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Research Article

Forecasting Rainfall and Temperature Trends in Bangladesh Based on Historical Data Analysis

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ABSTRACT

This study examined temperature and precipitation trends and spatial variations over a 40-year period at 34 meteorological stations in Bangladesh. Climate variability was assessed using a variety of statistical techniques, such as geographic information systems (GIS), inverse distance weighting (IDW) interpolation, linear regression, and coefficient of variation. The temperature and precipitation data were simulated using an autoregressive integrated moving average (ARIMA) model. With an average temperature increase of 0.20 °C every ten years, the results showed a significant warming trend. Northern, central, and southern regions saw the largest increases in minimum temperatures (from 0.80 to 2.4 °C), while southern and southeastern regions saw the largest increases in maximum temperatures (1.20 to 2.48 °C). Although pre-monsoon and post-monsoon rainfall showed declines of 0.75 mm and 0.55 mm per year, respectively, with significant variability in these seasons (44.84% and 85.25%, respectively), annual precipitation showed an upward trend (+7.13 mm per year). Projections for 2011–2020 suggest a temperature rise of 0.018 °C annually, potentially resulting in a 1.0 °C increase compared to 1971. Minimum temperatures are expected to rise more sharply (0.20 °C) than maximum temperatures (0.16 °C). Annual precipitation is predicted to decrease by 153 mm, with drying conditions anticipated in northwestern, western, and southwestern regions during pre- and post-monsoon periods.

Keywords: Climate Change; Rainfall Forecasting; Temperature Trends; GIS Analysis; Climate Variability

INTRODUCTION

Bangladesh, like other nations, will have to deal with the effects of its changing environment [1], [2]. According to a study [3], "environmental change" is defined as a change in the condition of the environment that lasts for a long period of time, often many years or more, and may be recognized (for instance, by using quantitative tests) by variations in the average or fluctuation of its features. The normal term for averaging these variables is 30 years, according to the World Meteorological Association (WMO). According to [4], the industry's most susceptible to environmental change—which can result in tornadoes, twisters, floods, and dry seasons—are horticulture and water.

As contributions to the territorial, global, and spatially represented scene models, the geographical dispersion of meteorological data is becoming increasingly important. Geographic information systems (GIS) and mathematical demonstration approaches are two examples of spatial developments that have become essential instruments for ecological and environmental evaluations [5]. The evaluation of environment time arrangement completes the gaps in the discussion of the environment as a whole. One of the practical uses of recreation is the prediction of climate conditions based on historical data [6]–[8]. Muddled numeric PC models are utilized in mathematical climate expectation estimation to produce precise climate forecasts while taking into consideration a variety of constraints.

Despite making up only 4% of the world's total land area, the SAARC countries are home to 21% of the world's population [9], [10]. According to this association, the district needs to have appropriate planning and prudent water resource management. Air-Sea General Course Models (AOGCMs) have recently been used to forecast the climatic effects of expanding air convergences of ozone-depleting substances. These expectations could be fulfilled for regions that are homogeneous, logically level, and far from coastlines.

Recent developments in machine learning (ML) present encouraging answers to the problems associated with rainfall prediction, especially with regard to lead time and accuracy. The intricate and nonlinear dynamics of precipitation systems can be accurately captured by ML models. Saxena et al. [11] offers a thorough analysis of machine learning (ML)-based rainfall forecasting systems, emphasizing the performance across various geographic regions, pre-processing methods, and the integration of satellite and radar data. Akinyemi et al. [12] shows that integrating historical satellite and meteorological data with machine learning models (ML) like Random Forest, XGBoost, and LSTM greatly increases prediction accuracy in the Nigerian context, particularly when ensemble and temporal models are employed. The advantages of combining cloud computing and big data analytics for managing atmospheric complexity are also highlighted by Pali and Verma [13], who reports high accuracy and low error rates in weather forecasting and climate analysis using ML. Despite these developments, a large number of studies on climate trends in Bangladesh have depended on insufficient observational data or coarse-resolution global climate models. Studies that generate localized, validated, and spatially explicit forecasts using high-resolution, long-term, ground-based station data are conspicuously lacking. Additionally, although ARIMA and GIS have been used separately in earlier research, their combined application in creating decadal forecasts that are specific to Bangladesh's climate is still understudied. The analytical framework, which combines statistical time-series modeling with spatial interpolation, is applicable worldwide, despite the fact that the current study focuses on Bangladesh. This lightweight and validated ARIMA-GIS approach can be used for short-term climate projections in vulnerable nations with limited high-performance computing infrastructure. The study's high predictive accuracy across Bangladesh's various climate zones highlights its applicability on a global scale.

According to projections from the global climate model (GCM), precipitation will increase, severe storms will occur more frequently, ocean levels will continue to rise, and air and ocean temperatures will continue to rise. The highest-level objective of any distributed AOGCM is about 300 km. However, to survey the expected effects of environmental change, local data of at least 100 km in size (usually about 50 km) is required.

According to the Intergovernmental Board on Environmental Change (IPCC), Bangladesh would lose 30% of its food manufacturing and 17% of its property by 2050 [14]. Using an RCM called Giving Provincial Environments to Effect Studies (Abstract), this study looks at how Bangladesh's precipitation climatology was adjusted and authorized for the gauge periods of 1961–1990 and 2000–2006 independently [15].

The study's objectives are to: (1) evaluate historical trends in temperature and rainfall in Bangladesh between 1971 and 2010; (2) build and validate forecasting models based on ARIMA using this data; and (3) produce high-resolution spatial projections based on GIS for the 2011–2020 timeframe. Supporting climate resilience planning with evidence-based climate projections is the ultimate goal.

STUDY AREA

The land area of Bangladesh is 144,000 square kilometers, and its scope is between 20° 34'N and 26° 38'N. Its longitude is between 88° 01'E and 92° 41'E (Figure 1). Bangladesh has a subtropical, humid climate with high humidity, relatively mild temperatures, and vast, unpredictable changes in precipitation. There are three different seasons in Bangladesh: (I) the dry winter/post-rainstorm season, which lasts from November to February; (ii) the stormy storm season, which lasts from June to October; and (iii) the warm summer season, which occurs from Spring to May and precedes storms. The country's verified average temperature is 25.75 °C, with a typical monthly range of 18.85 to 28.75 °C [16].

According to Rahman & Lateh [16], the average monthly temperature ranges from 12.5 to 25.7 °C and 25.2 to 33.2 °C, respectively, with the lowest and highest temperatures being 21.18 and 30.33 °C. In Bangladesh, April and May are the warmest months, whereas January is the coldest (Figure 2a). The country receives 2428 mm of precipitation annually on average [17]. In Bangladesh, precipitation varies greatly, ranging from 1400 to 4400 mm (Figure 2b).

The months of June, July, and August see the most precipitation. Between mid-May and September, when storms from the southern equator gather moisture and store a lot of precipitation over the South Asian continent, more than 75% of Bangladesh's precipitation occurs. According to Solomon et al. [18], Bangladesh is perhaps the country least equipped to handle the dire effects of environmental change and dangerous climatic deviations.

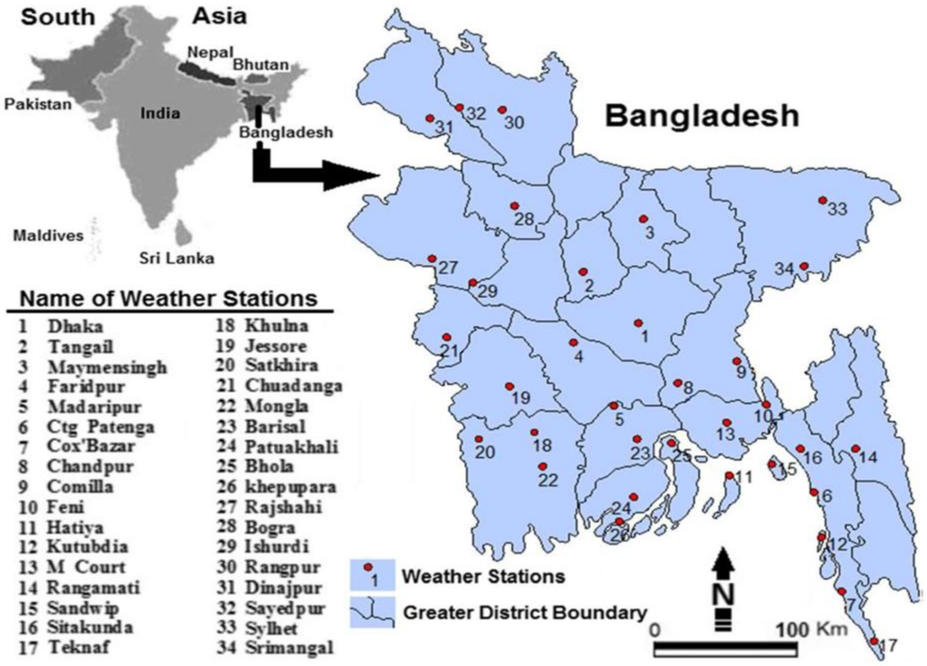

Figure 1. Study area with location of weather stations

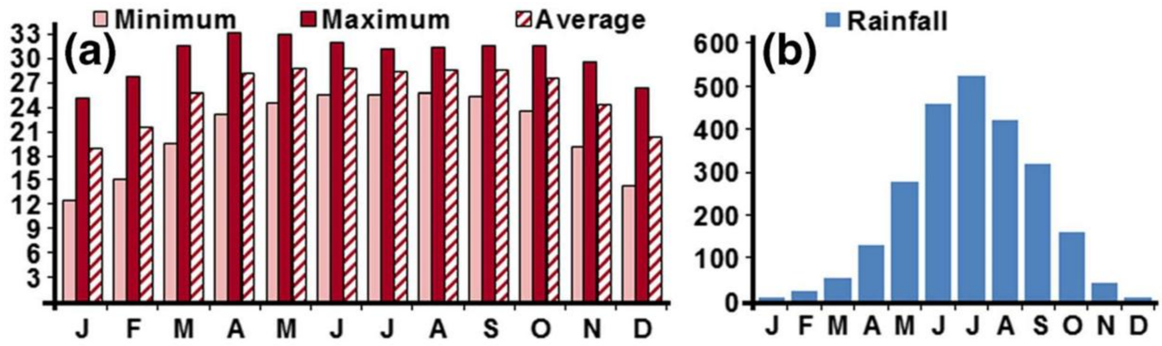

Figure 2. a) Average temperature (°C) and b) rainfall (mm) of Bangladesh

DATA AND METHODOLOGY

Data Collection:

The Bangladesh Meteorological Department received monthly precipitation and minimum and maximum temperature data from 34 Bangladeshi meteorological stations between 1971 and 2010 [17]. Figure 1 displays the locations of these stations. Five of these stations—Tangail (1987–2010), Kutubdia (1985–2010), Chuadanga (1989–2010), Mongla (1989–2010), and Sayedpur (1991–2010)—had data accessible for shorter periods of 20–26 years, whereas 29 stations provided data for the whole 40-year period [16]. Since there were no additional stations in the relevant area, these stations were included even though they had less data available. Figure 3 presents the research framework applied in this study, highlighting the sequence from data collection to spatial analysis and forecast validation.

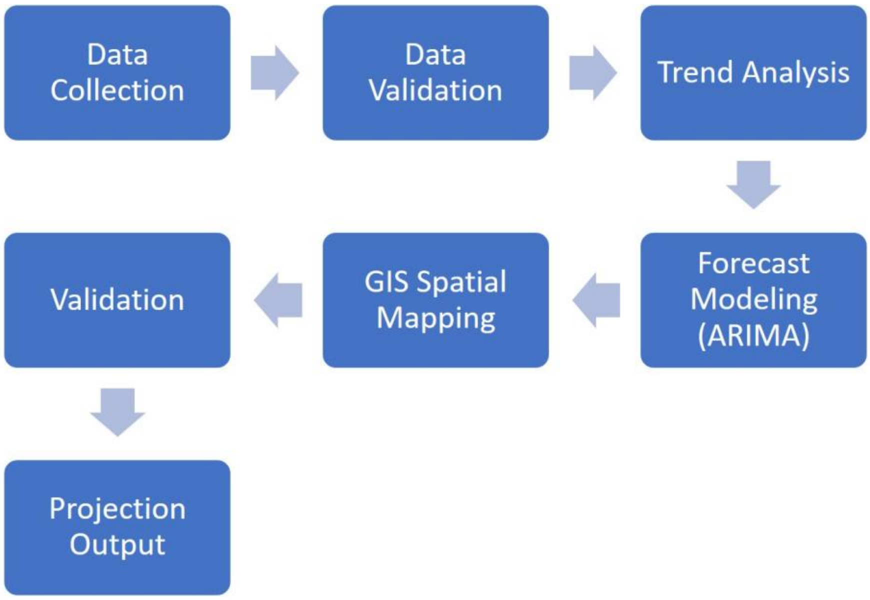

Figure 3. Research framework for trend analysis and forecasting

Data Validation:

The average for the same month in prior and subsequent years was used to replace values in an effort to address missing data (less than 2% of the dataset). Potential outliers were visually examined using histograms, and no discernible differences were found when compared to nearby weather stations. The temperature and precipitation time-series data were checked for homogeneity using a double mass curve analysis, and no statistically significant differences were found. Data from 1970 was used in place of the 1971 data, which was insufficient for the majority of stations.

Temperature and precipitation trends were found using linear regression analysis, which is based on the least squares method. A 95% confidence level was chosen as the significance threshold.

Trend Analysis and Forecasting:

Microsoft Excel (version 2010) was used to analyze trends and variability, and Geographic Information Systems (GIS) tools were used to map the spatial distributions and trends of temperature and precipitation. SPSS software was used to implement the autoregressive integrated moving average (ARIMA) model. The models that best fit each time series were identified by SPSS's "Expert Modeler" function using both seasonal and non-seasonal components. Predictor variables with statistically significant relationships were included in the models, and transformations such as differencing, square root, or natural log were applied as necessary. The first 30 years of observed data (1971–2000) were used to forecast temperature and precipitation for 2001–2010 in order to validate the model. Following that, a comparison was made between the observed and predicted values for the same time period. Following its successful validation, the model was applied to forecast temperature and precipitation for the years 2011–2020.

Calibration of Spatial Imagery Using GIS:

Cross-validation with observed station data was used to calibrate the IDW-based GIS imagery in order to guarantee accuracy in spatial interpolation. The inverse of the squared distance between known data points and interpolation locations is used by the IDW method to determine weights. IDW employed a power parameter of 2 to strike a balance between precision and smoothing. Leave-one-out cross-validation was used to assess the accuracy of the interpolation, and spatial resolution was set at a grid spacing of 1 km^2. By modifying the number of neighboring points (set to 12 for temperature and 10 for rainfall based on lowest RMSE), the interpolation errors were reduced. ArcGIS 10.2 was used to create all spatial layers, and the Bangladesh Meteorological Department provided the station metadata [17].

Integration with Previous Research:

This strategy is consistent with earlier research on Bangladesh's climate variability and geotechnical evaluations. For example, Hore et al. [19] used sands from Bangladesh to demonstrate the seismic behavior of wrap-faced retaining wall embankments, demonstrating how to integrate geotechnical and climatic data in infrastructure analysis. Additionally, studies like those conducted by Ariefin et al. [20] and Talukder et al. [21] looked at the state of Bangladesh's water, sanitation, and hygiene infrastructure as well as earthquake awareness, all of which are influenced by climate. Last but not least, Hore [22]'s stability analysis of rainfall-induced landslides in Bangladesh demonstrated the intimate relationship between rainfall variability and geotechnical stability. Because of these foundational studies, the methodological approach employed in this study is more reliable and pertinent.

Data Validation Process:

A comprehensive data validation procedure was carried out to guarantee the robustness and dependability of the dataset used in this investigation. Initially, temporal interpolation based on the monthly averages of nearby years was used to impute missing data (less than 2 percent). Visual inspections (box plots and histograms) were used to identify outliers, and to guarantee consistency, they were cross-checked against neighboring stations. The double mass curve method was used to test the homogeneity of the time series data, guaranteeing consistent relationships between the cumulative values of correlated stations. By dividing the dataset into two time periods—2001–2010 for testing and 1971–2000 for training—the validity of the ARIMA model was verified. Then, using statistical measures like coefficient of determination (R^2), mean absolute error (MAE), and root mean square error (RMSE), predicted values were contrasted with actual observations from 2001 to 2010.

Strong agreement between observed and predicted values was indicated by high R^2 values (0.90–0.97), demonstrating the accuracy and generalizability of the model.

RESULT AND DISCUSSION

The particular findings from the analysis of rainfall and temperature were examined. The Geographic Information System displays weather forecasts for the future. These findings were also contrasted with previous research published by a number of scholars. Potential effects are evaluated in light of the results, with a focus on population and land area.

TRENDS OF TEMPERATURE

An analysis of climatic data from 1971 to 2010 found that Bangladesh's mean annual temperature was 25.83 °C, with the lowest and highest mean temperatures being 21.21 °C and 30.44 °C, respectively. A positive trend of around 0.020, 0.018, and 0.022 °C was seen in the yearly mean, mean lowest, and mean most extreme temperatures, respectively. The results from [23]–[26] disagree from one another.

Jones [24] found no discernible change in Bangladesh's annual mean lowest and mean maximum temperatures, despite Warrick & Ahmad (eds.) [25] pointing out that the country's mean temperature was 0.5 °C higher than it had been for 100 years (0.005 °C year). For the annual, June–August (JJA), and September–November (Child) months, Bangladesh's surface air temperature has increased by 0.002, 0.007, and 0.012 °C year, respectively, over the past 50 years. The mean, mean minimum, and mean maximum temperatures rose by 0.0097, 0.0091, and 0.0102 °C each year [23].

Since 1960, Bangladesh has experienced positive average annual temperatures for both the winter and late spring seasons, averaging 0.019 and 0.024 °C, respectively. The rate of temperature change has accelerated over the past 30 years (Table 1). Compared to the most extreme temperature, the base temperature changed more slowly (0.022 versus 0.018 °C annually from 1971 to 2010). Therefore, the analysis of late information is likely a key area of interest for identifying the important patterns of the climatic boundaries. Figure 4 shows a geographic representation of the temperature pattern based on pattern measurements for the 34 climate stations, IDW, and GIS. With the exception of the Rangamati and Sitakunda stations for the mean lowest temperature and the Mymensingh station for the mean highest temperature, each climatic station presented a positive pattern, as seen in Figure 4.

The country's northern, northwestern, northeastern, focal, and focal southern regions show an annual increase of 0.02 to 0.06 °C in the spatial example of mean least temperature (Figure 4b), while the southern, southeastern, and northeastern regions show an exceptionally high pattern for the mean most extreme temperature (0.03 to 0.06 °C annually) (Figure 4c). Furthermore, the region's mean temperature pattern was found to be remarkably consistent (0.02–0.042 °C annually) in the southern, southeastern, northeastern, and outrageous northwest regions (Figure 4a).

The stations in Dinajpur, Sylhet, and Cox's Bazar had the most robust upward trend in the mean temperature. However, the Rangpur and Dinajpur stations had the strongest increasing trend for the mean least, while the Cox's Bazar and Sitakunda stations displayed the most rising pattern for the mean most extreme (Figure 4). The mean lowest temperature was moving downward at the Rangamati station, which is situated in southeast Bangladesh (Figure 4b). The average lowest temperature in this region has been inexplicably dropping, and more investigation is expected to ascertain the causes and consequences of the occasional occurrences. The remarkable rate of warming in the nation's northwest, south, southeast, and, to a lesser degree, focus regions may be explained by this theory. This may have something to do with the consequences of global warming and environmental change.

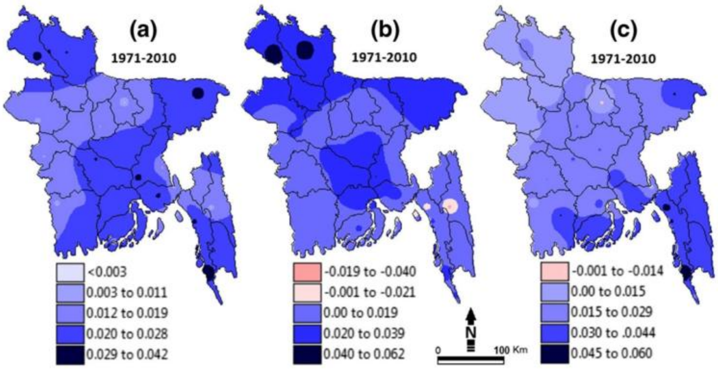

Figure 4. Trends of temperature (°C per year): a) mean, b) mean minimum and c) mean maximum

TRENDS OF RAINFALL

Between 1971 and 2010, the pre-rainstorm (MAM) months had an average of 2387 mm of precipitation, while the post-storm (NDJF) months had an average of 446 mm. The examination of the precipitation data using least-square fitting yields the following findings: Precipitation rose by 7.13 mm (a total of 14%) over the research period, but pre-rainstorm and post-storm precipitation decreased by −0.75 mm (a total of 17%) and −0.55 mm (a total of 39%) annually, respectively.

As a result, the country's overall precipitation trend was negative for intermittent precipitation and positive for the year. The post-monsoonal season had the biggest drop in precipitation throughout the course of the year (Table 1). The data also reveals that throughout the past 30 years, the annual and occasional rates of precipitation change have decreased (Table 1). Previous analyses showed that the annual (+5.5 mm annually) and pre-monsoonal (+2.47 mm annually) rainfall patterns were positive, and that the fluctuations in precipitation during the post-rainstorm season were not significant [23].

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

Similar to the pre-storm and post-rainstorm seasons, an OECD study conducted in 2003 found a positive annual precipitation pattern; however, there was no appreciable change during Bangladesh's colder months. Then, Bangladesh's winter precipitation exhibited an upward trend throughout the seasons and hardly changed [4]. Between 1960 and 2003, the mean precipitation over

Bangladesh dropped by 13.2 mm per decade (6%) but McSweeney et al. [23] state that this was not a measurably critical decrease. Nonetheless, the month's MAM exhibited a positive trend (+3.4%), whereas the June–August (JJA) months, which span from 1960 to 2003, displayed a negative trend (−1.7%). On the other hand, the Met Office Hadley Center [26] reports that the total precipitation over Bangladesh has been slightly increasing since 1960.

Most earlier analyses began in 1958 and broke down data as much as possible. Some minor differences with the current study may be explained by the fact that they did not include very late data. Regardless, the present analysis confirms the precipitation pattern in South Asia identified [18], who found that the region's intermittent precipitation basically decreased. The spatial pattern of precipitation differs by province, much like the various types of precipitation found in Bangladesh. The slope areas, which are in Bangladesh's southeast, had the most noticeable increase in yearly precipitation (9 to 43 mm annually) when location was taken into account. The Rajshahi, Ishurdi, Faridpur, Madaripur, and Patuakhali stations did, however, show a decreased trend in yearly precipitation. A negative pattern was created at all climatic stations by the post-storm precipitation, with the northwest, south, and southwestern regions seeing the most noticeable rate (−1.70 to −3.4 mm yearly). With the exception of those in the country's far northwest, northeast, and southeast, the majority of climate stations did, however, similarly display negative trends for pre-rainstorm precipitation. Throughout the focal, focal western, and focal southern sectors, the pre-storm rainfall showed the biggest descending trend (−2.10 to −10.88 mm yearly). This indicates that a dry climate or dry spell predominated across a significant area of Bangladesh, particularly in the northwest and southwest, during the pre- and post-storm seasons.

The results of the current study contradict the geographical example of irregular precipitation patterns in Bangladesh, even if they are consistent with those of McSweeney et al. [23], who found a positive trend in yearly precipitation. Although the current research revealed a substantial increasing trend mostly in the southern and northern parts of Bangladesh, McSweeney et al. [23] discovered a key increase pattern of yearly precipitation in the western region. In recent years, precipitation has been low in the northwest, western, focal, and focal southern regions, and high in the southeastern and northeastern regions [17]. McSweeney et al. [23]'s findings about the pre-rainstorm spatial pattern of precipitation, which indicated an increase in pre-storm precipitation in Bangladesh's southeastern and northwest regions, are supported by the current analysis.

VARIABILITY OF TEMPERATURE

The analysis of temperature inconsistency revealed that the mean, mean least, and mean most extreme fluctuations were, respectively, 0.081, 0.025, and 0.017 °C annually. In Bangladesh from 1971 to 2010, the difference between the mean least and mean greatest was not statistically significant, with the exception of mean temperature changeability. But according to the spatial example of mean least temperature inconstancy, the northwestern, northern, and northeastern regions had higher fluctuations (>0.027 to 0.051 °C annually) (Figure 5b). In contrast to other parts of the nation, the mean most extreme temperature (between 0.017 and 0.026 °C annually) varied more spatially in the northeastern, eastern, and southeast regions (Figure 5c). The spatial example of the mean temperature fluctuation (Figure 5a) revealed that the northeastern, southern, and southeastern regions had the highest inconstancy (0.11 to 0.25 °C annually). Very low mean least and mean greatest temperature inconstancy (<0.02 °C per year) was clearly observed in a small portion of the studied area (Figure 5b, c).

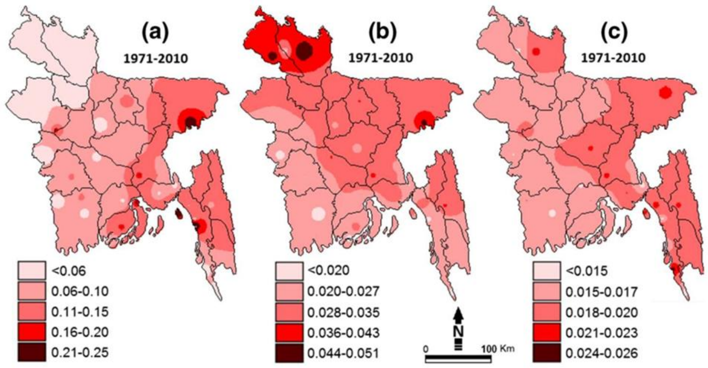

Figure 5. Variability of temperature (°C per year): a) mean, b) mean minimum and c) mean maximum

VARIABILITY OF RAINFALL

Precipitation in Bangladesh was also irregular during the pre-rainstorm season (44.84 percent annually) and significantly more irregular during the post-storm season (85.25 percent annually) over the previous 40 years, according to fluctuation analysis. It was determined that the annual precipitation inconstancy during the study period was 22.59% (ranging from 15.20 to 32.80%). The spatial example showed that annual precipitation changeability was most noticeable in the northwest, northern, and eastern regions (ranging from 22.25 to 32.80% annually) (Figure 6a). The most significant pre-storm (between 46 and 60 percent annually) and post-rainstorm (between 83 and 100 percent annually) precipitation inconstancy, however, was observed in Bangladesh's southern waterfront and southeastern slope regions. Pre-storm precipitation variation was similarly significant in the northwest and southwest (Figure 6b). The most severe precipitation inconstancy, especially during pre- and post-storm seasons, may be the cause of the overall dryness found in those areas of the country during that time, as low precipitation regions usually undergo more noticeable fluctuation.

The region's high precipitation inconsistency may also be explained by the increasing effects of twister downpours or early post-rainstorm discouragements in the southeast slope and southern beachfront areas in recent years. It should be noted that pre- and post-rainstorm seasons are when hurricanes strike Bangladesh. El Niño years generally had lower precipitation in all three seasons (pre-storm, rainstorm, and post-storm), according to a study of Bangladesh's precipitation [25], [27]. This might be due to the excessive precipitation inconstancy. Additionally, Rajeevan et al. [28] demonstrated that the irregularities and fluctuations of ocean surface temperatures (SST) across the central Indian Sea, particularly the East Indian Sea, which are linked to an unnatural weather shift, may be connected to the between-decadal and sporadic inconstancy of precipitation.

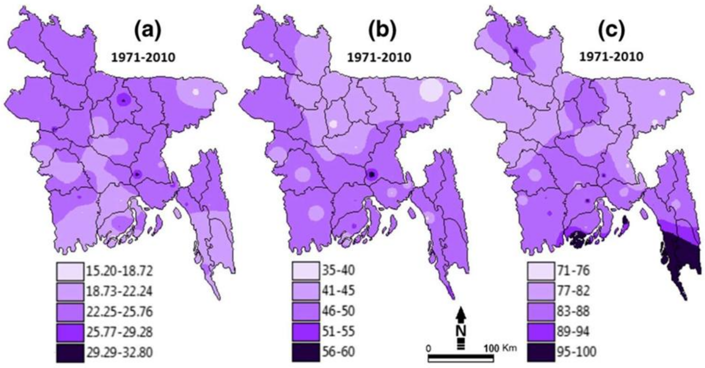

Figure 6. Variability of rainfall (% per year): a) annual, b) pre monsoon and c) post-monsoon

FORECASTING OF TEMPERATURE AND RAINFALL

As stated earlier in this analysis, we measure (current) precipitation and temperature using the ARIMA time arrangement investigation model. This was achieved by using the ARIMA Master Modeler of SPSS measurable investigation programming to play out the best-fitted reproduction of temperature and precipitation data that was programmed for each station.

The measured temperature and precipitation data were therefore employed separately for each station as a single time arrangement variable (360) in a continuous grouping from January to December (30 years). Prior to predicting the temperature and precipitation for the years 2011–2020, we first approved the gauge readings for the years 2001–2010 with the observed upsides of that decade. When comparing the actual and predicted qualities for the 2001–2010 period, it was clear from an external examination of the plot that the gauge values were close to the observed qualities.

The recorded mean lowest and mean most severe temperatures at the Rajshahi station were taken into consideration (as an example/apparent) using estimated values from the ARIMA model. For the mean most extreme and mean least temperatures at the Rajshahi station, the coefficients of assurance (R2) for these two informative sets of observed and calculated temperatures were +0.956 and +0.970 (exceptionally certain), respectively. A comparison of the observed and measured benefits of the annual normal precipitation from 2001 to 2010 revealed an extraordinarily high (+0.904) coefficient of assurance (R2), indicating that the model approved of estimation. Additionally, factual comparisons for several stations were found. Note that the main reason for the display of the three-level groupings was sporadic changes in the informative index. The ARIMA Master Modeler then clearly fits the optimal ARIMA model for reenactment for the time-arrangement informational index and may be used to predict local temperature and precipitation with high accuracy.

Several measures of statistical accuracy were used to assess the ARIMA forecasting model's performance. For the validation period (2001–2010), there was a high degree of accuracy in the comparison between the observed and predicted temperature and precipitation. At Rajshahi station, the R^2 values for the lowest and maximum temperatures were 0.970 and 0.956, respectively. A high correlation with observed data was indicated by the annual rainfall prediction's R^2 value of 0.904. Additionally, for temperature and precipitation, the mean absolute error (MAE) varied from 0.12 to 0.25 °C and 8 to 15 mm, respectively, for the majority of stations. In most cases, the RMSE for temperature and rainfall was less than 0.30 °C and 20 mm, respectively, suggesting minimal deviation. These results support the model's use for short-term climate projection in Bangladesh and validate its ability to simulate and forecast climatic variables with a respectable degree of accuracy.

For the upcoming decade (2011–2020) of the twenty-first century, we calculated Bangladesh's mean, mean least, and mean most extreme temperatures as well as its annual, pre-storm, and post-rainstorm precipitation. Monthly measurements were obtained from the informational index, and decadal insights were obtained from the annual insights. The spatial example of the estimated temperature and precipitation was later produced by employing a spatial addition technique that utilized GIS and IDW.

Figure 7 projects that between 2011 and 2020, the mean, mean least, and mean greatest temperatures will shift by 25.11–27.30, 20.04–23.06, and 29.78–32.08 °C, respectively. Over the course of this decade (2011–2020), the mean, mean least, and mean maximum temperatures are expected to rise by around 0.18, 0.20, and 0.16 °C, respectively, relative to the previous decade (2001–2010). In line with the fourth and fifth IPCC forecasts of 0.2 and 0.17 °C per decade, respectively, the mean temperature is predicted to increase by 0.18 °C each decade between 2011 and 2020 [3], [26]. According to other estimates, its reach is similar as well [29]. An in-depth examination of Bangladesh's aspirations for environmental change is given in Table 2.

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

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	[18]
2020	+0.09 (base 1951 – 1990)	+5.3	+1.3	[30]
2030	+1.0 (base 1960 – 1995)	+3.8	-1.2	[31]
2030	+1.0 (base 1951-1990)	+5	-2	[17]
2030	+0.8 (base 1960-2003)	+1	-2	[23]
2050	+0.5 to +2.1 (base 1961 – 1990)	-	-12	[14]
2075	+2.5 (base 1979-2006)	+1.4	+5.7	[16]
2100	+3.0 to +3.5 (base 1960 – 1990)	+5 to +10	-	[26]

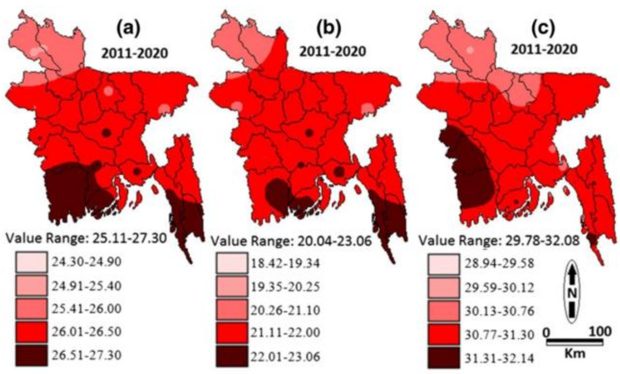

Figure 7. Spatial pattern of forecasted temperature (°C): 2011–2020. A) Mean, b) mean minimum and c) mean maximum

Precipitation is predicted to have dropped by about −153 mm (−15.3 mm per year) between the 2011–2020 and 2001–2010 periods. Furthermore, Rajshahi, Bogra, Jessore, and Kustia are predicted to have exceptionally low precipitation between 2011 and 2020 in comparison to other parts of the nation (Figure 8a). However, the annual precipitation is predicted to increase by approximately 5.5% by 2020 compared to the precipitation in 1971, which is in line with the IPCC's prediction of a 5–6% increase in precipitation by 2030 (Table 2). Precipitation in the pre-rainstorm season will be low in the northwest, southwest, and western parts of the nation, and it is predicted to gradually decrease between 2011 and 2020 (Figure 8b). Nonetheless, the post-rainstorm season will see little precipitation in the country's northwest, western, and northern regions, and this is probably going to keep getting worse (Figure 8c). By 2020, post-storm precipitation will be about 13% lower than in 1971 (Table 2). Regardless, the results indicate that the southwest and focal parts of the country will get somewhat more precipitation than other regions during the post-rainstorm season (Figure 8c). This is because post-monsoon rainfall in various regions of the nation is notably erratic.

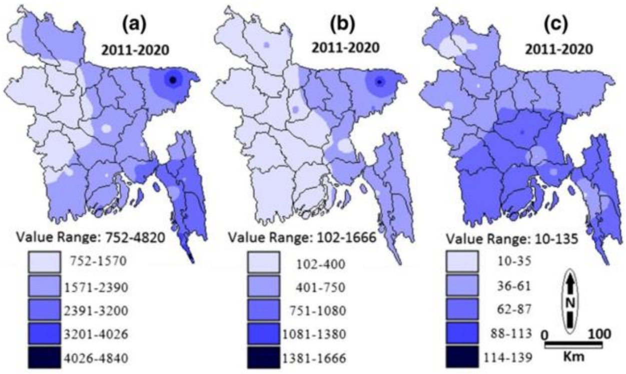

Figure 8. Spatial pattern of forecasted rainfall (mm per year): 2011–2020. A) Annual average, b) pre-monsoon and c) post-monsoon

All things considered, the 1971–2010 temperature and precipitation patterns improved the region's evaluation of environmental change, especially the expanded temperature pattern. The findings indicate that Bangladesh's warming is significantly more grounded in environmental change than the global perspective referenced in the IPCC report [3], [18]. Since 1971, Bangladesh's average temperature has risen by about 0.20 °C every ten years for the past forty years. In contrast, the global mean temperature rose by 0.074 °C ± 0.02 °C per decade during the most recent 100 years (1906–2005) and by 0.13 °C ± 0.03 °C per decade during the most recent long period (from 1956 to 2005) [18]. According to statistics from the Worldwide Verifiable Climatology Organization (GHCN), global direct trends have increased from 0.10 °C per decade in the 20th century to 0.16 °C per decade since 1950 [18]. Additionally, warming in Bangladesh happened far faster than it did between 1979 and 2012, with a worldwide temperature change rate of 0.16 °C each decade [30]. In addition, the IPCC's fifth assessment found that between 1951 and 2012, the average Earth temperature rose by 0.12 °C every ten years [3]. Once more, the temperature drifts analyzed in this study seem to be greater than those discovered in most earlier analyses carried out in Bangladesh.

This lends credence to the notion that Bangladesh's temperatures have increased more recently than in the past. Additionally, the southern, southeastern, and northeastern regions displayed the most notable positive pattern with the highest temperature, while the northern, northwestern, focal, and focal southern regions displayed the most notable positive pattern with the lowest temperature. Between 1971 and 2010, the temperature here rose by 0.80 to 2.4°C.

On the other hand, this analysis showed that between 1971 and 2010, annual precipitation increased by 14% (+7.13 mm annually) and pre-rainstorm and post-storm precipitation decreased by 17% (−0.75 mm annually) and 39% (−0.55 mm annually), respectively. Precipitation also fluctuated during the pre-storm season before increasing during the post-rainstorm season. Furthermore, during the pre- and post-storm seasons, many parts of Bangladesh—especially the northwest and southwestern regions during the post-rainstorm season—saw dry climates or dry spells. There was a 50–70% drop in precipitation between 1971 and 2010. This pattern of drying corresponded to the regions that were warming more quickly. Bangladesh's temperature would be roughly 0.98 °C hotter by 2020 than it was in 1971, according to the ARIMA time arrangement model, which projected that the average temperature would rise by 0.18 °C between 2011 and 2020 relative to the preceding decade.

In contrast, a 153 mm decrease in annual precipitation was anticipated between 2011 and 2020. The country's northwest, west, and southwest regions may experience a drying condition from 2011 to 2020 as a result of a slight decrease in pre- and post-monsoonal precipitation (3 and 5 mm, respectively). The IPCC's comprehensive analysis of 20 global climate models predicts that precipitation in the region will rise in the winter and fall in the summer [32]. Our examination of precipitation data, however, reveals drops in both pre-storm and post-rainstorm (winter) precipitation, which deviates from the IPCC's general occasional tendency overall. The main cause of this is the notable regional and worldwide variance in precipitation between districts. In fact, because of the high spatial and global fluctuation, we found a somewhat specific pattern of pre-rainstorm precipitation at the country's northeastern, southeast, and northern borders despite our investigation.

CONCLUSION

This paper examined Bangladesh's recent 40 years (1971–2010) of transient spatial environmental change using temperature and precipitation data. In Bangladesh, the assessment of the ARIMA time arrangement model-based future forecast of environmental change for the 2011–2020 period confirmed an exceptionally strong ongoing environmental change that depends on temperature and precipitation variations. The ARIMA time arrangement model is also validated for more limited time scale environment recreations, and it can undoubtedly be applied to more restricted environment information because the ARIMA demonstration is solely focused on the information rather than information-creating measures. However, because this model is only based on a measurable methodology, it is limited in its ability to predict outrageous and unpredictable events. This is because it cannot foresee ludicrous events brought on by frequent occurrences or outside forces. For instance, if a powerful worldwide air force, like a massive volcanic eruption, happens at that time, there might be good reason to reject the conjecture.

This kind of scenario should be considered a model constraint since it is definitely not a common occurrence. The climate of Bangladesh has warmed at a substantially faster rate than the global average since 1971 (0.20 versus 0.13 °C per decade), which is indicative of global warming. The average temperature is expected to increase by about 0.18 °C between 2011 and 2020, which means that by that time, Bangladesh's temperature will be 1.0 °C higher than it was in 1971. It is anticipated that the mean minimum temperature (0.20 °C) will increase considerably more than the mean maximum temperature (0.16 °C). The southern, southeastern, and northeastern regions experienced the greatest temperature warming during the 1971–2010 period, whereas the northern, northwestern, northeastern, focal, and focal southern regions experienced the greatest base temperature warming.

The mean least and mean most severe temperatures increased by almost 2.0 °C (0.50 °C every decade) in several of these regions, which is likely to generate problems for the local population. However, the primary findings were associated with dry circumstances due to the notable decrease in pre- and post-monsoonal rainfalls (−0.75 and −0.55 mm yearly, respectively) with a large fluctuation

(44.84 and 85.25% annually, respectively) over the examined period. Areas with high fluctuation and low precipitation, especially the northwest, are more susceptible to the hazards of dry spells because high precipitation changeability is a sign of the dry season. Precipitation forecasts indicate that, particularly during the pre- and post-rainstorm seasons, there will be a persistent drying condition and a decrease in precipitation from 2011 to 2020 (a decrease of 153 mm in annual precipitation). The northwest, western, and southwestern parts of the nation are more susceptible to environmental change in terms of rising temperatures, significant fluctuations, and downpour setbacks, especially for pre- and post-rainstorm downpours, according to geographic examples of temperature and precipitation patterns and inconsistencies.

In general, this study will aid in understanding the territorial environmental change in this South Asian region as well as illustrating suitable plans and strategies to counteract the effects of environmental change in Bangladesh. The pattern headings, greatness, and spatial examples that are differentiated for temperature and precipitation may also offer evidence for an unnatural weather change at the territorial/national level. The effects and the neighborhood population's incapacity to adopt the best practices to adapt to environmental change and manage the changing situation more skillfully can be explained with a better understanding of late environmental change.

DECLARATIONS

Conflict of Interest

We declare no conflict of interest, financial, or otherwise.

Ethical Approval

On behalf of all authors, the corresponding author states that the paper satisfies Ethical Standards conditions, no human participants, or animals are involved in the research.

Informed Consent

On behalf of all authors, the corresponding author states that no human participants are involved in the research and, therefore, informed consent is not required by them

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