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FORECASTING OF RAINFALL AND TEMPERATURE BASED ON THE ANALYSIS OF HISTORICAL DATA AND FUTURE IMPACTS

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Abstract
In this paper, temperature and rainfall data series were analyzed from 34 meteorological stations distributed throughout Bangladesh over 40 years (1971 to 2010) to evaluate the magnitude of these changes statistically and spatially. Linear regression, coefficient of variation, inverse distance weighted interpolation techniques, and geographical information systems were performed to analyze the trends, variability, and spatial patterns of temperature and rainfall. Auto-regressive integrated moving average time series model was used to simulate the temperature and rainfall data. The results confirm a particularly strong and recent climate change in Bangladesh with a 0.20 °C per decade upward trend of mean temperature. The highest upward trend in minimum temperature (range of 0.80–2.4 °C) was observed in the northern, northwestern, northeastern, central, and central southern parts while the greatest warming in the maximum temperature (range of 1.20–2.48 °C) was found in the southern, southeastern, and northeastern parts during 1971–2010. An upward trend of annual rainfall (+7.13 mm per year) and downward pre-monsoon (−0.75 mm per year) and post-monsoon rainfall (−0.55 mm per year) trends were observed during this period. Rainfall was erratic in the pre-monsoon season and even more so during the post-monsoon season (variability of 44.84 and 85.25 % per year, respectively). The mean forecast temperature exhibited an increase of 0.018 °C per year in 2011–2020, and if this trend continues, this would lead to approximately 1.0 °C warmer temperatures in Bangladesh by 2020, compared to that of 1971. A greater rise is projected for the mean minimum (0.20 °C) than the mean maximum (0.16 °C) temperature.

Annual rainfall is projected to decline 153 mm from 2011 to 2020, and a drying condition will persist in the northwestern, western, and southwestern parts of the country during the pre-and post-monsoonal seasons.

Keywords: Climate change, Temperature. Rainfall. Trends. Variability. GIS, Rainfall forecast, climate change, regional climate model, simulation, calibration, validation, Bangladesh

Introduction

Like many other countries, Bangladesh will face tremendous challenges from climate change (Huq et al. 1999, Karim et al. 1999). Climate change refers to a change in the state of the climate that can be identified (e.g., using statistical tests) by changes in the mean or the variability of its properties, which persists for an extended period, typically decades or longer (IPCC 2014). The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization (WMO). Agriculture and water are the most vulnerable sectors to climate change which can lead to floods, droughts, tornadoes, cyclones (Ali et al. 1999).

The spatial distribution of meteorological data is becoming important as inputs to spatially explicit landscape, regional, and global models. Spatial technologies, such as geographic information systems (GIS) and numerical modeling techniques, have been developed as powerful tools for ecological and environmental assessments (T Lorentzen, 2014). Within the context of the general climate discussion, the evaluation of climate time series is growing in importance. Predicting weather conditions using previous data is one of the real uses of simulation (Krivtsob et al. 2004, Kumar et al. 2006, Rahman et al. 2007). Numerical weather prediction for forecasting involves complicated numeric computer models to predict the weather accurately by taking many parameters into account.

It is accounted that in the SAARC countries 21% of the world population resides on only 4% of the world's total physical area (Field et al. 2014). In this connection, proper planning and judicious management of water resources are essential for this region. In recent years, Atmosphere-Ocean General Circulation Models (AOGCMs) have been used to predict the climatic consequences of increasing atmospheric concentrations of greenhouse gases. These predictions may be adequate for areas where the terrain is reasonably flat, uniform, and away from coasts.

Projections using the global circulation model (GCM) showing that sea and air temperatures will continue to increase, sea level is rising, intense storms and rainfall will become more frequent. The highest horizontal resolution of any AOGCM published is around 300 km. Yet to assess potential impacts of climate change, regional information at a scale of 100 km or finer (typically around 50 km) is needed. The intergovernmental Panel on Climate Change (IPCC) predicted that Bangladesh was on course to lose 17% of its land and 30% of its food production by 2050 (Rahman et al. 2013). This paper examines the calibration and validation of rainfall climatology in Bangladesh derived from an RCM called Providing Regional Climates for Impact Studies (PRECIS) for the baseline period (1961-1990) and 2000-2006 respectively (Mitchell et al. 2004). Calibration and validation for temperature are also performed along with the forecasting of rainfall and.

Study Area

The spatial extent of Bangladesh is between 20° 34'N to 26° 38'N latitude and 88° 01'E to 92° 41'E longitude (Fig. 1) with an area of 144,000 square km. Bangladesh has a subtropical humid climate characterized by wide seasonal variations in rainfall, moderately warm temperature, and high humidity. Three distinct seasons can be recognized in Bangladesh, (i) the dry winter/post-monsoon season from November to February, (ii) the pre-monsoon hot summer season from March to May, and (iii) the rainy monsoon season from June to October. According to Rahman et al. (2013), the historical average temperature of the country is 25.75 °C, with a range of 18.85 to 28.75 °C (monthly average).

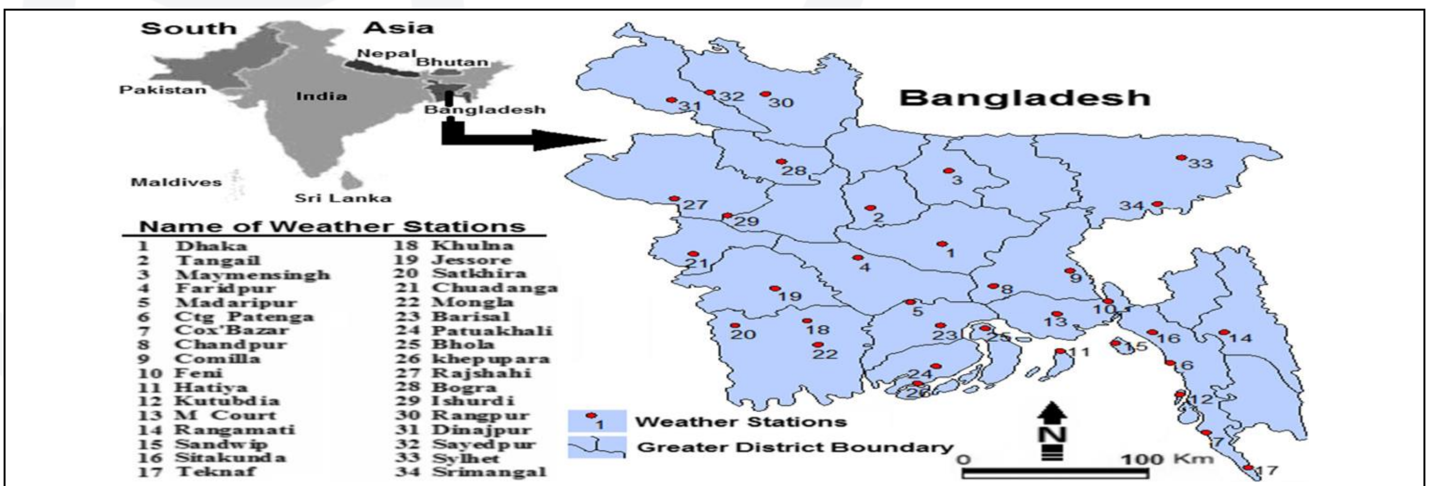


Fig. 1 Study area with location of weather stations

According to Rahman et al. (2017), the average minimum and maximum temperatures are 21.18 and 30.33 °C and vary from 12.5 to 25.7 °C (monthly average) and 25.2 to 33.2 °C (monthly average), respectively. January is the coldest and April and May are the hottest months in Bangladesh (Fig. 2a). The historical average rainfall of the country is 2428 mm per year (BMD 2013). And the rainfall is very much seasonal in Bangladesh (Fig. 2b), which varies from 1400 to 4400 mm.

The highest rainfall occurs in June, July, and August. More than 75% of the total rainfall in Bangladesh occurs during the monsoon season, caused by winds blowing from the Southern Hemisphere from mid-May to September, which accumulates moisture and deposits copious amounts of precipitation over the South Asian continent. Concerning global warming and climate change, Bangladesh is one of the most vulnerable countries in the world due to its least capacity to address the devastating impacts (IPCC 2007).

Data and Methodology

The monthly dataset of the minimum and maximum temperatures and rainfall from 34 stations in Bangladesh during the period 1971–2010 that was used and analyzed in this study was provided by the Bangladesh Meteorological Department (BMD 2013). And the locations of the 34 weather stations are shown in Fig. 1. However, out of 34 weather stations, data from 29 stations was available from the last 40 years while from the remaining five stations, namely Tangail (1987– 2010), Kutubdia (1985–2010), Chuadanga (1989–2010), Mongla (1989–2010) and Sayedpur (1991–2010), data was only available from the past 20 to 26 years (Rahman et al. 2017). Therefore, a shorter series of measurements (20 to 26 years) was used during analysis, and we considered these five stations in our study because no other stations were in those areas.

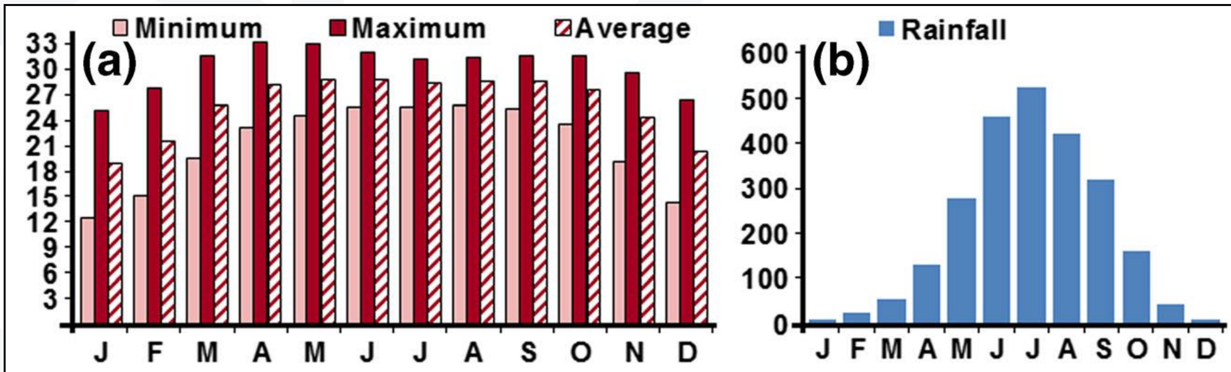


Fig. 2. a) Average temperature (°C) and b) rainfall (mm) of Bangladesh

After processing the data from each station, there was some missing data, which amounted to less than 2 %. When missing data was found, this was replaced by the average value of the same month but from the previous and subsequent years. The data were visually examined using histograms for any potential outliers as well as compared with neighboring weather stations. However, no significant anomalies were found.

Additionally, subjective double mass was performed to test homogeneity of temperature and rainfall time series data. There were no statistically significant variations existing in the time series data. Besides, in 1971, most of the stations have missed a significant number of observed data. Thus, data for the year 1971 was replaced by the data from 1970 in the data set. A linear regression analysis using the least square method was applied to detect any trends in temperature and rainfall time series data and the confidence level of 95%was taken as the threshold.

For trend and variability analysis, Excel software (Excel version 2010) was used. For mapping, the spatial distribution of temperature and rainfall and their trends and variability, geographical information systems (GIS) were applied. In SPSS software, the Expert Modeler automatically finds the best fitting model for each dependent series and considers both seasonal and non-seasonal models. In the process, if independent (predictor) variables are specified, the Expert Modeler selects those that have a statistically significant relationship with the dependent series. Model variables are transformed, where appropriate, using differencing and/or a square root or natural log transformation. ARIMA model involves explicitly specifying auto-regressive and moving average orders, as well as the degree of difference. To validate the model, the first 30 years of observed data (1971–2000) was used to forecast the temperature and rainfall for the decade of 2001–2010 and then the forecasted values were compared with the actual observed values for the decade of 2001–2010. After validation and acceptance, finally, the temperature and rainfall were forecasted for the decade 2011–2020 using the validated model.

Result and Discussion

This chapter discusses the detailed result found from the analysis for temperature, and rainfall. Forecasting on future scenarios of weather is shown with the Geographical Information System. Besides, these results were compared with the earlier literature published by several researchers.

Based on the findings, possible impact is assessed highlighting on Land Area and population.

Trends of temperature

From the last 40 years (1971–2010), weather data analysis shows that the annual mean, mean minimum, and mean maximum temperatures of Bangladesh were 25.83, 21.21, and 30.44 °C, respectively. The obtained annual mean, mean minimum, and mean maximum temperatures showed a positive trend of about 0.020, 0.018, and 0.022 °C per year, respectively. These results differ from those of Jones (1995), Ahmad and Warrick (1996), Shahid (2010), and Met Office Hadley Centre (Met Office 2011).

Jones (1995) found no significant change in the annual mean minimum and mean maximum temperatures of Bangladesh, while Ahmad and Warrick (1996) mentioned that the trend of the mean temperature of Bangladesh was 0.5 °C over 100 years (0.005 °C per year). Shahid (2010) found that the mean, mean minimum and mean maximum temperatures increased by 0.0097, 0.0091, and 0.0102 °C per year, respectively, in the last 50 the surface air temperature in Bangladesh has warmed at a rate of 0.002, 0.007, and 0.012 °C per year for the annual, June–August (JJA), and September–November (SON) months, respectively.

Since 1960, the mean temperature trend was positive during both the summer and winter seasons in Bangladesh at 0.019 and 0.024 °C per year, respectively. The rate of change of temperature was more accelerated in the last 30 years (Table 1). The changing rate of the maximum temperature was higher than that of the minimum temperature (0.022 vs. 0.018 °C per year for 1971– 2010). Therefore, recent data analysis is likely a key issue to find out the valid trends of the climatic parameters. The spatial pattern of temperature trend is shown in Fig. 3, which was generated using calculated trend statistics for the 34 weather stations, IDWand GIS. As seen in Fig. 3, all the weather stations presented a positive trend, except at the Rangamati and Sitakunda stations for the mean minimum and the Mymensingh station for the mean maximum temperature.

The spatial pattern of mean minimum temperature indicates a 0.02 to 0.06 °C upward trend per year in the northern, northwestern, northeastern, central, and central-southern parts of the country (Fig. 3b), while an extremely high trend for the mean maximum temperature (0.03–0.06 °C per year) was noticed in the southern, southeastern, and northeastern parts (Fig. 3c).

It was also found that the mean temperature trend was remarkably positive (0.02–0.042 °C per year) in the southern, southeastern, northeastern, and extreme

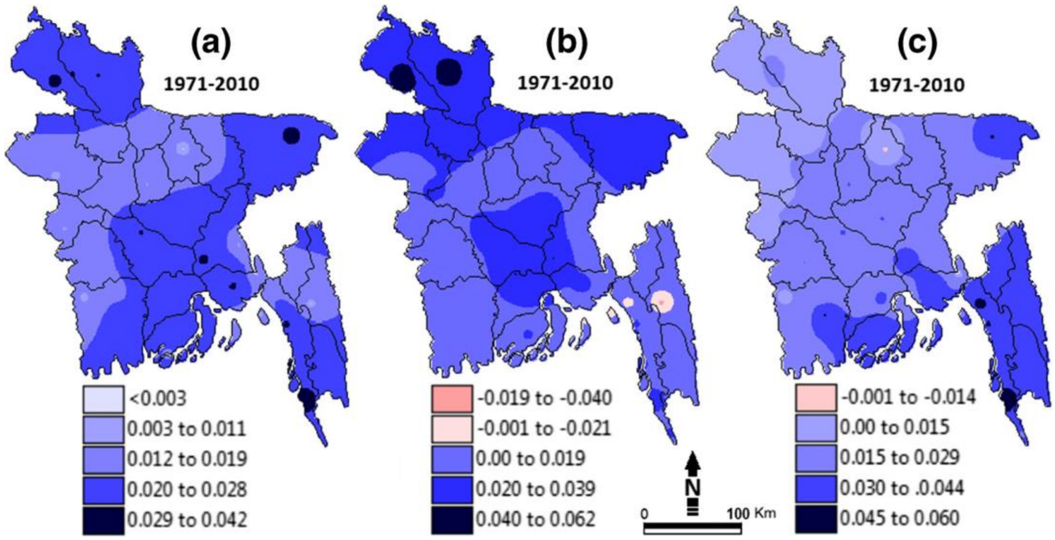


Fig. 3 Trends of temperature (°C per year): a) mean, b) mean minimum and c) mean maximum

northwestern parts of the county (Fig. 3a). The maximum positive trend was noticed at Cox's Bazar, Sylhet, and Dinajpur stations for the mean temperature. On the other hand, a maximum upward trend was found at the Rangpur and Dinajpur stations for the mean minimum and Cox's Bazar and Sitakunda stations for the mean maximum (Fig. 3). A downward trend of the mean minimum temperature was observed at the Rangamati station, situated in the southeastern part of Bangladesh (Fig. 3b). A downward trend of the mean minimum temperature in this area is unknown and further studies are needed to investigate the causes and their influences on the seasonal patterns. Thus, it may be said that the northern, northwestern, southern, southeastern, and, to some extent, central parts of the country are warming at an alarming rate. This may be linked to the impact of global warming and climate change.

Table 1 Trends of mean, mean minimum, mean maximum temperatures and annual, pre- and post-monsoon rainfalls of Bangladesh

Temperature (°C/year)	1971–2010 (40 years)	1981–2010 (30 years)
Mean	0.020	0.024
Mean minimum	0.018	0.021
Mean maximum	0.022	0.028
Rainfall (mm/year)	1971–2010 (40 years)	1981–2010 (30 years)
Annual average	7.130	−5.616
Pre-monsoon	−0.750	−4.769
Post-monsoon	−0.550	−1.296

Trends of Rainfall

The 1971–2010 period shows that the average annual, pre-monsoon (MAM months), and post-monsoon (NDJF months) rainfall were 2387, 446, and 77 mm, respectively. Analysis by least-square fitting for the rainfall data reveals the following results: during the investigated period, the annual rainfall rose by 7.13 mm per year (a total of 14 %), while pre-monsoon and post-monsoon rainfall declined by −0.75 mm (total of 17 %) and −0.55 mm (total of 39 %) per year, respectively. Thus, the general trend was positive for the annual and negative for seasonal rainfall in the country. The greatest decrease in rainfall over the year occurred during the post-monsoonal season (Table 1). The analysis further shows that the rate of rainfall change (annual and seasonal) decelerated in the last 30 years (Table 1). Previous studies showed that there was a positive trend in the annual (+5.5 mm per year) and pre-monsoonal (+ 2.47 mm per year) rains and changes to rainfall during the post-monsoon season were not significant (Shahid 2010).

A study by OECD (2003) pointed out a positive trend of precipitation annually as well as during the pre-monsoon and post-monsoon seasons, but there was no appreciable change during the winter in Bangladesh. Meanwhile, Ahmed and Alam (1999) mentioned that there was little change in winter rainfall and an upward trend in rainfall during the other seasons in Bangladesh. According to McSweeney et al. (2010), the mean rainfall over Bangladesh has decreased by 13.2 mm per decade (6 %) between 1960 and 2003, but this was not statistically significant. However, a positive trend (+3.4 %) was observed in the month's MAM and a negative trend (−1.7 %) in the months June–August (JJA) between 1960 and 2003. Conversely, the Met Office Hadley Centre pointed out that there has been a negligible positive trend in total precipitation over Bangladesh since 1960 (Met Office 2011).

Previous studies mostly analyzed data for the long-term and started from 1958 and did not include very recent data, which may explain slight differences with the current study. However, the present study corroborates with the trend in rainfall of South Asia obtained by Solomon et al. (2007) in which it was found that seasonal precipitation significantly decreased in southern Asia. The spatial trend of rainfall shows a regional disparity as well as variations of rainfall in Bangladesh (Fig. 4). When comparing the districts, an upward trend of annual rainfall was highest (9 to 43 mm per year) in the hill

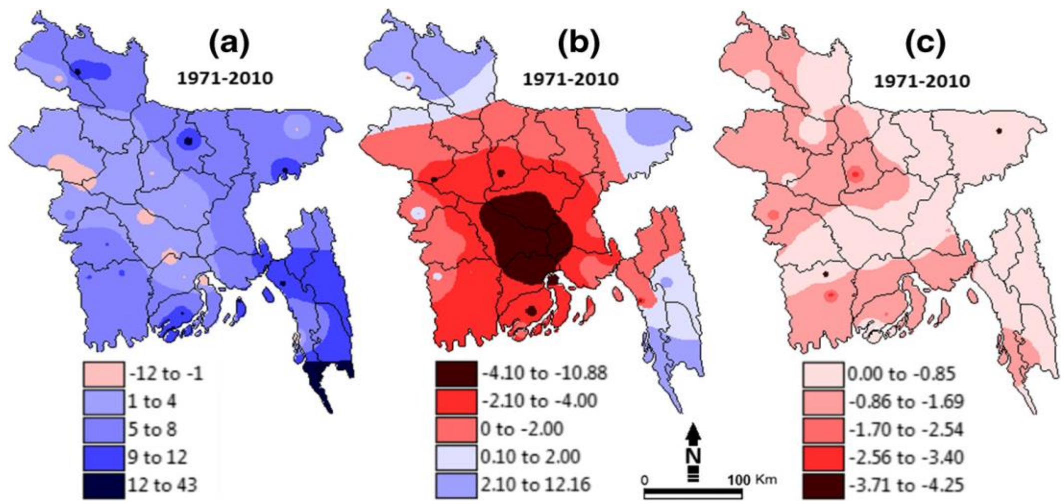


Fig. 4 Trends of rainfall (mm per year): a) annual, b) pre−monsoon and c) post-monsoon

districts, located in the southeastern part of Bangladesh. However, a negative trend of annual rainfall was found at the Rajshahi, Ishurdi, Faridpur, Madaripur, and Patuakhali stations (Fig. 4a). The post-monsoon rainfall presented a negative trend at all the weather stations, and the rate was highest (−1.70 to −3.4 mm per year) in the northwestern, southern, and southwestern parts (Fig. 4c). On the other hand, most of the weather stations also showed negative trends for the pre-monsoon rainfall, except for the stations located at the extreme northwestern, northeastern, and southeastern parts of the country (Fig. 4b). The maximum downward trend of pre-monsoon rain (−2.10 to −10.88 mm per year) was observed in the central, central-western, and central southern parts (Fig. 4b). This implies that dry weather or drought conditions occurred during the pre-and post-monsoon seasons over a wide area of Bangladesh, particularly in the northwestern and southwestern areas.

Though the findings of the present study agree with those of Shahid (2010), in which there was a positive trend in annual rainfall, it does not agree with the spatial pattern of seasonal rainfall trends in Bangladesh. Shahid (2010) found a significant upward trend of annual rainfall in the western part; however, in the present study, a significant upward trend was mostly observed in the southeastern and northern parts of Bangladesh. In the last decade, low rainfall was recorded in the northwestern, western, central, and central southern parts and high rainfall was recorded in the southeastern and northeastern parts (BMD 2013). The present study agrees with the findings of the pre-monsoon spatial trend of rainfall obtained by Shahid (2010) in which there was an increase in the pre-monsoon rainfall in the extreme northwestern and southeastern parts of Bangladesh.

Variability of temperature

The variability of the temperature shows that the mean, mean minimum, and mean maximum variabilities were 0.081, 0.025, and 0.017 °C per year, respectively. Except for the mean temperature variability, the variability of the mean minimum and mean

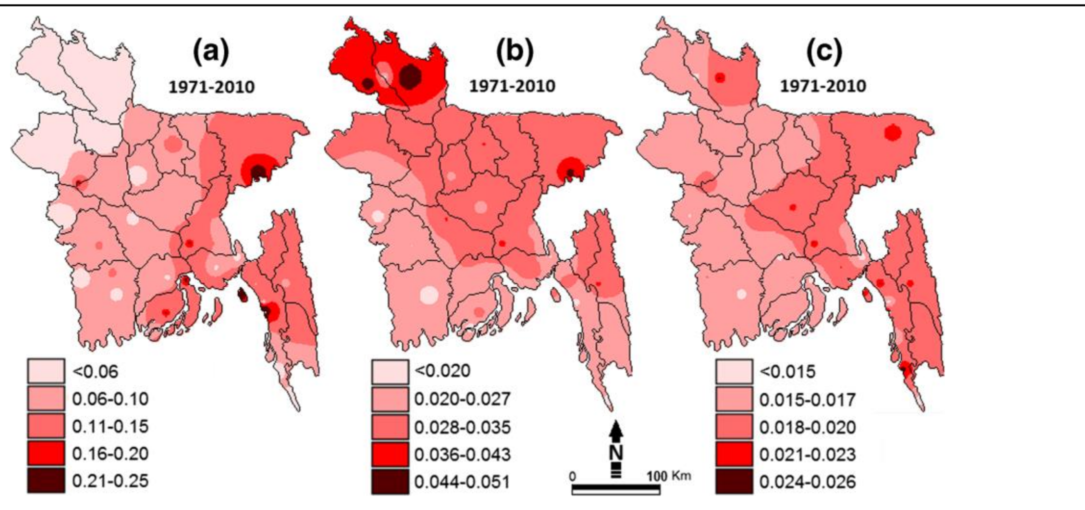


Fig. 5 Variability of temperature (°C per year): a) mean, b) mean minimum and c) mean maximum

maximum was not remarkable in Bangladesh during the investigated period of 1971–2010. However, the spatial pattern of the mean minimum temperature variability shows that a higher variability (>0.027 to 0.051 °C per year) was observed mainly in the northwestern, northern, and northeastern parts (Fig. 5b). The spatial variability in the mean maximum temperature was higher (between 0.017 and 0.026 °C per year) at the northeastern, eastern, and southeastern parts of the country (Fig. 5c) compared to other parts of the country. In the case of the spatial pattern of the mean temperature variability, maximum variability (0.11 to 0.25 °C per year) was found in the northeastern, southern, and southeastern parts (Fig. 5a).

Indeed, some parts of the investigated area showed very low variability of the mean minimum and mean maximum temperatures (<0.02 °C per year) [Fig. 5b, c].

Variability of Rainfall

Further, variability analysis showed that rainfall was erratic during the pre-monsoon season (44.84 % per year) and became much more erratic during the post-monsoon season (85.25 % per year) during the last 40 years in Bangladesh. The annual rainfall variability was found to be 22.59 % per year (range of 15.20–32.80 %) during the investigated period. The spatial pattern depicted that the annual rainfall variability was the highest (between 22.25 and 32.80%per year) in the northwestern, northern, and eastern parts (Fig. 7a). On the other hand, the maximum pre-monsoon (between 46 to 60 % per year) and post-monsoon (between 83 to 100 % per year) rainfall variability was highest in the southern coastal and southeastern hill districts of Bangladesh. The pre-monsoon rainfall variability was also remarkable in the northwestern and southwestern parts (Fig. 7b). The maximum rainfall variability, particularly in pre-and post-monsoon seasons, may be attributed to the relative dryness observed in those parts of the country during the period since generally, low rainfall areas experience greater variability.

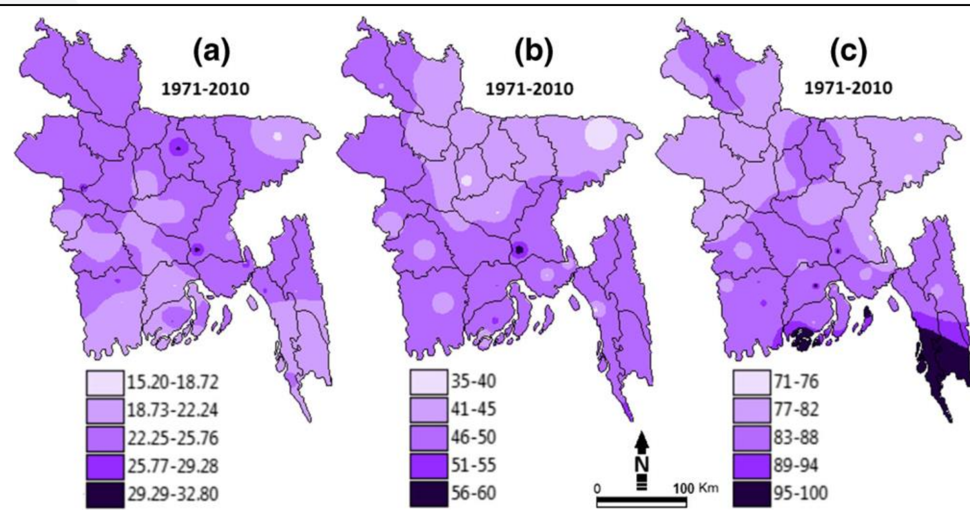


Fig. 6 Variability of rainfall (% per year): a) annual, b) pre monsoon and c) post-monsoon

Of course, the southern coastal and southeastern hill districts have early post-monsoon depressions or cyclone rain effects, which have been increasing in recent decades that could also explain the high rainfall variability in the area. It may be noted here that in Bangladesh, tropical cyclones occur during the pre-and post-monsoon seasons. A study on Bangladesh rainfall has shown that, in general, there was a decrease in rainfall during El-Niño years in all the seasons (the pre-monsoon, the monsoon, and the post-monsoon) (Ahmed et al. 1996), which may be linked to high rainfall variability. Further, in a study by Rajeevan et al. (2008), it was shown that the inter-decadal and seasonal variability of rainfall might be linked to the variations and anomalies of sea surface temperatures (SST) over the equatorial Indian Ocean, particularly the East Indian Ocean, which is associated with global warming.

Forecasting of Temperature and Rainfall

It was mentioned earlier in this study that we forecasted (short-term) temperature and rainfall using the ARIMA time series analysis model. To do so, the ARIMA Expert Modeler of SPSS statistical analysis software was used to perform the automatic best-fitted simulation of temperature and rainfall data for each station.

Therefore, in a continuous sequence from January to December (30 years), observed temperature and rainfall data were used separately for each station as a single time series variable (360). We validated the forecasted values for the decade 2001–2010 with observed values of the same decade first and then, finally forecasted the temperature and rainfall for the decade of 2011–2020. When comparing the observed values and the forecasted values for the 2001–2010 period and visually inspecting the plot, it was quite evident that the forecasted values were very close to the observed values.

The observed mean maximum and mean minimum temperatures from the Rajshahi station were compared (as a sample/evident) with ARIMA model forecasted values. Between these two data sets, of observed and forecasted, the coefficient of determination (R^2) was found to be +0.956 and +0.970 (highly positive) for the mean maximum and mean minimum temperatures, respectively, at the Rajshahi station (Fig. 8b, d). Again, when comparing the observed and forecasted values of the annual average rainfall during the 2001–2010 period, this also showed a highly positive (+0.904) coefficient of determination (R^2) (Fig. 9b), indicting validation of forecasting by the model. For other stations, we also found similar statistical comparisons.

It may be noted here that in Fig. 8d, three horizontal clusters were noticed mainly because of seasonal variations in the data set. Thus, it is apparent that the ARIMA Expert Modeler, which automatically fitted the best ARIMA model for simulation for the specific time-series data set, can be applied with adequate accuracy to forecast temperature and rainfall in the area.

Here, temperature (mean, mean minimum and mean maximum) and rainfall (annual, pre-monsoon, and post-monsoon) of Bangladesh during the second decade (2011–2020) of the twenty-first century was forecasted and yearly statistics were calculated from the monthly data set and then decadal statistics were calculated from the yearly statistics. Afterward, a spatial interpolation technique was followed using IDW and GIS to generate the spatial pattern of the forecasted temperature and rainfall. The spatial variation of the mean, mean minimum and mean maximum temperatures in 2011–2020 are predicted to be 25.11–27.30, 20.04– 23.06, and 29.78–32.08 °C, respectively (Fig. 10). Within this decade (2011–2020), the temperature is predicted to rise by about 0.18, 0.20, and 0.16 °C for the mean, mean minimum, and mean maximum temperatures, respectively, compared to the previous decade of 2001–2010. The forecasted warming of 0.18 °C per decade (mean temperature) during 2011–2020 is consistent with the fourth and fifth IPCC's predictions of 0.2 and 0.17 °C per decade, respectively (IPCC 2007; IPCC 2014). It is also comparable in magnitude to other forecasts (Lean and Rind 2009). Comparative statistics of climate change predictions in Bangladesh are given in Table 2.

Prediction of rainfall shows a decrease of about −153 mm (−15.3 mm per year) rainfall in the decade of 2011–2020, compared to the previous decade 2001–2010. Moreover, from 2011 through 2020, a remarkable low rainfall is projected for the Rajshahi, Bogra, Jessore, and Kustia districts, compared to the others parts of the country (Fig. 11a). However, by 2020, the annual rainfall is projected to increase by about 5.5 % (Table 2), compared to the rainfall in 1971 which is consistent with the IPCC's prediction of a 5–6 % increase in rainfall by 2030 (IPCC 2007). During the pre-monsoon season, the northwestern, southwestern, and western parts of the country will receive low rainfall, which is predicted to continually decrease during the 2011–2020 period (Fig. 11b). On the other hand, during the post-monsoon season, the northwestern, western, and northern districts of the country will receive very low rainfall and this will likely continue to decrease (Fig. 11c). By 2020, the post-monsoon rainfall will decrease by about 13%, compared to 1971 (Table 2).

However, the data predicts that during the post-monsoon season, the southwestern and central parts of the country will receive slightly more rainfall than other parts (Fig. 11c). This is mainly because of the high variability of post-monsoonal rains in these parts of the country.

In summary, the trends of temperature and rainfall during the 1971–2010 period enhanced the attention of the region by climate change, particularly concerning the trend of increased temperature.

Year	Mean temperature (°C)	Annual rainfall (%)	Post-monsoon rainfall (%)	Reference
2020	+0.98 (base 1971–2010)	+5.5	−13	Present study
2020	+0.9 to +1.0 (base 1960–2000)	+5 to7	+3	Tanner et al. 2007
2020	+0.09 (base 1951–1990)	+5.3	+1.3	Islam 2009
2030	+1.0 (base 1960–1995)	+3.8	−1.2	Agrawala et al. 2003
2030	+1.0 (base 1951–1990)	+5	−2	GOB 2005
2030	+0.8 (base 1960–2003)	+1	−2	McSweeney et al. 2010
2050	+0.5 to +2.1 (base 1961–1990)	–	−12	Rahman et al. 2012a
2075	+2.5 (base 1979–2006)	+1.4	+5.7	Rahman and Ferdousi 2012
2100	+3.0 to +3.5 (base 1960–1990)	+5 to +10	–	Met Office 2011

Table 2. Projected change scenarios in temperature and rainfall of Bangladesh

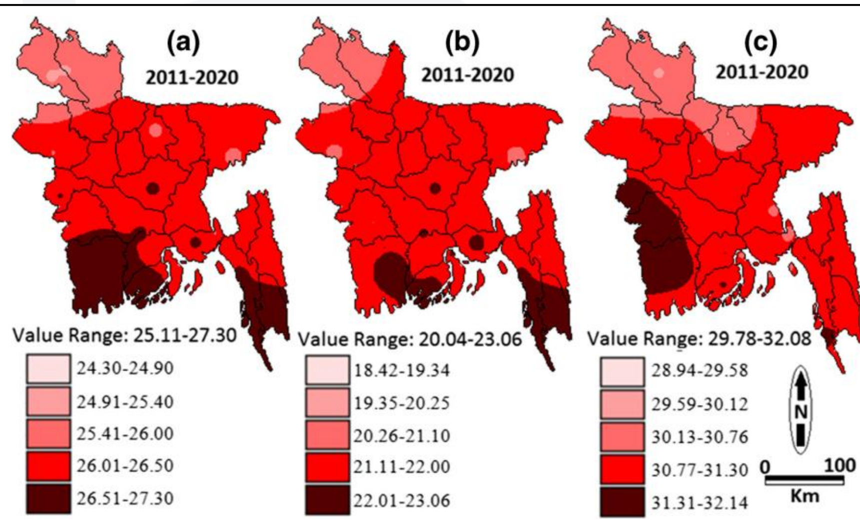
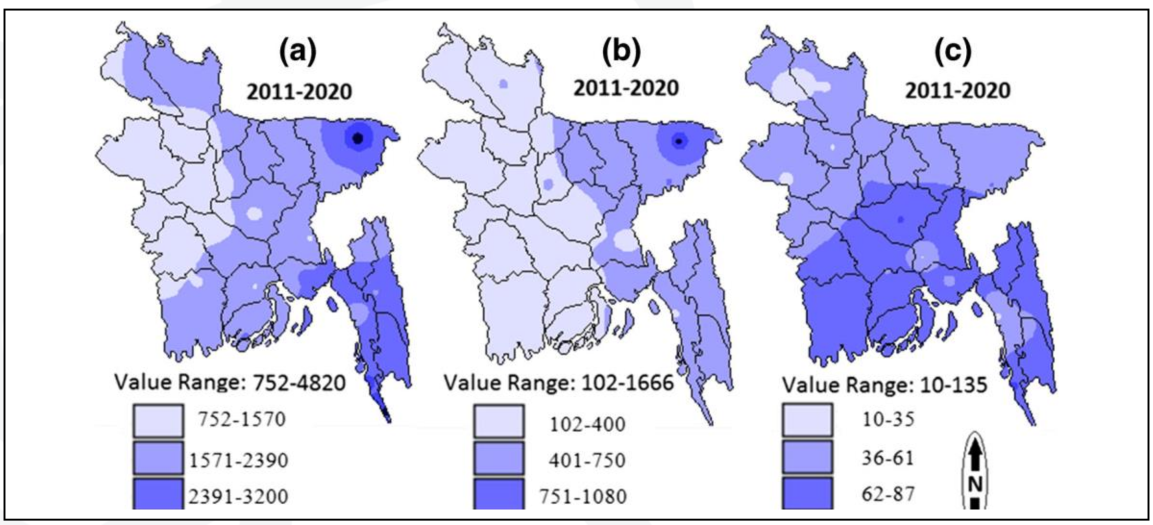


Fig. 7. Spatial pattern of forecasted temperature (°C): 2011-2020. A) Mean, b) mean minimum and c) mean maximum

The results indicate that climate change shows much stronger warming in Bangladesh than what was mentioned by the global view published in the IPCC report (IPCC 2007; IPCC 2014). In Bangladesh, starting from 1971, the mean temperature increased by about 0.20 °C per decade in the last 40 years. This is in contrast with the global mean temperature, which increased by 0.074 °C ± 0.02 °C per decade in the last 100 years (1906–2005) and 0.13 °C ± 0.03 °C per decade in the last 50 years (from 1956 to 2005) (IPCC 2007). Based on the Global Historical Climatology Network (GHCN) database, global linear trends of 0.10 °C per decade in the twentieth century have accelerated since 1950 to 0.16 °C per decade (IPCC 2007). Moreover, warming in Bangladesh was even faster than the 1979–2012 period with global warming rates of 0.16 °C per decade (Morice et al. 2012). Furthermore, the fifth assessment of the IPCC stated that the average temperature of the Earth has risen by 0.12 °C per decade during the period 1951–2012 (IPCC 2014). Again, the investigated temperature trends in this study appear to be higher than most other studies in Bangladesh so far.

This supports the observation that an increase in temperature has taken place more in recent decades than in previous ones in Bangladesh. Besides, the highest positive trend in minimum temperature was observed in the northern, northwestern, central, and central southern parts, while the highest positive trend was noticed in the southern, southeastern, and northeastern parts in the case of the maximum temperature. In these areas, temperatures increased between 0.80 and 2.4°C over the 1971–2010 period.



Conversely, this study exhibited a 14 % (+7.13 mm per year) upward trend in the annual rainfall and 17 % (−0.75 mm per year) and 39 % (−0.55 mm per year) downward trend in pre-monsoon and post-monsoon rainfall, respectively, during 1971–2010. The rainfall was also erratic during the pre-monsoon season, which then increased during the post-monsoon season. Furthermore, dry weather or drought conditions were noticed during the pre-and post-monsoon seasons over a wide area of Bangladesh, particularly in the northwestern and southwestern parts of the country during the post-monsoon season. In these areas, rainfall decreased by about 50–70 % during the 1971–2010 period. The areas under a faster warming trend coincided with the areas having this drying trend. The ARIMA time series model predicted that the mean temperature exhibited a 0.18 °C elevation during the 2011–2020 period compared with the previous decade, indicating an approximately 0.98 °C warmer temperature in Bangladesh by 2020 compared to 1971.

On the other hand, there was a prediction for a 153-mm decline of annual rainfall over the 2011–2020 period. Moreover, it is predicted that the pre-and post-monsoonal rainfall would decrease at a small rate (3 and 5 mm, respectively) which might lead to a drying condition that would persist in the northwestern, western, and southwestern parts of the country during 2011–2020. The general tendency derived by the IPCC from analyzing 20 global climate models indicates that winter precipitation in the region will increase and summer precipitation will decrease (Reiter et al. 2012), however, the analysis of rainfall data from our study depicts decreases of both post-monsoon (winter) and pre-monsoon rainfall which do not match with the IPCC's general seasonal tendency. This is mainly due to the high spatial and temporal variability of rainfall from region to region. Even in our study, because of high spatial and temporal variability, we observed a slightly positive trend of pre-monsoon rainfall at the extreme northwestern, northeastern, and southeastern parts of the country.

Conclusion

In this paper, we discussed the last 40 years (1971–2010) of temporal-spatial climate change in Bangladesh based on temperature and rainfall data. The ARIMA time series model-based future prediction of climate change for the 2011–2020 period was evaluated and confirmed a particularly strong recent climate change in Bangladesh based on temperature and rainfall changes.

This study also validates the ARIMA time series model for shorter time scale climate simulations and can easily be applied to more localized climate data since the ARIMA modeling focuses purely on the data rather than data generating processes. However, since this model is solely based on a statistical approach, it is limited in terms of extreme and irregular events since this model cannot predict extreme events due to any external force or natural events. For example, if a strong global external force of the atmosphere, like a major volcanic eruption occurs, this might be a sound reason to invalidate the forecast for that time.

Therefore, this should be considered as a limitation of the model since the type of situation is not a regular event. For the climate of Bangladesh, the temperature changes reflect warming as a whole and since 1971, the climate of Bangladesh is warming at a much higher rate of global average warming (0.20 versus 0.13 °C per decade). Prediction of the temperature shows that in the decade of 2011–2020, the mean temperature will increase by about 0.18 °C, indicating the temperature will be 1.0 °C warmer in Bangladesh by 2020 compared to 1971. An even greater rise is projected for the mean minimum (0.20 °C) than the mean maximum (0.16 °C) temperature. The minimum temperature warmed more in the northern, northwestern, northeastern, central, and central southern parts while the maximum temperature warmed more in the southern, southeastern, and northeastern parts during the 1971– 2010 period.

In some of these parts, the mean minimum and mean maximum temperatures rose by more than 2.0 °C (0.50 °C per decade), which will likely pose challenges to the population in those parts of the country. On the other hand, the most significant results were related to the dry conditions, since, during the investigated period, a remarkable decrease in the pre-and post-monsoonal rainfalls was noticed (−0.75 and −0.55 mm per year, respectively) with very high variability (44.84 and 85.25 % per year, respectively). High rainfall variability is an indicator of drought, and therefore, the areas under very high variability with low rainfall, particularly the north-western districts, are prone to drought hazards. Predictions of rainfall reveal that declining rainfall will continue and a drying condition will persist during 2011–2020 (153 mm decrease of annual rainfall), especially during the pre-and post-monsoon seasons.

Spatial patterns of trend and variability of temperature and rainfall indicate that the northwestern, western, and southwestern parts of the country are more susceptible to climate change concerning rising temperature, high variability, and rain shortfalls, particularly for the pre-and post-monsoon rains.

It is expected that this study will not only help to delineate appropriate policies and planning to combat the impact of climate change in Bangladesh but also help to understand the regional climate change in this part of South Asia. The trend directions, magnitude, and spatial patterns identified for both temperature and rainfall may also provide helpful information on global warming on a regional/country level scale. Improved understanding of recent climate change helps to elucidate the impacts and vulnerability of the local population to implement the most appropriate practices to cope with climate change and manage the changing situation in a better way.

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