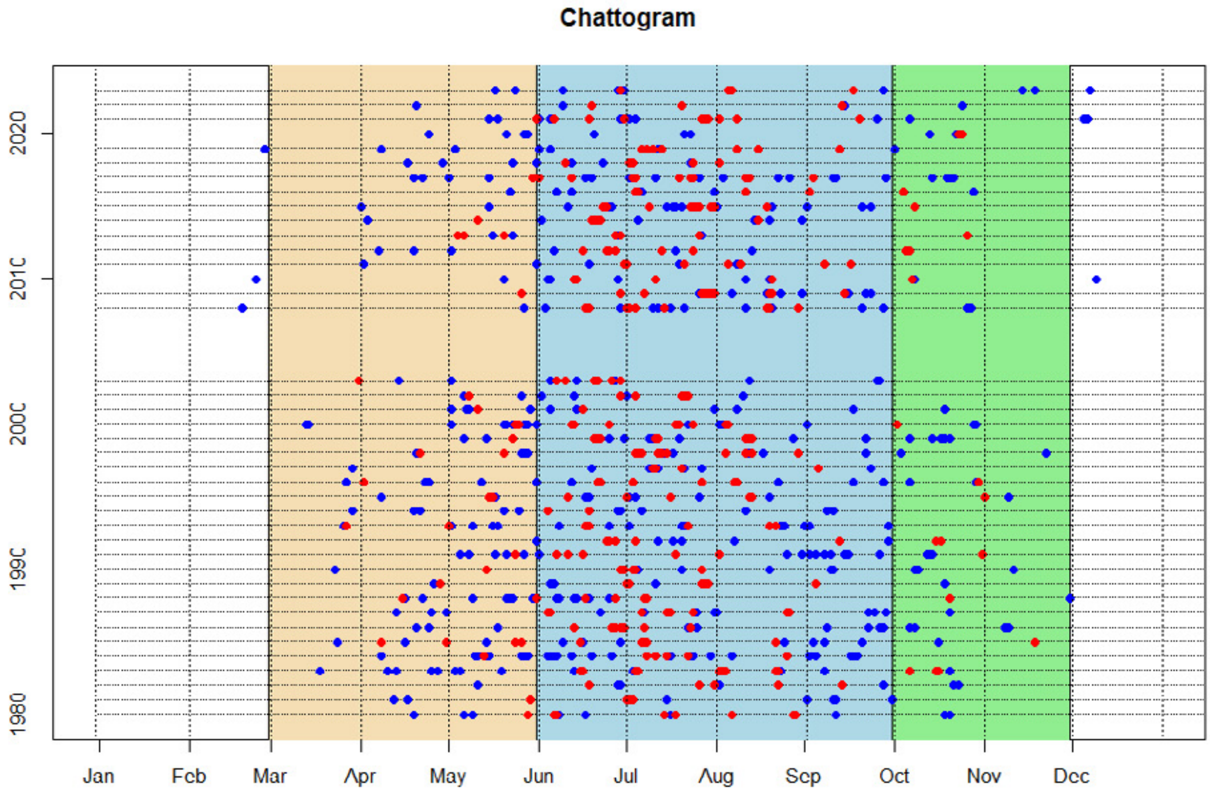


Figure 4.16: Number of heavy (red colour) and very heavy (blue) rainfall observations in Chattogram.

Sylhet

In Sylhet, the observational records showed only one instance of very heavy rainfall in the winter season (in February 2017) and six instances of heavy rainfall (3 each in December and February) (see Figure 4.17). In the pre-monsoon season, very heavy rainfall events were observed more often, with the highest frequency of occurrence in May, just before the monsoon season, and fewer events earlier in the season (March and April). The graph indicates that the heavy to very rainfall observations decreased after 2005 in the pre-monsoon season. In the monsoon season, heavy to very heavy rainfall observations were almost equal throughout the whole observational period, but very heavy rainfall occurrence was stable throughout the whole observational period, but the number of very heavy rainfall incidents appear to have increased over the last decade. In the post-monsoon season, a large number of very heavy rainfall observations were recorded in October (only two in November) and there appears to have been an increase in the last decade.

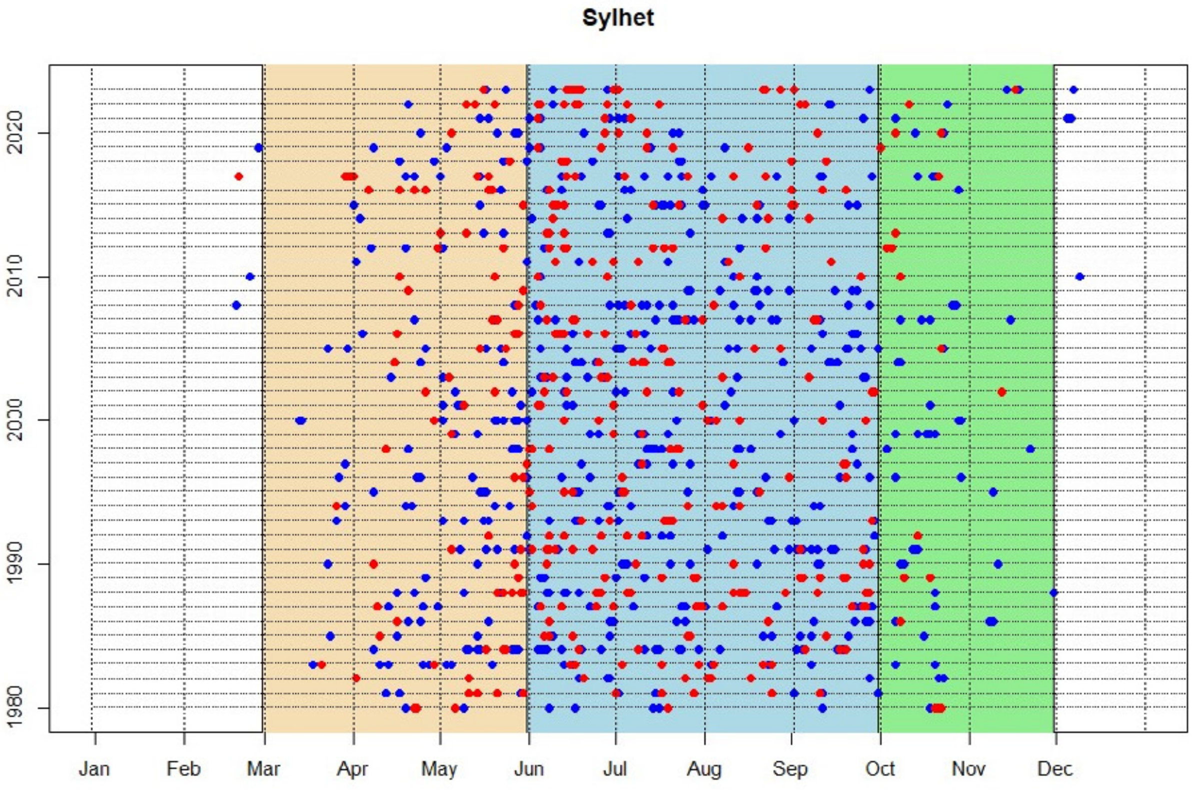


Figure 4.17: The number of heavy (blue) and very heavy (red) rainfall observations in Sylhet.

Mymensingh

Mymensingh has no record of very heavy rainfall events during the winter season but there were three heavy rainfall incidents in December and three in February (Figure 4.18). In the pre-monsoon season, there were a few very heavy rainfall observations. In March, there were no very heavy rainfall incidents but two very heavy rainfall observations in April. After 2000, very heavy rainfall has been observed in May but not earlier in the pre-monsoon season, and heavy rainfall occurrences seem to have decreased in March.

In the monsoon season, heavy to very heavy rainfall observations were almost uniform throughout the whole observational period 1980-2023. In the post monsoon season, all of the very heavy rainfall occurrences were recorded in October and none in November.

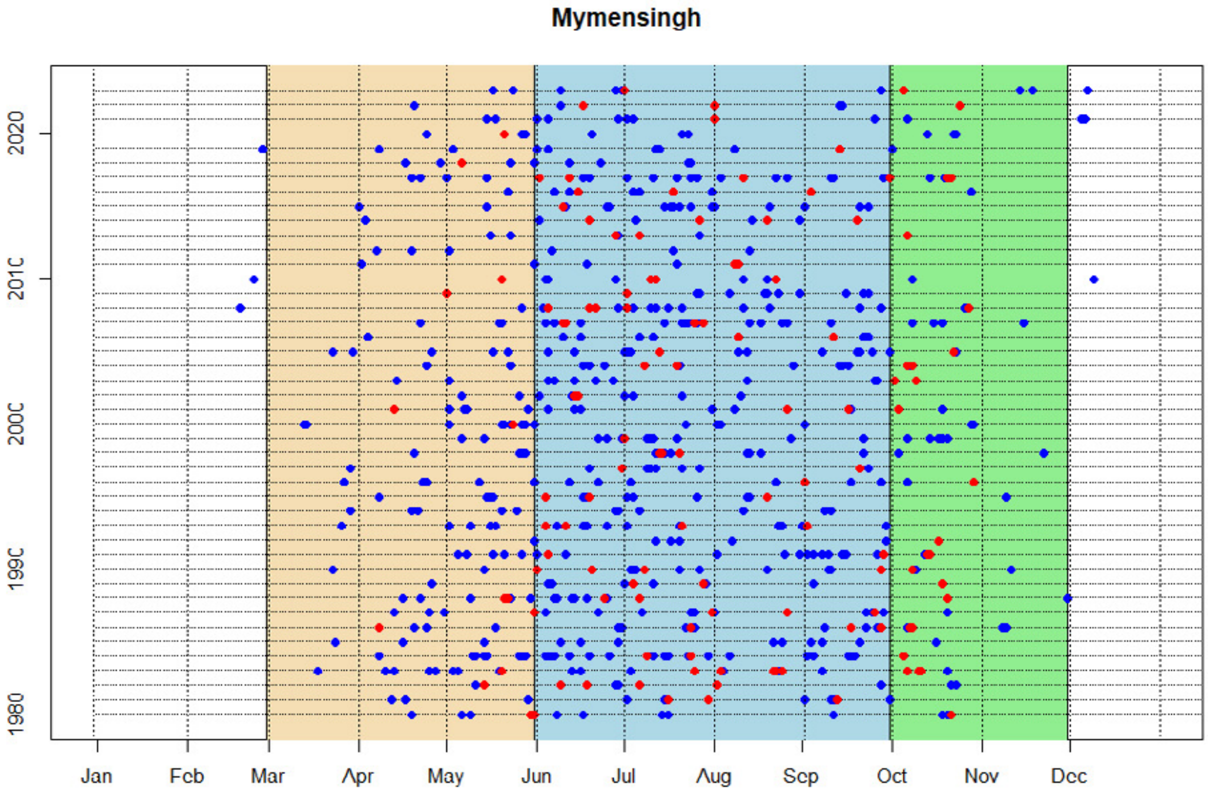


Figure 4.18: Number of heavy (blue) and very heavy (red) rainfall observations in Mymensingh.

National summary of the number of heavy rainfall events

Looking at the seasonal number of heavy and very heavy rainfall events, there are no indications of widespread statistically significant changes in Bangladesh in any season (Figures 4.19 and 4.20). Trend analysis of the number of days with heavy rainfall (44-88 mm) and very heavy rainfall (> 89 mm) in the period 1980-2020 showed significant changes at only a few stations. This suggests that the frequency of heavy to very heavy rainfall has been relatively stable in the last 40 years.

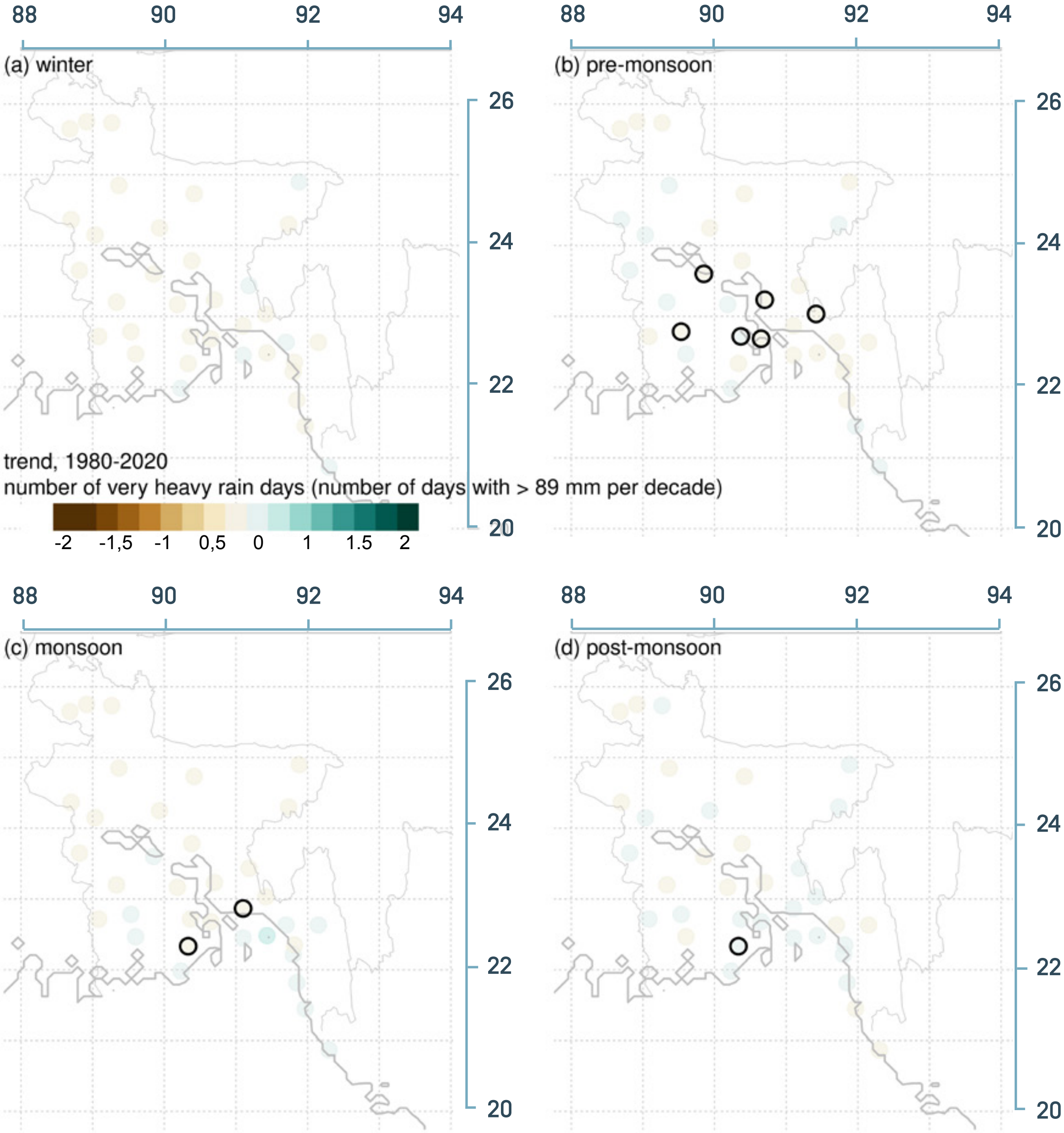


Figure 4.19: Trends in the number of very heavy rainfall days (> 89 mm) in the period 1980-2020 (days/decade). Stations with significant trends (p<0.05) are marked with black outlines.

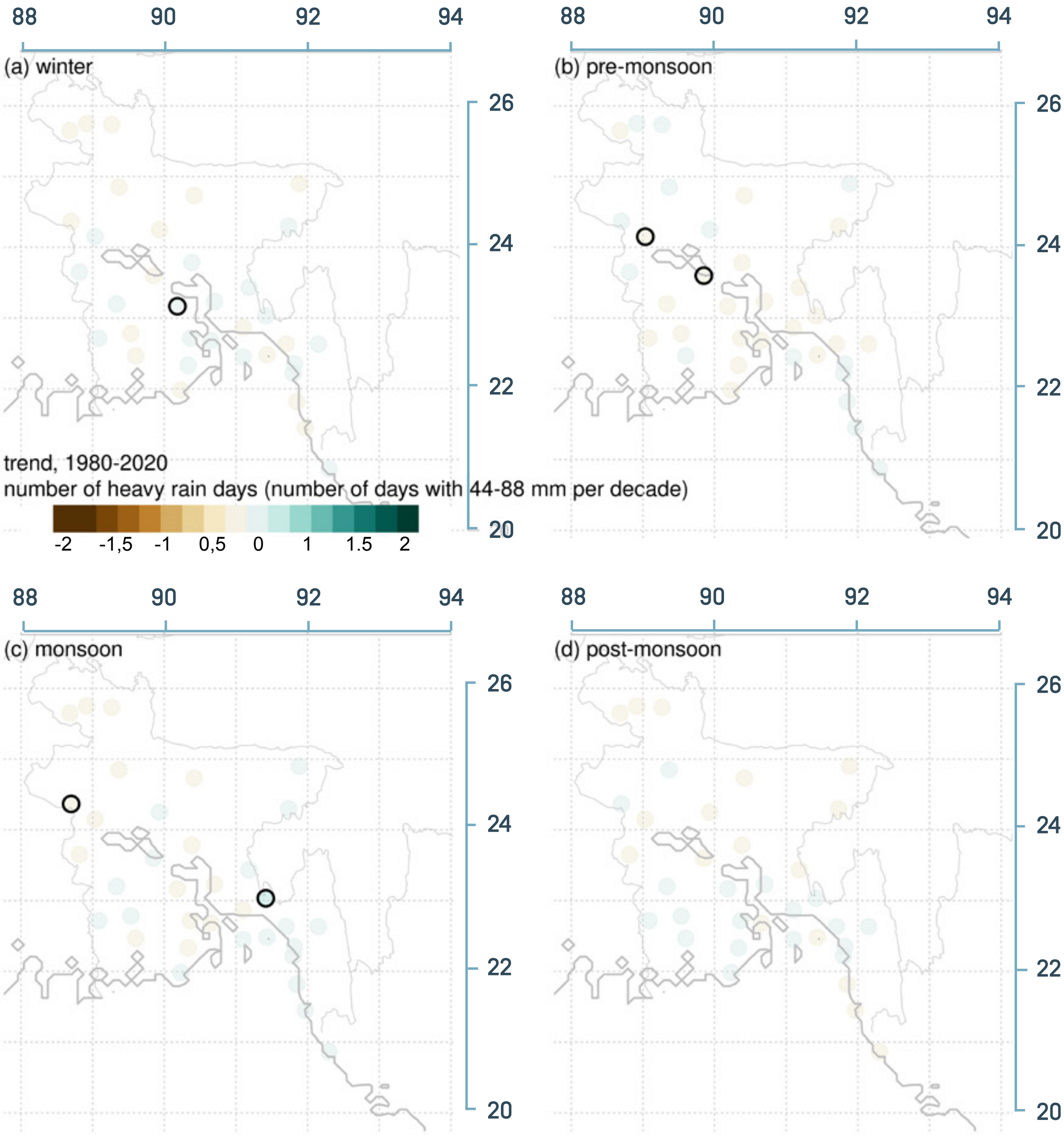


Figure 4.20: Trends in the number of heavy rainfall days (44-88 mm) in the period 1980-2020 (days/decade). Stations with significant trends (p<0.05) are marked with black outlines.

4.3 Shift in monsoons

The monsoon is probably the most significant feature of the Bangladeshi climate, giving necessary water to the agricultural sectors, and a relief from the heat for the population. Changes in the Monsoon, like onset or precipitation amount, might impact the people of Bangladesh in multiple ways, especially the economy in regions highly dependent on the agricultural sector. The onset and cessation of the monsoon is highly important and has been studied at several occasions, e.g. by Rao (1976), Lau and Yang (1997), Wang and LinHo (2002), Zhang (2010), and Reeve (2015). BMD keeps a record of onset and withdrawal of Monsoon from Bangladesh and parts of Bangladesh, here presented in table 4.1.

Year	Monsoon Onset		Monsoon Withdrawal	
	Over Bangladesh-12 June		**From Bangladesh-16 October**	
2023	Dhaka, Mymensingh and Barishal Divisions	10 June	Central part of the Country	13 Oct
	Chattogram and Sylhet Divisions	09 June		
	Cox's Bazar coast	08 June		
2022	**Over Bangladesh-03 June**		**From Bangladesh-20 Oct**	
	Teknaf Coast	31 May	Northern part of the Country	15 Oct
	Cox's Bazar coast	01 June		
	Chattogram and Sylhet Divisions	02 June		
2021	**Over Bangladesh-11 June**		**From Bangladesh-22 Oct**	
	Chattogram, Barishal, Sylhet, Mymensingh and Dhaka divisions	06 June	Northern part of the Country	12 Oct
	Chattogram, Barishal, Dhaka, Mymensingh, Sylhet and eastern part of Rangpur & Rajshahi divisions	10 June		
2020	**Over Bangladesh-12 June**		**From Bangladesh-22 Oct**	
	Cox's Bazar coast	08 June	North-Western part of Country	31 Oct
	Chattogram Coast	10 June	Rangpur, Rajshahi, Khulna, Barishal, Mymensingh, Sylhet & Dhaka divisions and the region of Cumilla & Noakhali.	26 Oct
	Chattogram, Barishal, Sylhet and eastern part of Dhaka divisions.	11 June		
			Chattogram	28 Oct
2019	**Over Bangladesh-20 June**		**From Bangladesh-14 Oct**	
	Teknaf Coast	09 June	Rangpur & Rajshahi Div	13 Oct
	Dhaka, Barishal & Sylhet div	15 June		
	North-Western Part	17 June		
2018	**Over Bangladesh-12 June**		**From Bangladesh-05 Oct**	
	Teknaf Coast	01 June		
	Chattogram & Sylhet divisions	02 June		
	Mymensingh & Dhaka divisions.	04 June		
	Khulna & Barishal divisions.	11 June		

Year	Monsoon Onset		Monsoon Withdrawal	
	Over Bangladesh-12 June		**From Bangladesh-16 October**	
2017	Chattogram coast	30 May	North-Western part of the Country	15 Oct
	Chattogram & Sylhet division	01 June		
	Barishal, Dhaka & Mymensingh divisions.	03 June		
2016	**Over Bangladesh-17 June**		**From Bangladesh-15 Oct**	
	Teknaf Coast	10 June	North-Western part of the Country	14 Oct
	Chattogram, Sylhet, Barishal & Mymensingh Division	14 June		
	Dhaka Divisions	16 June		
2015	**Over Bangladesh-11 June**		**From Bangladesh- 17 Oct**	
	Teknaf Coast	05 June		
	Chattogram	06 June		
	Central Part of Country	10 June		
2014	**Over Bangladesh-18 June**		**From Bangladesh- 18 Oct**	
	Teknaf Coast	28 May		
	Chattogram Coast	06 June		
	Central Part of Country	10 June		
	Rangpur	17 June		
2013	**Over Bangladesh-11 June**		**From Bangladesh- 23 Oct**	
	Teknaf Coast	06 June	Western part of Country	20 Oct
	Chattogram Division	07 June		
	Central Part	09 June		
2012	**Over Bangladesh-17 June**		**From Bangladesh- 16 Oct**	
	Teknaf-Cox's Bazar Coast	31 May	Western part of Country	15 Oct
	Chattogram Division	06 June	North-Eastern Part	15 Oct
	Dhaka Division	07 June	Central Part	15 Oct
2011	**Over Bangladesh- 12 June**		**From Bangladesh- 11 Oct**	
	Central Part	10 June		
	Eastern Part	11 June		
2010	**Over Bangladesh- 06 June**		**From Bangladesh- 19 Oct**	
	Teknaf Coast	03 June	North South-Western part	16 Oct
	Chattogram Division	04 June	Central Part	16 Oct
	Central Part	05 June	Dhaka	18 Oct
2009	**Over Bangladesh- 26 May**		**From Bangladesh- 14 Oct**	
			North-west, North-east & Central part	13 Oct
2008	**Over Bangladesh- 05 June**		**From Bangladesh- 11 Oct**	
	Teknaf Coast	29 May	North-Western part	09 Oct
	Cox´s Bazar Coast	30 May		
	Chattogram	31 May		
	Eastern & Central Part	04 June		

Year	Monsoon Onset		Monsoon Withdrawal	
2007	**Over Bangladesh- 10 June**		**From Bangladesh- 18 Oct**	
	Teknaf Coast	03 June	North-Western part	15 Oct
	Chattogram Division	06 June	Central Part	17 Oct
	Eastern & Central Part	08 June		
2006	**Over Bangladesh- 05 June**		**From Bangladesh- 11 Oct**	
	Teknaf Coast	28 May	North-Western part	08 Oct
	Chattogram Division	31 May	Central Part	10 Oct
	Central Part	01 June		
2005	**Over Bangladesh- 20 June**			
	Teknaf Coast	05 June	North-Western part (Bang/India)	29 Sept
	Chattogram Coast	06 June	Bihar, Jharkhand & West of WB.	07 Oct
	Central Part	15 June		
	Eastern Rajshahi	19 June		
2004	**Over Bangladesh-03 June**		**From Bangladesh- 16 Oct**	
	Teknaf Coast	29 May	North-Western part of Country	11 Oct
	Chottogram Div.	31 May	Central Part	12 Oct
	Central Part	02 June		
2003	**Over Bangladesh-08 June**		**From Bangladesh-05 Oct**	
	Teknaf Coast	03 June	North-Western part of Country	01 Oct
	Chottogram Div.	04 June	Central Part	04 Oct
	Sylhet & Dhaka Div.	06 June		
2002	**Over Bangladesh-08 June**		**From Bangladesh-07 Oct**	
	Teknaf Coast	31 May	North-Western part of Country	02 Oct
	North-Eastern part of Country	06 June	Rajshahi, Dhaka & Khulna Division	05 Oct
	Central Part	07 June	Central Part	06 Oct
2001	**Over Bangladesh-06 June**		**From Bangladesh-15 Oct**	
	Chattogram coast	03 June	Barisal, Rajshahi, Khulna Dhaka,	14 Oct
	Central Part	04 June	Chattogram & Sylhet divisions.	
	Barishal, Dhaka,Chattogram & Sylhet divisions.	05 June		
2000	**over Bangladesh-07 June**		**From Bangladesh-14 Oct**	
	Cox's Bazar-Teknaf Coast	01 June		
	Chattogram division	04 June	Central Part	12 Oct
	Central Part	06 June		
1999	**Over Bangladesh-29 May**		**From Bangladesh- 09 Oct**	
	Chattogram Coast	27 May	North-Western part of Country	03 Oct
1998	**Over Bangladesh-11 June**		**From Bangladesh- 15 Oct**	
	Teknaf Coast	01 June		
	Chattogram & Sylhet Div	09 June		
	Barishal & Dhaka Div	10 June		

Year	Monsoon Onset		Monsoon Withdrawal	
1997	**Over Bangladesh-10 June**		**From Bangladesh-05 Oct**	
	Chattogram Division	09 June		
1996	**Over Bangladesh-18 June**			
	Cox's Bazar Coast	01 June	North Bay	11 Oct
	Khulna, Barisal, Chattogram & Dhaka divisions.	16 June		
1995	**Over Bangladesh-08 June**		**From Bangladesh-13 Oct**	
	Akyab Coast	03 June	North-Western part of Country	07 Oct
	Chattogram region	05 June		
	Dhaka & Barisal Div	06 June		
	Rajshahi Div	07 June		
1994	**Over Bangladesh-09 June**		**From Bangladesh-03 Oct**	
	Chattogram, Barisal, Dhaka, Khulna Division	08 June		
1993	**Over Bangladesh-06 June**		**From Bangladesh-10 Oct**	
	Southern Part of Chottogram div	31 May	Northern & Central Part of the Country	09 Oct
	Central Part	01 June		
1992	**Over Bangladesh-13 June**		**From Bangladesh- 17 Oct**	
	Chattogram & Dhaka Div	10 June	North Bay	20 Oct
1991	**Over Bangladesh-10 June**		**From Bangladesh- 11 Oct**	
	Chattogram Coast	06 June	Northern & Central part of the Country	10 Oct
	Central Part	09 June		
1990	**Over Bangladesh-11 June**		**From Bangladesh- 12 Oct**	
	North-East Bay	29 May		
	Chattogram-Cox's Bazar Coast	06 June		
	Dhaka Division	10 June		
1989	**over Bangladesh-13 June**		**From Bangladesh-14 Oct**	
	North-East Bay	03 June		
	Bangladesh Coast	04 June		
	Chattogram division	08 June		
1988	**Over Bangladesh-12 June**		**From Bangladesh-08 Oct**	
			North Bay	12 Oct
1987	**Over Bangladesh-15 June**		**From Bangladesh-04 Oct**	
	Chattogram-Cox's Bazar Coast	08 June	North Bay	12 Oct
1986	**Fairly active over Bangladesh-21 June**		**From Bangladesh-15 Oct**	
	North Bay	17 June	North-Western part of Country	14 Oct
	Chattogram, Sylhet, Barishal & Mymensingh Division	14 June		
	Dhaka Division	16 June		
1985	**Over Bangladesh-07 June**			
	North Bay	05 June	North Bay	21 Oct
	Southern Part	06 June		

Year	Monsoon Onset		Monsoon Withdrawal	
1984				
	Monsoon is feeble over Bangladesh-09 June		**From Bangladesh-27 Sept**	
	North Bay Southern Part Bangladesh	05 June 05 June	North Bay	29 Sept
1983	**Monsoon is fairly active over Bangladesh-17 June**		**From Bangladesh-17 Oct**	
	Southern Chottogram Bangladesh Coast	07 June 08 June	North Bay	17 Oct
1982	**Monsoon active over Bangladesh-10 June**		**From Bangladesh-06 Oct**	
	Monsoon advanced over Bangladesh	09 June	North Bay	06 Oct
1981	**Monsoon is fairly active over Bangladesh-07 June**			
	Chattogram Coast Coastal Bangladesh	04 June 06 June	North Bay	17 Oct

Table 4.1: BMDs list of dates for onset and withdrawal of Monsoon over Bangladesh from 1981 to 2023

Based on the data in table 4.1 a time series for onset over Bangladesh is constructed and shown in figure 4.21. Comparing the later years with earlier years there is no significant change in the onset date.

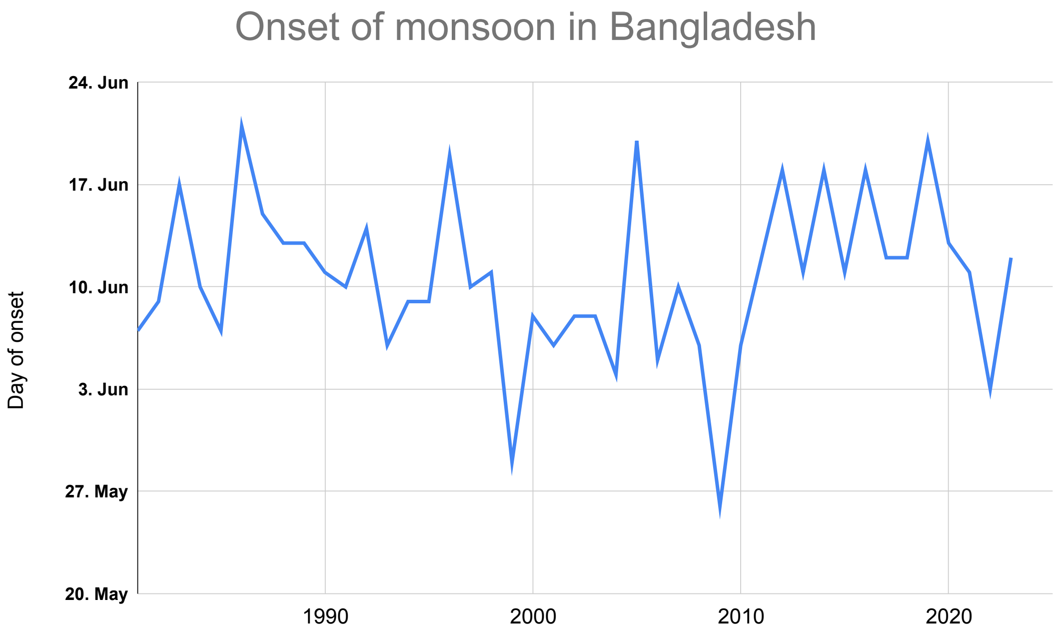


Figure 4.21: Onset of Monsoon over Bangladesh

Photo: Hans Olav Hygen/MET Norway

4.3.1 Onset of Monsoon

The onset of the monsoon is currently detected manually and catalogued as shown above. There are studies that have tried to detect the monsoon onset automatically, with more or less complicated indices taking e.g. rainfall and wind direction into account (Reeve, 2015). It is challenging to find an objective method that consistently identifies the monsoon onset and results differ depending on which aspect of the climate is considered.

In preparation of this report, a preliminary study was conducted looking into large scale climate patterns around the time of the monsoon onset, using ERA5 reanalysis data (mean sea level pressure, total precipitation, and the low and high level wind speed and wind direction). A composite analysis was performed, calculating the average field over the period 1981-2023 for each day from 6 days before to 5 days after the monsoon onset. The average mean sea level pressure showed some indication of a shift in the pattern around the monsoon onset (Figure 4.22). However, looking at individual years there were considerable variations in the pressure patterns. No single large scale variable appears to be useful as an identifier for the monsoon onset in and of itself, and it is likely necessary to define a more complex index taking multiple variables into consideration to pinpoint the monsoon onset. Further research is needed to find a method that is robust enough to provide certain detection in the historic climate, and thus able to describe the further development of the monsoon in a changing climate.

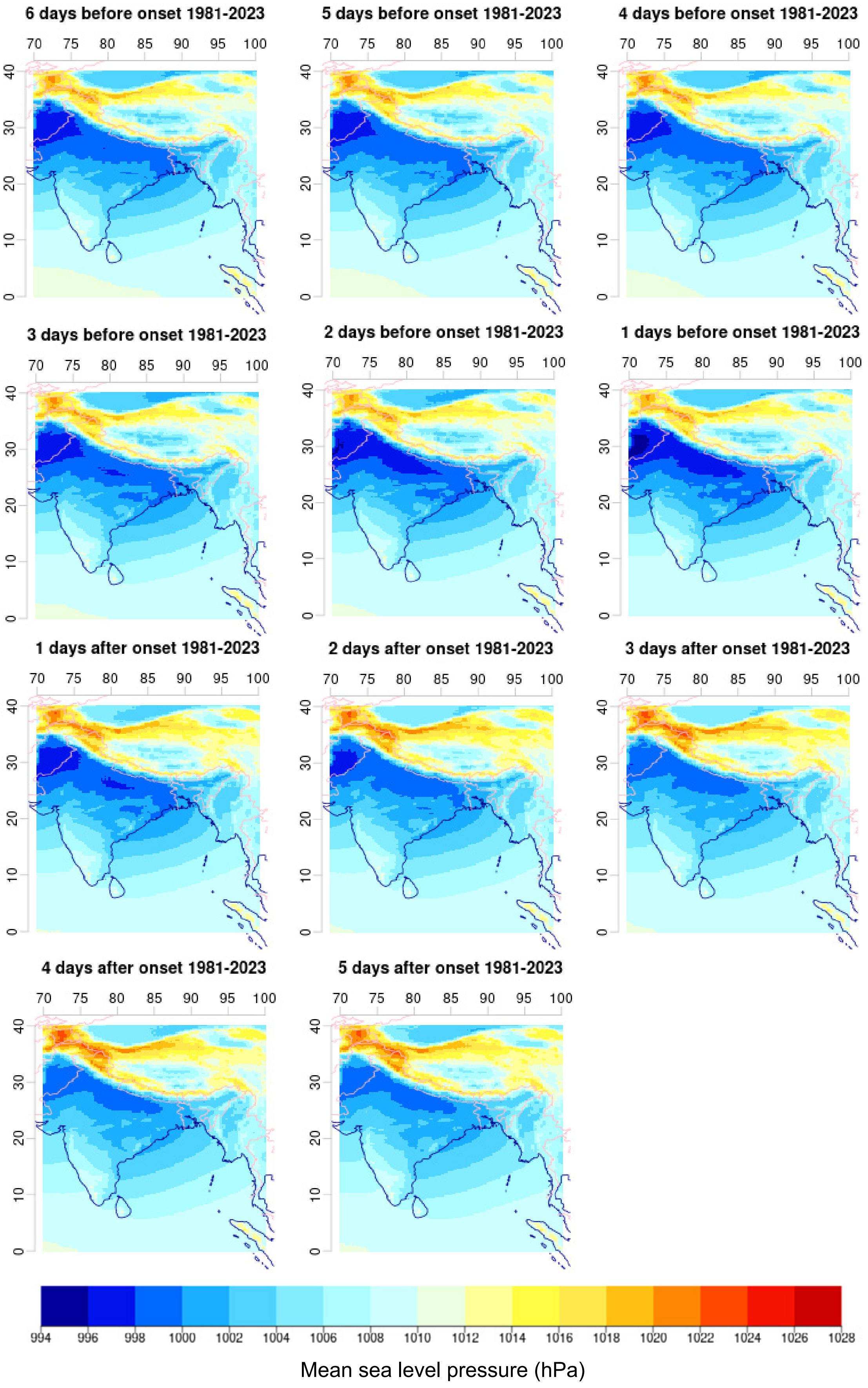

6 days before onset 1981-2023
5 days before onset 1981-2023
4 days before onset 1981-2023
3 days before onset 1981-2023
2 days before onset 1981-2023
1 days before onset 1981-2023
1 days after onset 1981-2023
2 days after onset 1981-2023
3 days after onset 1981-2023
4 days after onset 1981-2023
5 days after onset 1981-2023
70 75 80 85 90 95 100
0 10 20 30 40
994 996 998 1000 1002 1004 1006 1008 1010 1012 1014 1016 1018 1020 1022 1024 1026 1028
Mean sea level pressure (hPa)

Figure 4.22: Composite analysis of the ERA5 mean sea level pressure (mslp). The panels show the average mslp over the period 1981-2023 for each day from six days preceding the monsoon onset to 5 days after.

Acknowledgements

NORAD is acknowledged for providing the funding of the project “SAREPTA - Institutional Support and Capacity Building for Weather and Climate Services". We will also thank colleagues at MET Norway for support and Mai-Linn Finstad for design and typesetting of the document.

References

Aguilar E, Auer I, Brunet M, Peterson TC, Wieringa J (2003) Guidelines on climate metadata and homogenization. WMO-TD No. 1186, WCDMP No. 53. World Meteorological Organization, Geneva.

Costa, A.C. and Soares, A. (2008) Trends in Extreme Precipitation Indices Derived from a Daily Rainfall Database for the South of Portugal. International Journal of Climatology, 29, 1956-1975.

IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2391 pp. doi:10.1017/9781009157896.

Joelsson, L. M. T., Engström, E., & Kjellström, E. (2023). Homogenization of Swedish mean monthly temperature series 1860–2021. International Journal of Climatology, 43(2), 1079–1093.

Khatun, Mossammat Ayesha., Rashid, Md. Bazlur and Hygen, Olav. Hans, (2016), “Climate of Bangladesh”, MET report, no. 08/2016, ISSN 2387-4201, Climate, Norwegian Meteorological Institute.

Kuya E.K., Gjelten H.M. & Tveito O.E. 2020. Homogenization of Norway’s mean monthly temperature series. METreport 03/2020. ISSN 2387-4201.

Kuya E.K., Gjelten H.M & Tveito O.E. 2021. Homogenization of Norwegian monthly precipitation series for the period 1961-2018. METreport 04/2021. ISSN 2387-4201

Lau K, Yang S (1997) Climatology and interannual variability of the Southeast Asian summer monsoon. Advances in Atmospheric Sciences 14: 141-162.

Mamara, A., Argiriou, A.A. and Anadranistakis, M. (2014) Detection and correction of inhomogeneities in Greek climate temperature series. International Journal of Climatology, 34, 3024– 3043.

Menne, M. J. and Williams, C. N.: Homogenization of Temperature Series via Pairwise Comparisons, J. Climate, 22, 1700–1717.

Mestre O., Domonkos P., Picard F., Auer I., Robin S., Lebarbier E., Böhm R., Aguilar E., Guijarro J., Vertachnik G., Klancar M., Dubuisson B. & Stepanek P. 2013. HOMER: A homogenization software - methods and applications. IDŐJÁRÁS - Quarterly Journal of the Hungarian Meteorological Service Vol. 117, No. 1, January–March 2013, pp. 47-67.

Peterson, T. C., Easterling, D. R., Karl, T. R., Groisman, P., Nicholls, N., Plummer, N., Torok, S., Auer, I., Boehm, R., Gullett, D., Vincint, L., Heino, R., Tuomenvirta, H., Mestre, O., Szentimrey, T., Salinger, J., Førland, E. J., Hanssen-Bauer, I., Alexandersson, H., Jones, P. D., and Parker, D.: Homogeneity adjustments of in situ atmospheric climate data: a review, Int. J. Climatol., 18, 1493–1517 1998.

Reeve, M. A. (2015). Monsoon onset in Bangladesh: reconciling scientific and societal perspectives. Doctoral thesis, University of Bergen.

Rao YP (1976) Southwest monsoon: India Meteorological Department New Delhi.

Wang B, LinHo (2002) Rainy season of the Asian-Pacific summer monsoon. Journal of Climate 15: 386-398.

WMO 2011. Guide to Climatological Practices, Vol.100.World Meteorological Organization Geneva, Switzerland

All appendices (pages 80-323) are available at the website.