



Rainfall and Temperature Characteristics in the Coastal Zones of Bangladesh and West Bengal, India

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Climate is one of the most important factors in agricultural production and livelihoods of the coastal zone of Bangladesh and the bay of West Bengal, India. In this study, nearly 40 years (1970 – 2017) of historical rainfall and temperature data from six weather stations located in the coastal zone were analysed to assess their key characteristics influencing crop growth and yield. The results revealed that the rainfall in the coastal zone varied both spatially and seasonally. The total annual rainfall generally increased from the west to east and from north to south, resulting in rainfall difference up to 1000 mm year⁻¹. In addition to spatial variations, the rainfall varied seasonally, with the wettest 25% of days during the wet season contributing to more than 70% of the annual total precipitation. Heavy rainfall (> 40 mm day⁻¹) was found to occur in the dry season (from December to February), including around the sowing time of *rabi* crops, resulting in a risk of waterlogging. Daily temperature and rainfall were also investigated to detect linear trends over the 40-year period. Maximum temperature was found to have increased at five weather stations with an average rate of 0.04°C year⁻¹ except at Canning, West Bengal showing that the coastal zone has been experiencing hotter and longer summers. The rainfall behaviour was more varied, although it exhibited a general increase in the recent decade.

(**Key words:** Coastal areas, Extreme events, Rabi season, Rainfall, Temperature)

The focus of the special issue in agriculture of the coastal zone of Bangladesh and West Bengal, India is soil, water and crop management to increase crop production (Bell *et al.*, 2019; Mainuddin *et al.*, 2019). A key objective of the overall research work is to develop strategies for growing dry season crops in an area where it is not practiced traditionally. The success of growing dry season crops depends partly on the weather as too much rain around sowing may lead to waterlogging and failure of seedlings; whereas, modest rain at sowing or at other times in the dry season is beneficial for crop growth and yield realization. The various experimental trials described elsewhere on this subject, of course, subject to the vagaries of the weather, but may not give a representative picture of the prospects for crop growth and yield. The intention of this study is to understand variations in temperature and rainfall and enhance the value of the experimental trials by assessing the extent to which the historic weather patterns in the coastal region might help or constrain crop growth and yield. A comprehensive knowledge on weather data will not

only help in updating the crop calendar but also help farmers in increasing crop yields, minimise crop failures and equip them in adapting to erratic weather patterns and natural disasters triggered by global warming and climate change.

A number of studies found to examine the historic climate of the region, particularly focussing on trends in rainfall and temperature (Tables 1 and 2). Some researchers examined extreme events such as droughts (Shahid and Behrawan, 2008) and extreme rainfall (Sultana and Roni, 2015). Studies of historical temperature and rainfall trends in the region observed that the average temperature has increased everywhere (Tables 1 and 2), this is also generally true for maximum and minimum temperatures, and in different seasons (Islam and Neelim, 2010; Shahid *et al.*, 2012; Mondal *et al.*, 2013; Shahid *et al.*, 2014). However these studies do not yield a single, consistent picture with respect to rainfall (Tables 1 and 2), though several studies (Shahid and Khairulmaini, 2009; Shahid, 2010, 2011; Mondal *et al.*, 2013; Rahman *et al.*, 2017) agree that rainfall has increased in the coastal region. The differences in the

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Table 1. Climate studies in Bangladesh

Area studied	Period studied	Main findings	Reference
SW coastal Bangladesh	1948-2010	Temperature increases. Rainfall increases, both in magnitude and number of rainy days.	Mondal <i>et al.</i> (2013)
SW coastal Bangladesh	1948-2007	Rainfall increases.	Hossain <i>et al.</i> (2014)
Coastal Bangladesh	1966-2014	Khulna has large risk of having extreme rainfall in the next 10, 20, 50 and 100 years return periods.	Sultana and Roni (2015)
Western Bangladesh	1961-1999	Western Bangladesh including the coastal zone is prone to moderate to severe droughts.	Shahid and Behrawan (2008)
Whole of Bangladesh	Up to 2007	Temperature increases in coastal zone. No temperature increases or even decreases in northwest. No significant rainfall trends are found.	Islam and Neelim (2010)
Whole of Bangladesh	1958-2007	Rainfall increases in annual and pre-monsoon. The number of wet months increases.	Shahid (2010) and Shahid (2011)
Whole of Bangladesh	1969-2003	Rainfall increases in coastal zone and NW and decreases in central regions.	Shahid and Khairulmami (2009)
Whole of Bangladesh	1961-2008	Temperature increases.	Shahid <i>et al.</i> (2012)
Whole of Bangladesh	1954-2013	Diurnal temperature range increases in SE and decrease in north. No significant trends in rainfall are found.	Rahman <i>et al.</i> (2017)
Whole of Bangladesh	1975-2014	Rainfall increases in coastal regions and decreases in NE.	Hossain <i>et al.</i> (2017)
Whole of Bangladesh	1958-2007	Rainfall decreases and shifts to post-monsoon. Temperature increases.	Shahid <i>et al.</i> (2014)
Whole of Bangladesh	1958-2007	Rainfall increases in north only.	Sultana and Roni (2015)
Whole of Bangladesh	1980-2011	Extreme rainfall events increase, and consecutive dry days decrease. Precipitation concentration varies by region, period of year and has changed over recent decades.	Mondol <i>et al.</i> (2018)

Table 2. Climate studies in West Bengal, India

Sagar Island, West Bengal	1982-2010	decreasing rainfall trend in Sagar Island of Sundarbans	Mandal <i>et al.</i> (2013)
Sagar Island, West Bengal	1891-1970	During 80 years the average daily temperature increased 0.1°C at Sagar island in Sundarbans	WWF-India (2010)
Sundarbans, West Bengal	1966-2015	No change in total annual rainfall but decreasing trend in number of rainy days in recent decades.	Mandal <i>et al.</i> (2019)
West Bengal	1901-2000	Increased rainfall in south of West Bengal, though decreases elsewhere	Mukherjee (2017)
West Bengal	1901-2000	Increased rainfall in West Bengal, statistically significant trend in south	Mukhopadhyay <i>et al.</i> (2016)
West Bengal	1901-2016	Increase in dry years after 1990, and increase in rainfall from 2001	Nandargi and Barman (2018)
All India, for each state	1951-2010	No annual temperature trends in West Bengal but winter mean minimum temperature has increased whereas summer mean temperature has decreased. Annual, summer and winter rainfall has increased.	Rathore <i>et al.</i> (2013)

suggested rainfall trends may result from the substantial variability of rainfall, coupled with differences in the periods and areas studied.

Whereas, the studies noted above give a reasonable picture of the climate trends over Bangladesh and West Bengal as a whole, and to some extent the coastal region in particular, but they generally do not address some of the climate characteristics critical for increasing cropping intensity in the coastal zone. None of the studies examine the likelihood of heavy rainfall (which may result in waterlogging and seedling failure) in the sowing period for winter crops. While some of the studies assessed trends of winter rainfall, none was found to assess the likelihood of rainfall in useful quantities (or, conversely, extended dry periods) at critical periods (such as grain filling). Keeping the research gap in mind this study attempts to assess the historic climate in terms of key characteristics of temperature and precipitation for crop growth and yield.

MATERIALS AND METHODS

We examined more than 40 years (1970 - 2017) of historical daily temperature and rainfall data at the six weather stations (Khulna, Mongla, Barishal, Patuakhali, Khepupara in Bangladesh and Canning in West Bengal, India) as shown in Fig. 1. The stations at Khulna and

Mongla, are around the cropping experiment site in Polder 31, Patuakhali and Khepupara are in the vicinity of the sites in Polder 43, and Canning is close to the experiment site on Gosaba Island. Locations and data information of all observatories are listed in Table 3.

In order to evaluate impacts of both small and large amounts of daily rainfall, this study looked into contributions of the different classes of daily precipitation in the coastal area in Bangladesh and West Bengal, India, by assessing the rainfall concentration index. The details of theory and calculation process could be found in Harrison (1983) and Martin-Vide (2004). The accumulated percentages of precipitation (Y), contributed by the accumulated percentage of rainy days (X), was analysed using Eq. 1.

$$X_i = \frac{\sum_1^i n_i}{\sum_1^k n_i} \times 100, \text{ and } Y_i = \frac{\sum_1^i p_i}{\sum_1^k p_i} \times 100, i = 1, 2, \dots, k \dots (1)$$

In the present study, a rainy day is defined as a day with precipitation of at least 1 mm, according to Martin-Vide (2004) and Khatun *et al.* (2016). The daily rainfall during the entire period was classified at an interval of 1 mm. The number of rainy days (n_i) and amount of total rainfall (p_i) were calculated at each class (i). The cumulative percentages of rainy days and precipitation

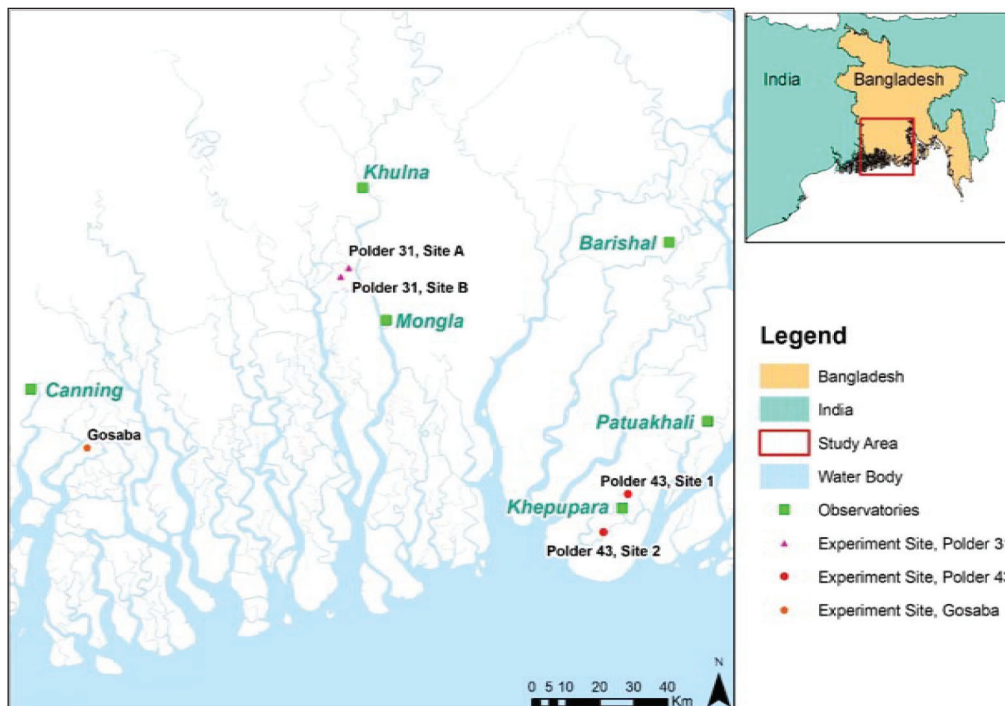


Fig. 1. The field experiment sites and surrounding weather stations in the study coastal area in Bangladesh and West Bengal, India

Table 3. Observatories in coastal zone in Bangladesh and West Bengal

Observatories	Canning	Khulna	Mongla	Barishal	Patuakhali	Khepupara
Division	West Bengal	Khulna	Khulna	Barishal	Barishal	Barishal
Latitude (N)	22°18′	22°47′	22°28′	22°43′	22°20′	21°50′
Longitude (E)	88°40′	89°34′	89°36′	90°22′	90°20′	90°41′
Elevation (m)	3.5	2.1	1.8	2.1	1.5	1.8
Data Start	1966	1974	1991	1949	1973	1974
Data End	2017	2017	2017	2017	2017	2017

were calculated and fitted into an exponent function (Eq. 2) at each station,

$$Y = aX \exp(bX), 0 \leq X \leq 100 \text{ and } 0 \leq Y \leq 100 \dots(2)$$

where k denotes the maximum class, a and b are the constant coefficients of exponential functions. To describe the irregularity of rainfall distribution, the rainfall concentration index, CI, was calculated for each observatory as follows (Eq. 3).

$$CI = \frac{5000 - \int_0^{100} Y dX}{5000} \dots(3)$$

Large amounts of daily rainfall usually result in water logging. Therefore, it is virtually important to accurately evaluated exceedance probabilities and returning periods of extreme rainfall events to inform risk-based crop and water management practices. Extreme rainfall probabilities and their return periods were calculated using Eqs. 4 and 5, by applying Weibull's ranking method (Rao, 1985; Khan and Mainuddin, 1991),

$$\text{Exceedance probability} = \frac{m}{M + 1} \dots(4)$$

$$\text{Return period} = \frac{1}{\text{probability}} \dots(5)$$

where M is the total number of observations to be considered and m is the rank of an observation.

To further investigate the variations in extreme weathers in long term, 27 climate indices of different climate parameters, such as annual maximum temperature and rainfall and annual longest dry period, were computed using software RClimDex designed by Climate Research Division, Canada (<http://etccdi.pacificclimate.org/index.shtml>). Here we focus on nine indices which are listed in Table 4. Based on the daily precipitation over the last 40 years, the variation in trends was detected and the significance was tested.

Table 4. Definition of extreme air temperature and precipitation indices applied in this study

Indices	Definition	Unit
TMAXmean	Annual average of monthly maximum value of daily maximum temperature	°C
TMINmean	Annual average of monthly minimum value of daily minimum temperature	°C
SU25	Annual count of days when daily maximum temperature > 25°C	days
DTR	Monthly mean difference between daily maximum and minimum temperature	°C
RX1day	Monthly maximum 1-day precipitation	mm
RX5day	Monthly maximum consecutive 5-day precipitation	mm
PRCptot	Annual total precipitation in wet days with precipitation >= 1 mm	mm
CDD	Annual maximum number of consecutive days with precipitation < 1 mm	days
CWD	Annual maximum number of consecutive days with precipitation >= 1 mm	days

RESULTS AND DISCUSSION

Basic climatic conditions of the six stations are summarised in Table 5. For all the stations together, the annual mean daily maximum and minimum temperatures were around 30.8°C and 22.0°C, respectively, with small coefficients of variation, indicating similar warm weather across the region.

Annual precipitation and concentration

The annual precipitation was found varied spatially, which is decreasing from more than 2000 mm in the east (Khepupara and Patuakhali) to 1800 mm in the west (Canning). Similar spatial variation was found in the number of rainy days, changing from 123 days in the east to 100 days in the west. This implies that the eastern part of the coastal region generally experiences longer

Table 5. Basic temperature and rainfall conditions in coastal zones

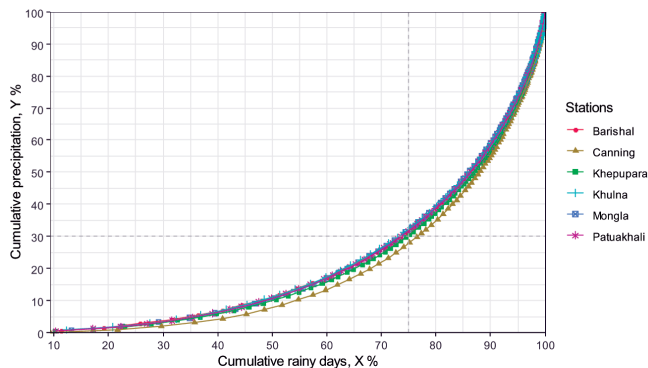
Observatory		Canning	Khulna	Mongla	Barishal	Patuakhali	Khepupara
Study Periods		1966-2017	1974-2017	1991-2017	1949-2017	1973-2017	1974-2017
Annual mean daily maximum temperature (°C)	Mean	30.9	31.3	31.1	30.5	30.7	30.5
	CV %	1.08	1.44	1.13	1.38	1.82	1.73
Annual mean daily minimum temperature (°C)	Mean	21.9	21.9	22.5	21.4	22	22.2
	CV %	2.16	2.26	1.56	2.09	1.56	1.28
Annual total rainfall (mm)	Mean	1833	1853	1962	2112	2643	2783
	CV %	19.08	17.6	17.29	19.74	17.58	14.22
Annual numbers of rainy days (count)	Mean	100	112	120	122	123	123
	CV %	11.74	12.41	6.78	21.96	12.57	10.58

and wetter rainy periods. In addition, lower latitudes were found to have larger amounts of total precipitation, as seen by comparing Khepupara with Patuakhali, and Mongla with Khulna. Overall, the precipitation generally increased from west to east, and from north to south (1853 mm in Khulna and 2783 mm in Khepupara) within the study area.

Although the annual rainfall varied spatially, a similar rainfall distribution structure was found at all six stations. The curves of accumulated percentages of precipitation, Y , contributed by the accumulated percentage of rainy days, X , are shown in Fig. 2. The maximum and minimum concentration indices, CI , are 0.66 at Canning and 0.61 at Mongla, respectively. Fig. 2 shows that the wettest 25 percent of days (equivalent to the 75th percentile of cumulative rainy days) contributed about 70% of precipitation at all stations. Thus, heavy to extremely heavy rainfall events make a large contribution to total rainfall.

Extreme rainfall events

The annual cumulative precipitation (from the 1st Dec to 30th Nov) between 1998 and 2017 for all stations

**Fig. 2.** Concentration curves of cumulative rainfall in the coastal zones

is shown in Fig. 3. Little precipitation occurs during December to February, which is the *rabi* season. The precipitation is comparatively higher between March and September, with average slopes of approximately $15 \text{ mm per day}^{-1}$ at Khepupara and Patuakhali, and 11 mm day^{-1} for the other stations. The total annual precipitation can reach up to 2000 mm at Canning in the west and 3000 mm at Khepupara in the eastern coastal region. The annual rainfall differed in different five-year periods, with the period 2008-2012 being the driest at all stations, with a reduction of about 20% compared to other three periods. The reduction is attributed to reductions of extreme rainfall events during that period. The 10-year moving averages of annual maximum 5-day precipitation are shown in Fig. 4. An average of 28% reduction in annual maximum 5-day precipitation was found in the south of the coastal zone (Canning, Patuakhali and Khepupara) between 2010 and 2017, which again indicates the reductions of extreme rainfall events in the recent years.

Fig. 4 shows three other features of extreme rainfall events. The most significant events were observed at Khepupara, which recorded maximum precipitation more than 450 mm in 5 consecutive days. At Patuakhali, maximum precipitation up to 400 mm was recorded in 5 days. The extreme events occurred at the other stations were from 250 to 300 mm.

Return periods of extreme rainfall events at observatories with $R^2 > 0.95$ in K-S tests are shown in Fig. 5. At a return period of 5 years, one-day maximum precipitation was generally larger than 150 mm. Extreme one-day precipitation reaches approximately 230 mm day^{-1} in the west and 350 mm day^{-1} in the east at a return period of 100 years.

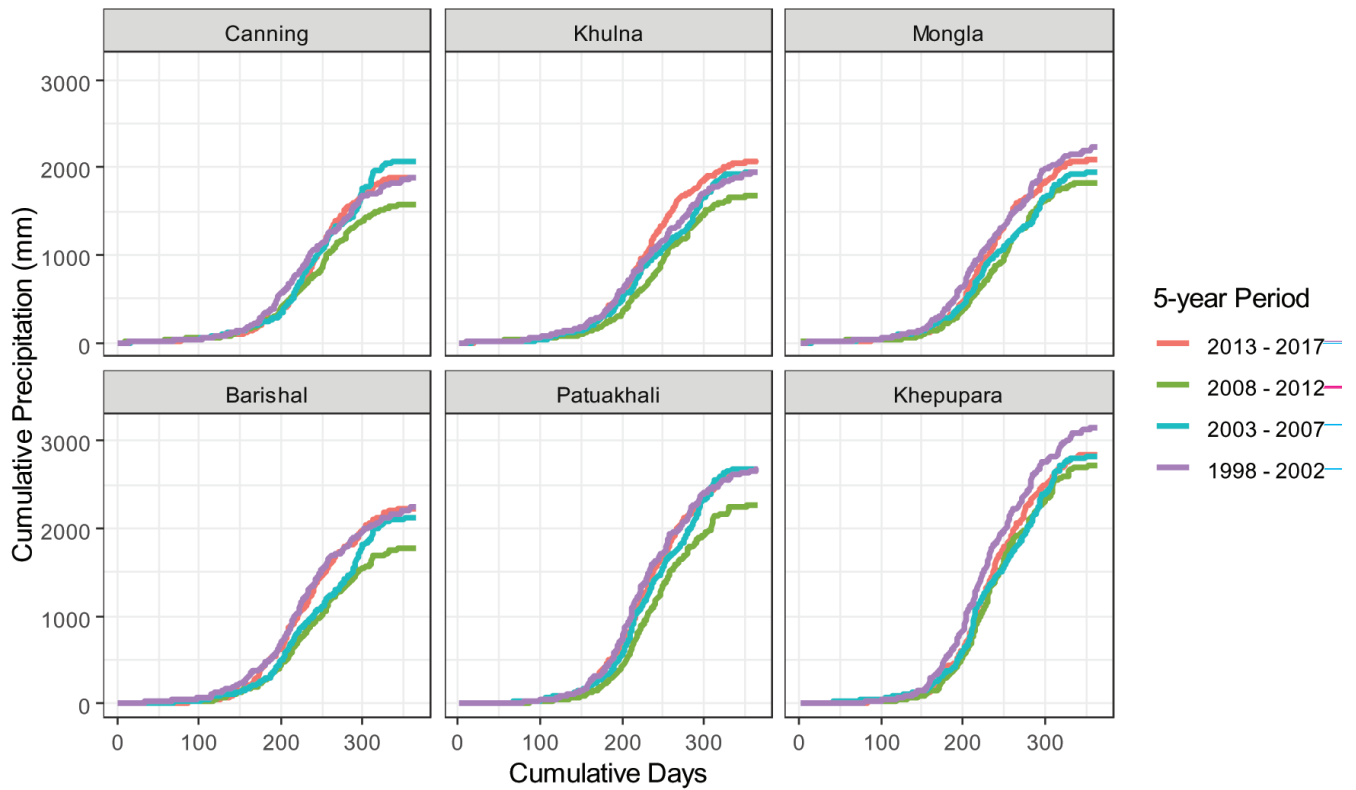


Fig. 3. 5-year average of annual cumulative precipitation at 6 observatories between 1998 and 2017

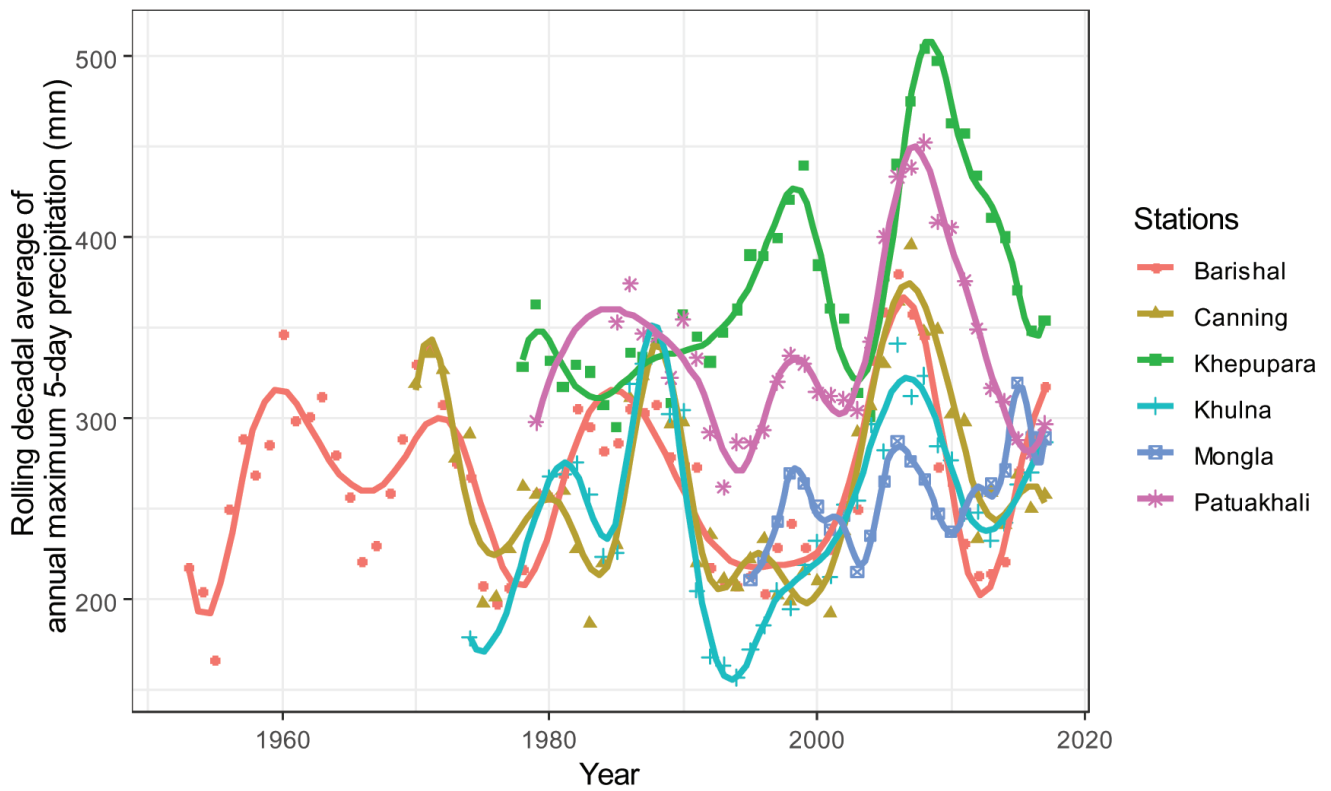


Fig. 4. Rolling decadal average of annual maximum precipitation for 5 consecutive days at 6 observatories

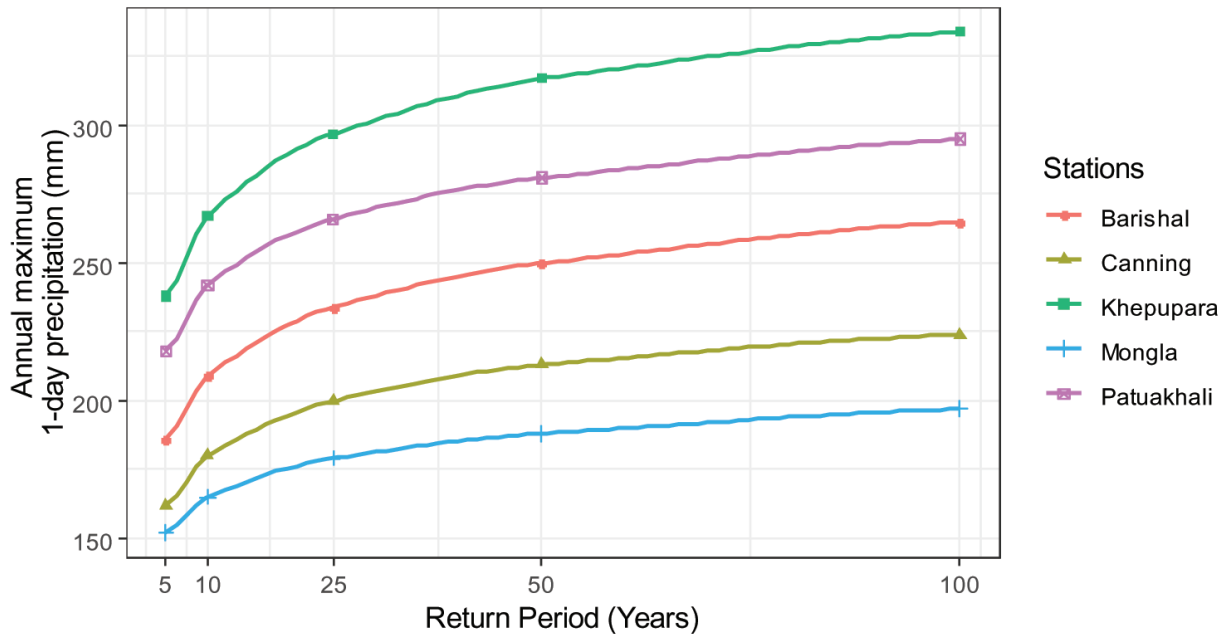


Fig. 5. Return periods at 5 observatories in the coastal zones

The occurrence of heavy rainfall also varies significantly during different seasons. The monthly minimum and maximum rainfalls were 0 and 254 mm, respectively, in the study area from December to March, during the *rabi* season crop growing period. The exceedance probabilities of precipitation over a year was summarised in Fig. 6. The probability of receiving at least 10 mm day⁻¹ was less than 25% in December and January. There was also small chance (< 10%) of very high rainfall during this period. In contrast, extreme

event as large as 50 mm day⁻¹ rainfall occurs with a probability of 75 % during the monsoon season.

Rainfall events during the *rabi* season

Depending on the seasonal distribution, quantity and timing, rainfall either contributes beneficially to agricultural production through reduced demand of irrigation and increased yield, or negatively through increased risks of crop waterlogging. Based on the long-term rainfall records, it is evident that some

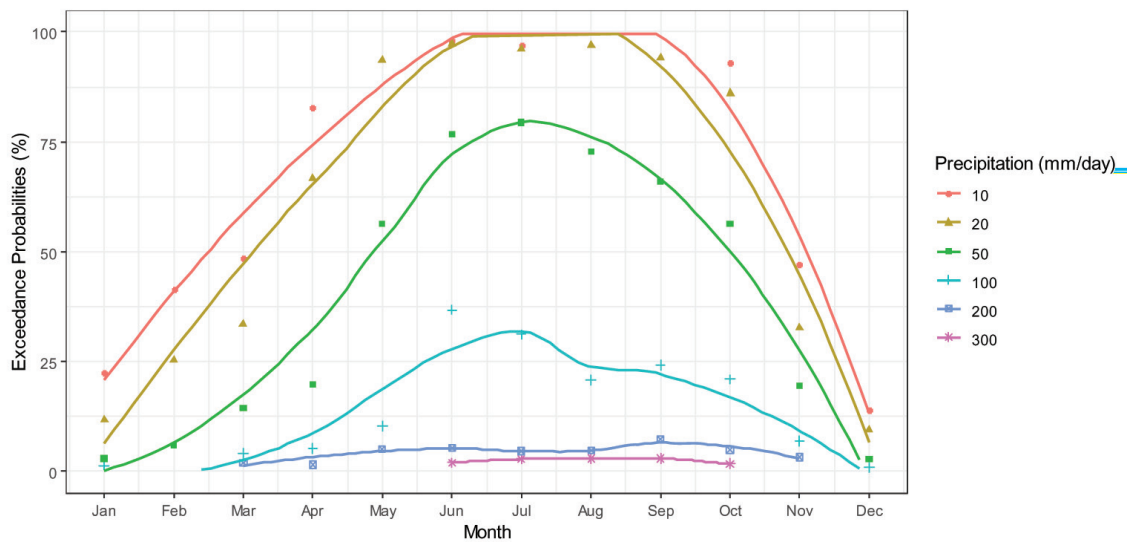


Fig. 6. Exceedance probability in each month in the coastal zones

sudden heavy rainfalls have occasionally taken place during the *rabi* season in the recent years, which might have negative effects on crop production. Fig. 7 shows 10-day accumulated quantity and timing of sudden heavy rainfall at all observatories between December and February over the last two decades. The 10-day accumulated precipitation was generally less than 50 mm in December, but could reach approximately 100 mm in January and February. Occurrences of sudden heavy rainfall increased in the early January during the decade 2008-2017, compared to the previous decade. In addition to quantity and timing of sudden rainfalls, it was also found that despite being the driest location, Canning may receive some of the heaviest sudden rainfall during the *rabi* season, such as 30 mm in the mid December and early January, 75 mm in the late January, 90 mm in the late February. Notwithstanding the heavier sudden rainfall, Canning also experienced longer drought periods than the other stations. It can be seen from Fig. 8 that the median drought periods (consecutive dry days) lasted approximately 80 days, with the 75th quantile of 100 days, and a maximum value of 150 days in Canning.

Linear trends in long term

The annual trends of extreme indices of temperature and rainfall are shown in Table 6. The highlighted numbers are statistically significant trends ($p < 0.05$). Annual average daily maximum temperature increased

at all stations, with average rates of $0.01^{\circ}\text{C year}^{-1}$ at higher latitudes (Khulna and Barishal) and $0.028^{\circ}\text{C year}^{-1}$ or more at lower latitudes (Mongla, Patuakhali and Khepupara). This finding is consistent with that of other studies (Islam and Neelim, 2010; Shahid *et al.*, 2012; Mondal *et al.*, 2013). The trend was statistically significant at all stations except Canning. Though globally there was increasing trend in air temperature, there was no change in air temperature observed at Canning may be because there was also a decreasing trend of sunshine hour in the region. That might be responsible for compensation of the increasing behaviour of air temperature (Mandal *et al.*, 2019). Stations at lower latitudes in the east, Khepupara and Patuakhali, have longer summer seasons (SU25), increasing at a rate of $0.35 \text{ days year}^{-1}$, and their ranges of daily temperature (DTR) are also rising at $0.03^{\circ}\text{C year}^{-1}$, indicating a large temperature difference over a day.

In contrast to the trends of increasing temperature, trends in precipitation are less uniform and generally less significant statistically in the study area. At Khepupara, the maximum 5-day accumulated precipitation (RX5DAY) and total precipitation (PRCptot) both show increasing trends with statistical significance. However, there were no similar long-term trends at other places in the coastal zone. Several other studies found increasing rainfall (Shahid and Khairulmaini, 2009; Shahid, 2010, 2011; Mondal *et al.*, 2013; Rathore *et al.*, 2013; Hossain *et al.*, 2014; Mukhopadhyay

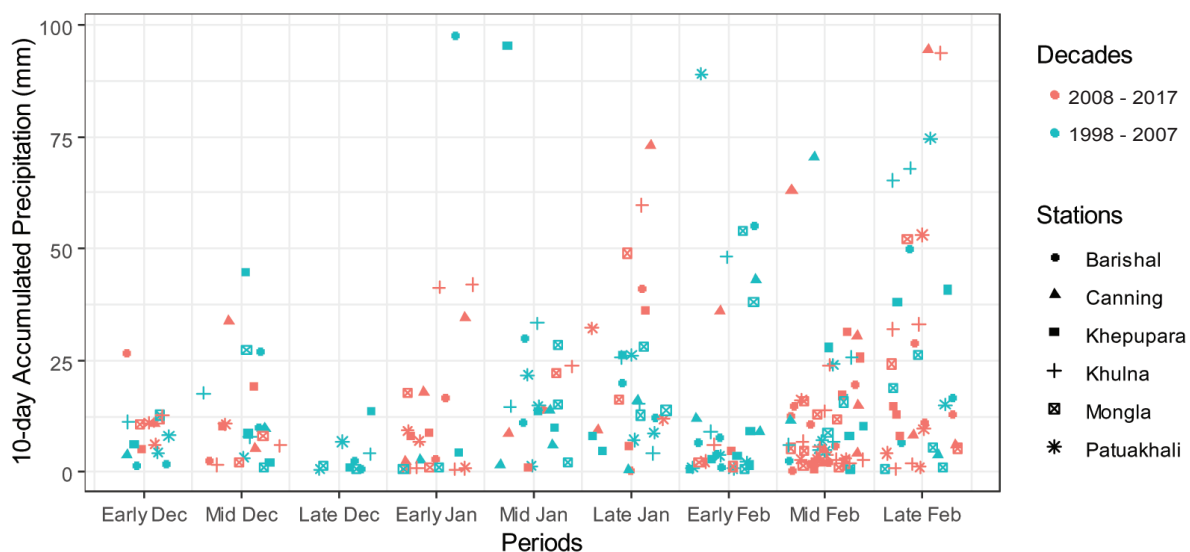


Fig. 7. Sudden rainfall events during the *rabi* seasons over the last two decades

Table 6. Annual trends of the extreme indices of temperature and rainfall in coastal zones

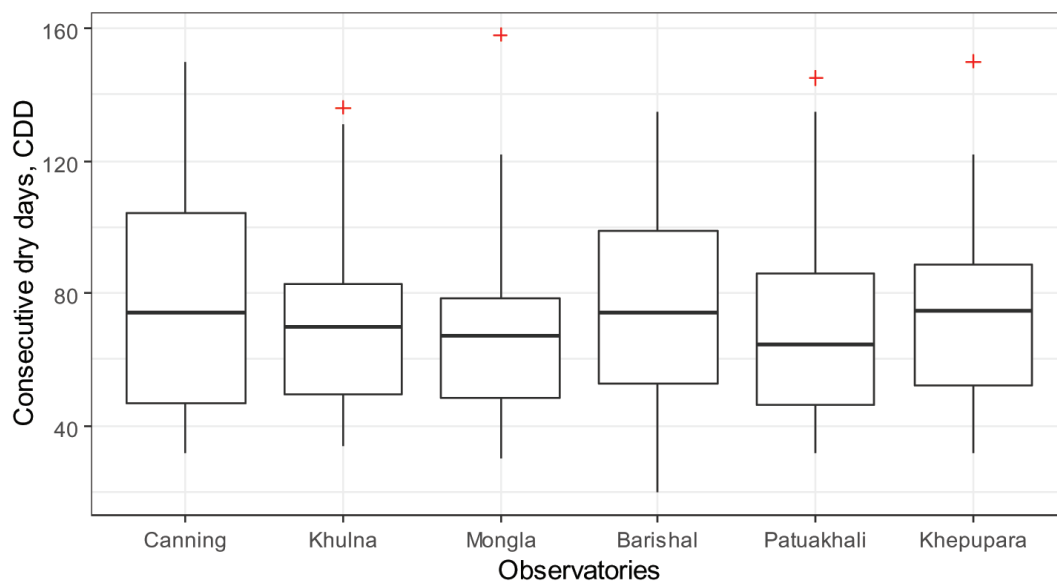
		Canning	Khulna	Mongla	Barishal	Patuakhali	Khepupara
Temperature Indices	TMAXmean	0.01	0.01	0.03	0.01	0.04	0.04
	TMINmean	0.01	0	0	0	0.01	0.01
	SU25	-0.21	-0.05	0.04	0.00	0.34	0.35
	DTR	0.00	0.01	0.03	0.01	0.03	0.03
Rainfall Indices	RX1DAY	0.19	-0.22	0.09	0.22	-0.79	0.56
	RX5DAY	-0.04	0.55	3.02	0.38	-0.25	3.10
	CDD	-0.31	0.58	1.15	-0.11	0.62	0.42
	CWD	-0.03	0.09	0.22	-0.42	0.08	0.10
	PRCptot	-0.88	2.01	10.12	-0.96	-7.59	9.65

et al., 2016; Mukherjee, 2017; Rahman *et al.*, 2017), but some found that there was no significant trend in rainfall (Islam and Neelim, 2010; Shahid *et al.*, 2014), or that there was a decrease in rainfall accompanied by shift in the timing of rainfall (Hossain *et al.*, 2017). However, many of the studies referred to, while encompassing the coastal zone, covered a wider region such as the whole of Bangladesh or West Bengal. Overall, both annual maximum precipitation and daily temperature generally increased over the years in the coastal zone, as shown in Fig. 9, associated with longer durations of consecutive wet period.

Climate is one of the most important factors in crop production. Spatial and temporal variations in precipitation and temperature in the coastal zone were

investigated to update the current knowledge, which may in turn beneficially contribute to agricultural management in coastal zones.

It was found that precipitation exhibits spatial and seasonal variations in the coastal zone. The total precipitation generally increased from the west to east, and from the north to south. Khepupara received the largest amounts of rainfall, comparing with the other 5 locations. Although the occurrence of extreme rainfall events reduced during the monsoon in the recent years, some sudden heavy rainfall events took place during the *rabi* season, particularly in the early January and late February. The annual precipitation generally increased, associated with longer and wetter summers. The investigation of long-term trends of climate condition

**Fig. 8.** Annual maximum consecutive dry days at 6 observatories

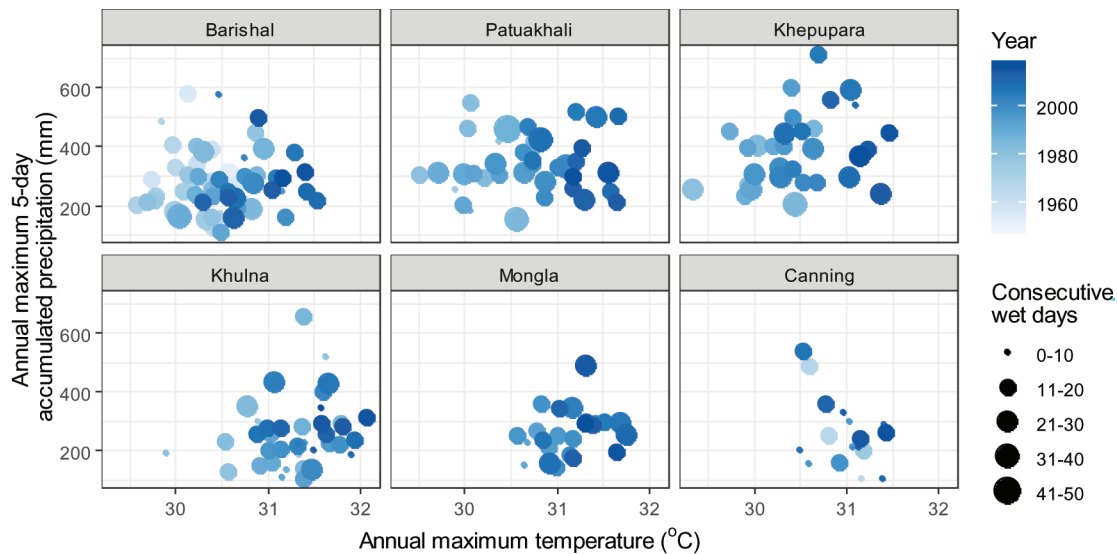


Fig. 9. Annual maximum 5-day accumulated precipitation, temperature and the longest consecutive wet days of the year at 6 places in the coastal zone

indicated that the maximum temperature has been rising at a rate of $0.04^{\circ}\text{C year}^{-1}$, while no statistically significant rainfall trends have been found throughout the coastal zone implying that rainfall behaviour is more varied.

Increased annual rainfall can reduce the pressure on groundwater for irrigation, particularly in the southeast coast that has longer and wetter rainy periods, comparing with the rest of coastal area. The drought vulnerability in the western coastal region, such as Canning, may increase due to its longer drought periods and relative less amount of rainfall with comparison to other places. In addition, increased possibility of sudden heavy rainfalls during the *rabi* season may impact the sowing date and crop growth due to failure of seedling and a risk of water logging.

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REFERENCES

- Bell, R. W., Mainuddin, M., Barrett-Lennard, E. G., Sarangi, S. K., Maniruzzaman, M., Brahmachari, K., Sarker, K. K., Burman, D., Gaydon, D. S., Kirby, J. M., Glover, M., Rashid, M. H., Khan, M. S. I., Kabir, M. E., Rahman M. A. and Hossain, M. B. (2019). Cropping systems intensification in the coastal zone of the Ganges delta: opportunities and risks. *Journal of the Indian Society of Coastal Agricultural Research* **37**(2): 153-161.
- Harrison, M. S. J. (1983). Rain day frequency and mean daily rainfall intensity as determinants of total rainfall over the eastern Orange Free State. *Journal of Climatology* **3**: 35-45.
- Hossain, M. M., Hasan, M. Z., Alauddin, M. and Akhter, S. (2017). Historical and future rainfall variations in Bangladesh. *International Journal of Environmental and Ecological Engineering* **11**: 694-699.
- Hossain, M. S., Roy, K. and Datta, D. K. (2014). Spatial and temporal variability of rainfall over the south-west coast of Bangladesh. *Climate* **2**: 28-46; doi:10.3390/cli2020028.
- Islam, T. and Neelim, A. (2010). *Climate Change in Bangladesh: A Closer Look into Temperature and Rainfall Data*, The University Press Limited, Dhaka, Bangladesh.
- Khan, M. B. R. and Mainuddin, M. (1991). Some probability aspects of rainfall in Gazipur. *Bangladesh Journal of Agriculture* **16**: 61-70.
- Khatun, M. A. Rashid, Md. B. and Hygen, H. O. (2016). *Climate of Bangladesh*, Met report No. 08/2016,

Norwegian Meteorological Institute, Norway.

- Mainuddin, M., Bell, R.W., Gaydon, D. S., Kirby, J. M., Barrett-Lennard, E. G., Glover, M., Razzaque Akanda, M. A., Maji, B., Ansar Ali, M., Brahmachari, K., Maniruzzaman, M., Aziz, M. A., Burman, D., Biswas, J. C., Rahman, M. M. and Sarangi, S. K. (2019a). An overview of the Ganges coastal zone: climate, hydrology, land use, and vulnerability. *Journal of the Indian Society of Coastal Agricultural Research* **37**(2): 1-11.
- Mandal, S., Choudhury, B. U., Mandal, M. and Bej, S. (2013). Trend analysis of weather variables in Sagar Island, West Bengal, India: a long-term perspective (1982-2010). *Current Science* **105**(7): 947-953.
- Mandal, U. K., Nayak, D. B., Mullick, S., Samui, A., Jana, A. K., Mahanta, K. K., Raut, S., Roy, S. and Burman, D. (2019). Trend analysis of weather parameters over Indian Sundarbans. *Journal of Agrometeorology* **21**(3): 307-315.
- Martin-Vide, J. (2004). Spatial distribution of a daily precipitation concentration index in Peninsular Spain. *International Journal of Climatology* **24**: 959-971.
- Mondal, M. S., Jalal, M. R., Khan, M. S. A., Kumar, U., Rahman, R. and Huq, H. (2013). Hydro-meteorological trends in southwest coastal Bangladesh: perspectives of climate change and human interventions. *American Journal of Climate Change* **2**: 62-70. <http://dx.doi.org/10.4236/ajcc.2013.21007>.
- Mondol, M. A. H., Al-Mamun, Iqbal, M. and Jang, D. H. (2018). Precipitation concentration in Bangladesh over different temporal periods. *Advances in Meteorology*, Article ID 1849050, 18 pages, <https://doi.org/10.1155/2018/1849050>
- Mukherjee, K. (2017). Trend analysis of rainfall in the districts of West Bengal, India, a study for the last century. *Journal of Engineering Computers & Applied Sciences* **6**(1): 1-13.
- Mukhopadhyay, S., Kulkarni, S., Kulkarni, P. and Dutta, S. (2016). Rainfall statistics change in West Bengal (India) from period 1901-2000. In: *Geostatistical and Geospatial Approaches for the Characterization of Natural Resources in the Environment: Challenges, Processes and Strategies*, N. Janardhana Raju (ed.) Springer, Cham, Switzerland and Capital Publishing Company, New Delhi, India. pp 173-182.
- Nandargi, S. S. and Barman, K. (2018). Evaluation of climate change impact on rainfall variation in West Bengal. *Acta Scientifica Agriculture* **2**(7): 74-82.
- Rahman, M. A., Yunsheng, L. and Sultana, N. (2017). Analysis and prediction of rainfall trends over Bangladesh using Mann-Kendall, Spearman's rho tests and ARIMA model. *Meteorology and Atmospheric Physics* **129**: 409-424.
- Rao, C. R. (1985). Weighted distribution arising out of methods of ascertainment: what population does a sample represent. In: *A Celebration of Statistics: The ISI centenary Volume*, A. C. Atkinson and S. E. Fienberg (eds.), Springer-Verlag, New York.
- Rathore, L. S., Attri, S. D. and Jaswal, A. K. (2013). *State Level Climate Change Trends in India*. Meteorological Monograph No. ESSO/IMDEMRC/02/2013, India Meteorological Department, New Delhi, India.
- Shahid, S. (2010). Rainfall variability and the trends of wet and dry periods in Bangladesh. *International Journal of Climatology* **30**(15): 2299-2313.
- Shahid, S. (2011). Trends in extreme rainfall events of Bangladesh. *Theoretical and Applied Climatology* **104**: 489-499.
- Shahid, S. and Behrawan, H. (2008). Drought risk assessment in the western part of Bangladesh. *Natural Hazards* **46**: 391-413.
- Shahid, S., Harun, S. and Katimon, A. (2012). Changes in diurnal temperature range in Bangladesh during the time period 1961-2008. *Atmospheric Research* **118**: 260-270.
- Shahid, S. and Khairulmaini, A. S. (2009). Spatio-temporal variability of rainfall over Bangladesh during the time period 1969-2003. *Asia Pacific Journal of Atmospheric Sciences* **45**: 375-389.
- Shahid, S., Wang, X. and Harunm S. B. (2014). Unidirectional trends in rainfall and temperature of Bangladesh, Proceedings FRIEND-Water 2014

- Conference on *Hydrology in a changing world: environmental and human dimensions*, October 7-10, 2014, Montpellier, France. IAHS Publ. 363, 2014. pp 177-182. <https://iahs.info/uploads/dms/16587.33-177-182-363-28-Paper-154-ShahidR1.pdf>.
- Sultana, N. and Roni, R. (2015). Rainfall modelling of coastal areas in Bangladesh: Extreme-value approach. *Journal of Science, Technology & Environment Informatics* 2(2): 42-50.
- WWF-India (2010). *Sundarbans: Future Imperfect*. Climate Adaptation Report. A. Danda (Ed.), WWF India, New Delhi, India. pp 1-29.