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Historical and Future Rainfall Variations in Bangladesh

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Abstract**—**Climate change has become a major concern across the world as the intensity along with quantity of the rainfall, mean surface temperature and other climatic parameters have been changed not only in Bangladesh but also in the entire globe. Bangladesh has already experienced many natural hazards. Among them changing of rainfall pattern, erratic and heavy rainfalls are very common. But changes of rainfall pattern and its amount is still in question to some extent. This study aimed to unfold how the historical rainfalls varied over time and how would be their future trends. In this context, historical rainfall data (1975-2014) were collected from Bangladesh Metrological Department (BMD) and then a time series model was developed using Box-Jenkins algorithm in IBM SPSS to forecast the future rainfall. From the historical data analysis, this study revealed that the amount of rainfall decreased over the time and shifted to the post monsoons. Forecasted rainfall shows that the pre-monsoon and early monsoon will get drier in future whereas late monsoon and post monsoon will show huge fluctuations in rainfall magnitudes with temporal variations which means Bangladesh will get comparatively drier seasons in future which may be a serious problem for the country as it depends on agriculture.

Keywords**—**Monsoon, Pre-monsoon, rainfall, pattern, variations, IBM-SPSS.

I. Introduction

CLIMATE change is the greatest threat to the Earth today and rainfall is one of the most important climatic parameters regarding the issue. There is strong evidence that the pattern of rainfall has been changed in both global and regional scale [1], [2]. Being a flat and low-lying country, Bangladesh is highly vulnerable to natural disasters due to its geographical location [3], [4].

Bangladesh mainly depends on agriculture as it is the mainstay of the country's economy. As a significant climatic parameter, rainfall may affect the agriculture of the country in many dimensions [5]. There are several examples of climatic extremes related to rainfall that affected the agricultural production in Bangladesh [6], [7]. All crops have critical stages when they need certain amount of water for their growth and development but excessive rainfall may cause flooding and water logging which in turn may lead to crop failure. However, reductions of rainfall quantity along with spatial and temporal variations affect the crop production not only in Bangladesh but also in the entire globe [8]–[11]. Besides these, changes of rainfall pattern have the great influence on both crops and human health. For instance, heavy or erratic rainfall causes floods and water logging problems in both rural and urban areas which directly or indirectly affects human health [12]. As the variations of rainfall play vital role on the agricultural production in the both national and global level, a question has been arisen in the scientific community that how the rainfall varied historically and how it may vary in future. To this end many researchers across the academia attempted to explore the historical variability of the rainfall in Bangladesh. But based on the research interests, data availability, research methodology and operation, many researchers came with different outcomes. For instance, Basak et al. [13] and Farhana [14] analyzed only the trends of different seasons where they revealed that total rainfall showed increasing trend for monsoon and post-monsoon seasons, while decreasing trend was observed for the winter; pre-monsoon rainfall did not show any significant change. However, in the analysis of the seasonal variations many researchers showed that overall rainfall increased in pre-monsoon, monsoon and post monsoon [15] which is inconsistent with Roy [16] who argued that the average rainfall in the monsoon was decreased. Some researchers focused on the rainfall intensity and frequency where wetter monsoon and dryer winter were observed [15] with more frequent rainy day in June but more frequent heavy rainfall in July [17]. In case of temporal and spatial variations, Rahman & Lateh [18] observed downward trend of the average rainfall in the pre-monsoon which does not consistent with the observation of Shahid [19] and Hasan et al. [15]. Very few researchers worked on the future prediction of rainfall trend with magnitude using different analytical techniques [20], [21]. However, it is really very difficult and challenging task to forecast the future rainfall as the rainfall data are multi-dimensional and non-linear [21]. Forecasting of average and maximum rainfall using a valid model and rainfall variations of individual months of different seasons are very limited whereas seasonal variations and trend analysis are very common practice in rainfall research. For this reason this study aimed to disclose the historical monthly average and monthly maximum rainfall variations for the time period from 1975 to 2014. Based on the historical data analysis, the research also intended to forecast how the rainfall, both monthly average and monthly maximum, may vary in future up to 2040.

II. Methodology

A. Data Collection, Processing and Historical Analysis

Daily rainfall data of 35 stations of the country were collected from the BMD. All the rainfall records were for the time period from 1975 to 2014. Based on the hydrological regions (Fig. 1) 13 stations were selected which cover all hydrological regions as well as all divisions of Bangladesh.

At first daily rainfall of the selected stations were converted to monthly mean and monthly maximum rainfall and then plotted against time for individual months. For example, for

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January, the monthly mean rainfalls were plotted for the time period from 1975 to 2014. Likewise, the graphs of the monthly mean and monthly maximum rainfall were plotted for February to December for the same time period. After plotting these graphs, we face some difficulties in interpreting the precise results as all the rainfall either average or maximum fluctuated greatly through the entire time period. To infer the historical rainfall variations clearly over the entire time period, histogram of the decadal averages of the each type of rainfall of the individual months were also plotted.

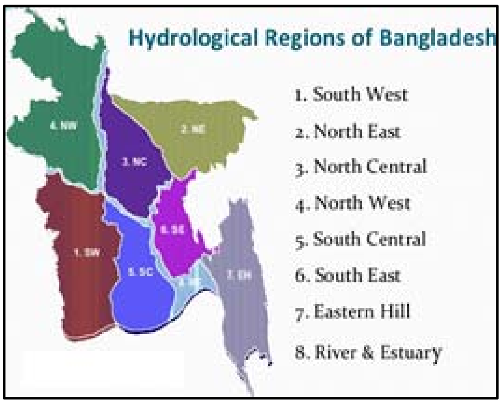

Fig. 1 Hydrological regions of Bangladesh [22]

TABLE I
STUDY AREAS WITH CORRESPONDING HYDROLOGICAL REGIONS AND NUMBERS

Station	Hydrological Regions (no.)
Dhaka	North central (3)
Mymensing	North East (2)
Rajshahi	North West (4)
Bogra	North West (4)
Rangpur	North West (4)
Chittagong	Eastern Hill (7)
Comilla	South East (6)
Cox's Bazar	Eastern Hill (7)
Barisal	South Central (5)
Khepupara	South Central (5)
Khulna	South West (1)
Jessore	South West (1)
Sylhet	South Central (2)

B. Stationary Test

Checking the stationarity of the historical rainfall is the prerequisite for choosing model type and forecasting process. In this study, the stationarity tests were conducted for all the rainfall data of all stations by plotting the residual Auto Correlation Function (ACF) and residual Partial Auto Correlation Function (PACF) with maximum number of lags 24 and 95% confidence interval were plotted (Fig. 2). The graphs of ACF and PACF were used as an indicator of consistency of the data. If all the spikes (Fig. 2) lied within the upper and lower boundary limits, then the data were considered as consistent or stationary otherwise inconsistent. Almost all rainfall data were inconsistent as they are non-linear and multi-dimensional.

C. Model Identification

To forecast the future rainfall up to 2040, a time series model was developed in IBM-SPSS using Box-Jenkins approach. SPSS stands for Statistical Package for Social Science which is a data mining and text analytics software available from IBM. It is usually used to build predictive models and conduct other analytic tasks like manipulation and managing data, calculating a wide variety of statistics and analyses with simple instructions. SPSS allows access to data mining and leverage statistical operations due to its visual interface. In this study, a time series model was used in IBM SPSS as the performance and validity of the model for forecasting was justified and recommended by many researchers [23]-[25]. However, to identify the appropriate model type that fits with the historical data, residual ACF and Residual PACF with maximum number of lags 24 and 95% confidence interval were plotted at first (Fig. 2). From the stationary test, it became very clear that all data were inconsistent or non-stationary.

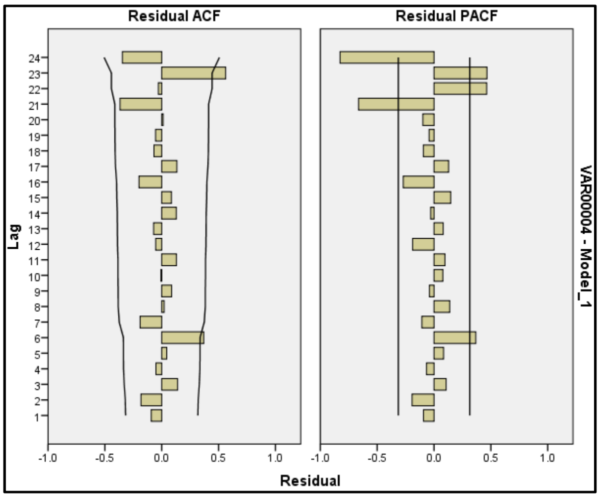

Fig. 2 Auto Correlation Factor and Partial Auto Correlation Factor

The Box-Jenkins algorithm to modeling Auto Regression Incorporated Model Analysis (ARIMA) was chosen as the data were non-stationary or inconsistent. ARIMA models describe the current behavior of the variables in terms of linear relationships with their past values. ARIMA model can be decomposed into two parts. First, it has an integrated (I) component (d) which represents the order of differentiating to be performed on the series to attain stationary. ARMA is the second component of ARIMA which is further divided into Auto Regressive (AR) and Moving Average (MA) components. AR components capture the correlation between the current values and some of its past values of the time series. For example, if the value of AR is 3 then it means that the current observations are correlated with its immediate past three consecutive values at time and the Moving Average represents the duration of the influence of a random shocks. The ACF and PACF are used to estimate the values of p and q. The models were run several times on trial and error basis using different p, d, and q values until the spikes reach the boundary limits which indicates the data are stationary (Fig. 3). However, almost all rainfall data were inconsistent where ARIMA (p,d,q) was used for the forecasting [26].

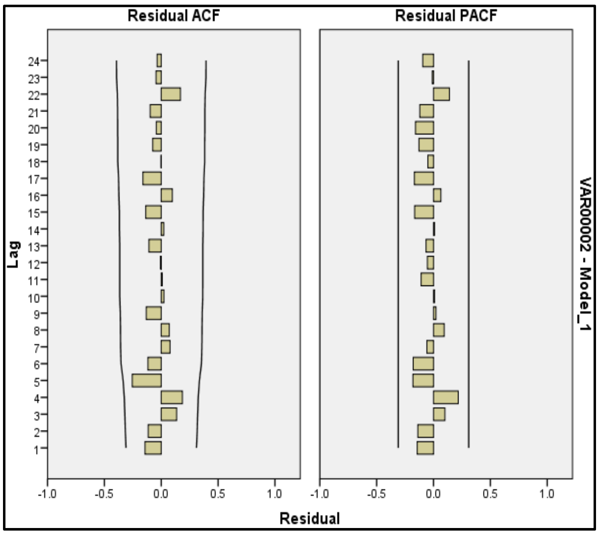

Fig. 3 ACF and PACF after becoming the data stationary

In the ARIMA (p, d, q) model p means the number of autoregressive order which specify how many previous values from the series are used to predict the current values [26]. For example, an autoregressive order of 10 specifies that the value of the series ten time periods in the past be used to predict the current value. In this study a higher value of *p (29)* was preferred almost in all cases. The parameter *d (1)* refers the order of differencing applied to the series before estimating models. The order of differencing corresponds to the degree of series trend--first-order differencing accounts for linear trends, second-order differencing accounts for quadratic trends, and so on [26]. The last parameter q (0) refers the number of moving average orders which specify how deviations from the series mean for previous values are used to predict the current values. For example, moving-average orders of 1 and 2 specify that deviations from the mean value of the series from each of the last two time periods be considered when predicting the current values of the series [27].

For the forecasting ARIMA (29,1,0) model was used in almost all cases. Pure mathematical form of ARIMA model can be written as follows:

$$W_t = \mu + \frac{\theta(B)}{\varphi(B)} \alpha_t$$

where, t is the index time, Wa is the response series Y_t or a difference of the response series, μ is the mean term, B is the backshift operator that is; $B X_t = X_{t-1}$, $\varphi(B)$, autoregressive operator which is represented as a polynomial in the back shift operator: $\varphi(B) = 1 - \varphi_1 B \ldots\ldots\ldots \varphi_p B^p$, $\theta(B)$ is the is the moving-average operator, represented as a polynomial in the back shift operator: $\theta(B) = 1 - \theta_1 B \ldots\ldots\ldots \theta_p B^p$, α_t is the independent disturbance, also called the random error.

D. Forecasting the Rainfall

For the forecasting process, at first the rainfall of each month from 1975 to 2014 (for instance, monthly average rainfall of January from 1975 to 2014) were incorporated in the data view of IBM SPSS and then the rainfall data were defined from the data define option. To select the ARIMA model this study followed the, *Analyze => Forecasting => Create Models => ARIMA (29,1,0)* pathways. To set the forecasting limit 2040 was incorporated in the specific option. In each execution of the model some statistical parameters like stationary R^2, R^2, Root Mean Square Error (RMSE) and normalized Bayesian information criterion (BIC), of the model were chosen to plot. When the model was run, it showed both graphical and numerical forecasted values and the forecasted values were saved along with other model statistical parameters.

E. Model Calibration

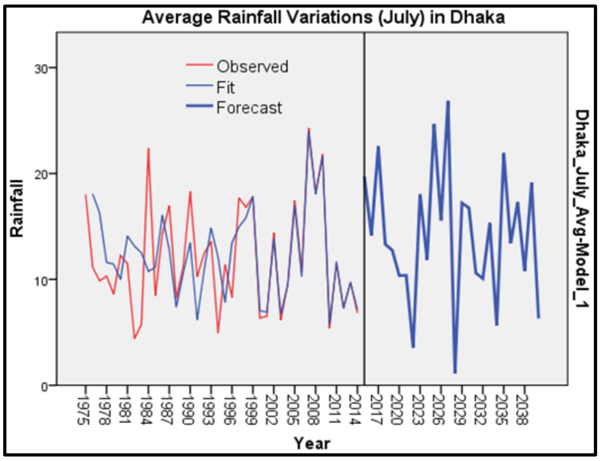

Fig. 4 Comparison of historical and forecasted rainfall

To test the performance of a model prior to forecasting any data is known as the model calibration. Calibration provides an impression about the degree of accuracy of the model in forecasting process. This model was calibrated using the historical rainfall data. In this study, forecasting started from 1975 and ends at 2040. To calibrate the model, the observed rainfall data of last 10 years was emphasized and found that model fit values matched with the observed values showing variations not more than 0.6 percent only (Fig. 4). In the beginning of the time period the forecasted values (or model fit values) showed significant differences with the observed values but with being time the model fit values got closer and showed almost same as observed rainfall of last 10 years. This scenario authenticates the forecasted data as well as the calibration of the model for this analysis. The graphical representation of the observed and model fit values is shown in Fig. 4.

III. Results and Discussion

From the analysis of the historical monthly average and monthly maximum rainfall records, it was found that overall rainfall decreased throughout the country. Specifically in the early pre-monsoon and early monsoon the rainfall decreased in almost all stations whereas in the late pre-monsoon, late monsoon and in the post monsoon rainfall increased in the maximum stations. This is a clear indication of shifting the rainfall intensity from pre-monsoon to monsoon and monsoon to post monsoon (Fig. 5-6).

According to the regional variation, it was also exposed that annual rainfall decreased in North West, North Central, South East and upper Eastern Hill regions whereas increased in South West, South Central, North East and lower Eastern Hill regions. The monthly maximum rainfall showed heavy fluctuations both temporally and spatially but significant increasing trends was observed in almost all stations in the month of October, late monsoon. On the contrary, in the late pre-monsoon, the maximum rainfall also showed increasing trend in the Eastern hill, South west and south central regions which is an indication of erratic rainfall pattern due to climate change. So from the observation of both monthly mean and monthly maximum rainfall it can be clearly stated that climate change in Bangladesh is really not a fun.

However, based on the analytical methods, data type and different study area, researchers may come up with different results as the rainfall data are multi-dimensional and non-linear which create complexities to draw specific conclusions [21]. For example, Basak et al. [13] found no change in the pre-monsoon and increasing trend in monsoon and post monsoon which is not consistent with the result of this study except the post monsoon. The causes of inconsistency may be due to the analysis of individual months where Basak et al. [13] analyzed seasonal variations.

In the seasonal variations the total rainfall of the individual seasons was sum up where rainfall shifting and variations in individual months could not be observed. Such as: March, April and May are the months of pre-monsoon and if the rainfall decreases in first two months and increase in the last month then the variations among the individual months can be minimized. In this case rainfall shifting or variations through the individual seasons cannot be recognized. Meanwhile, Hasan et al. [15] worked on the southwest region and found that the average annual and pre-monsoon rainfall increased where a trend analysis using Mann-Kendall method performed which is consistent with this research output but inconsistent with the Shahid [19] who worked on 17 stations and used rainfall data of the time period 1958-2007. The monthly maximum historical rainfall fluctuated both temporally and spatially but significant increasing trends was observed in almost all stations in the month of October, late monsoon. On the contrary, in the late pre-monsoon, the maximum rainfall also showed increasing trend in the Eastern hill, South west and south central regions. From the monthly maximum rainfall, it is observed that the heavy rainfall occurred in the late monsoon and late pre-monsoon which was expected in the early or mid-monsoon. This is called erratic rainfall which is a clear sign of climate change in Bangladesh. Note that, only in the eastern hilly region the heavy rainfall increased almost in the entire monsoon.

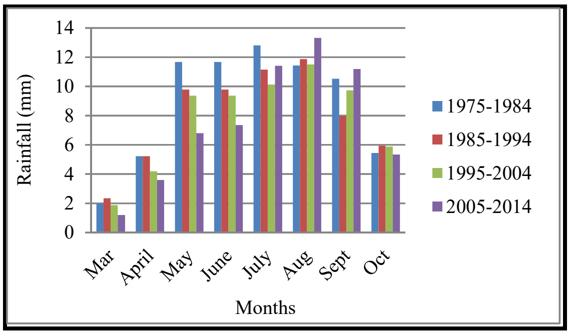

Fig. 5 Historical monthly average (decadal) rainfall at Dhaka

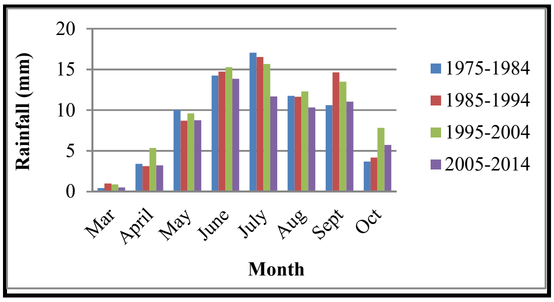

Fig. 6 Historical average (decadal) rainfall at Rangpur

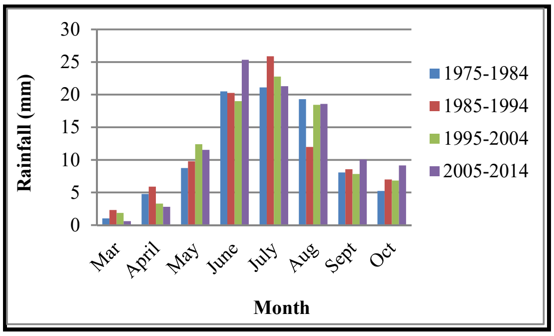

Fig. 7 Historical monthly mean (decadal) rainfall at Chittagong

A time series model, ARIMA (29,1,0) is used in this study for the forecasting as ARIMA is the most effective to predict future precipitation with a 95% confidence interval [20]. Forecasted rainfall shows enormous fluctuations and erratic behavior through the entire country rather than the historical records. From the forecasted rainfall the observation is, the pre-monsoon and early monsoon will get drier in future (Fig. 10) whereas late monsoon and post monsoon will show huge fluctuations in rainfall magnitudes with temporal variations which is consistent with the other studies [5], [14], [16], [17] which worked with different stations for different time periods. Another vital prediction is that from North to South the central part of Bangladesh will be drier compared to the other parts of this country (Fig. 9). The detail results of all stations are given in Table II (ANNEX). However, rainfall is not a continuous data like temperature. It is multi-dimensional and non-linear which creates difficulties in the forecasting process [21].

It is worth noting that the forecasting of rainfall is kind of prediction only which may be or may not turnout exact in the future. But if the existing state contains business as usual then the forecasted results may come true over time.

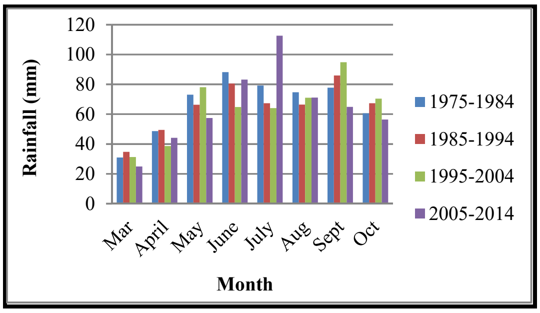

Fig. 8 Monthly maximum (decadal average) rainfall at Dhaka

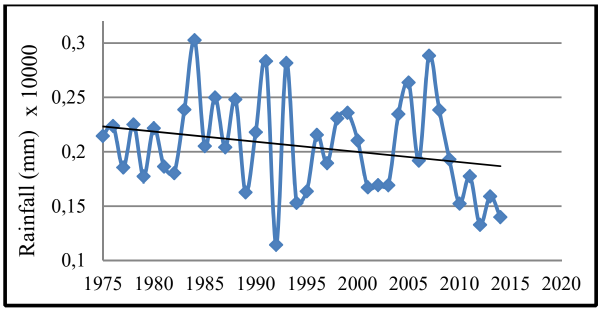

Fig. 9 Annual rainfall at Dhaka

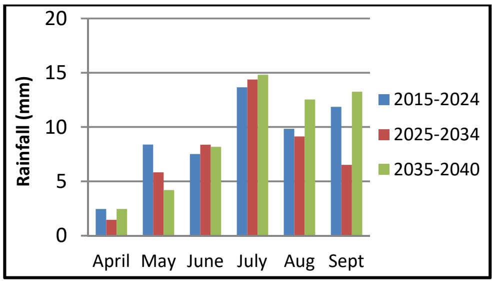

Fig. 10 Forecasted monthly mean (decadal) rainfall at Dhaka

IV. Conclusions

Based on the analysis results of the historical records and the forecasted rainfalls, it can be concluded that the overall rainfall in Bangladesh decreased over the total time period that may also continue in future. The central part of Bangladesh will be drier than its other counter parts. In case of monthly mean (decadal average) and monthly maximum (decadal average) rainfall, expected rainfall pattern in the early or mid-monsoons would be replaced by the late seasons. The post monsoon will be comparatively wetter than the past. If this situation continues then the north-central and northern part of Bangladesh will be comparatively drier in coming decades which is very dangerous news for this agriculture dependent country.

Appendix

TABLE II
RAINFALL AT DIFFERENT STATIONS

Stations	Historical Rainfall		Forecasted Rainfall	
	Pre-monsoon (MAM)	Monsoon (JJA)	Pre-monsoon (MAM)	Monsoon (JJA)
Dhaka	Average rainfall decreased over the total time period.	Decreased over the total time period but increased only in July of last decade.	Will decrease over the entire time period	Will decrease over the entire time period
Chittagong	Increasing trend was observed only in May.	Decreasing trends with fluctuations.	Increasing trend was observed only in May	Increasing trends
Rajshahi	Decreasing trend with fluctuations	Decreasing trend with fluctuations	Decreasing trend throughout the total time period.	Decreasing trend throughout the total time period.
Rangpur	Fluctuation with decreasing trend.	Little increasing trend in early monsoon otherwise decreased.	Same as historical trends	Same as historical trends
Bogra	Decreased in all months	Fluctuated throughout the entire time period.	Decreasing trend	Increasing trend in August only otherwise will decrease.
Sylhet	Decreased in all months	Decreased in all months except in August where little increase observed.	Will increase in May otherwise will decrease	Little increase in August otherwise will decrease.
Srimangal	Fluctuated with decreasing trend	Fluctuated with decreasing trend but little increase was observed in late monsoon	Increasing trend was observed in May otherwise decreased.	Increasing trend was observed in August otherwise decreased.
Mymensing	Decreased in all months over the total time period	Little increasing trend was observed in August otherwise decreased.	Will fluctuate	Will fluctuate
Khulna	Decreased in all months over the total time period	Increased in only in the mid monsoon otherwise decreased.	Decreased in all months.	Decreased in only in the early monsoon otherwise will remain same.
Khepupara	Increasing trend in May otherwise decreased.	Significant increase in July otherwise decreased in all months.	Increasing trend in May otherwise will decrease	Little increasing trend was observed in all months
Barishal				
Mongla	Increased in May only.	Little fluctuation observed in June otherwise increased.	Same as historical rainfall	Same as historical rainfall
Cox's Bazar	Increased in May only otherwise decreased	Overall increased in all months	Will increase in May only	Will increase in all months

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REFERENCES

[1] M. Hulme, T. J. Osborn, and T. C. Johns, "Precipitation sensitivity to global warming: Comparison of observations with HadCM2 simulations," Geophys. Res. Lett., vol. 25, p. 3379, 1998.
[2] G. Fu, N. R. Viney, S. P. Charles, and J. Liu, "Long-Term Temporal Variation of Extreme Rainfall Events in Australia: 1910–2006.," J. Hydrometeorol., vol. 11, no. 4, pp. 950–965, 2010.
[3] A. Khan, "Bangladesh – The Most Climate Vulnerable Country," The World Bank, 2013. .
[4] R. S. J. Tol, "The economic impact of climate change in the 20th and 21st centuries," Clim. Change, vol. 117, no. 4, pp. 795–808, 2013.
[5] M. Hossain, K. Roy, and D. Datta, "Spatial and Temporal Variability of Rainfall over the South-West Coast of Bangladesh," Climate, vol. 2, no. 2, pp. 28–46, 2014.
[6] A. Aziz, I. Hossain, and N. F. Rahman, "Effects Of Rainfall And Maximum Temperature On Aman Rice Production Of Bangladesh : A Case Study For Last Decade," Dep. Environ. Dhaka, vol. 3, no. 2, pp. 131–137, 2014.
[7] J. K. Basak, "Changing Rainfall Pattern Effects on Water Requirement of T . Aman Cultivation in Bangladesh," vol. 11, no. June, pp. 1–8, 2011.
[8] J. De Dios Miranda, F. M. Padilla, R. Lázaro, and F. I. Pugnaire, "Do changes in rainfall patterns affect semiarid annual plant communities?," J. Veg. Sci., vol. 20, no. 2, pp. 269–276, 2009.
[9] M. Beyer, M. Wallner, L. Bahlmann, V. Thiemig, J. Dietrich, and M. Billib, "Rainfall characteristics and their implications for rain-fed agriculture: a case study in the Upper Zambezi River Basin," Hydrol. Sci. J., p. 150527103244004, 2014.
[10] R. Sikder and J. Xiaoying, "Climate Change Impact and Agriculture of Bangladesh," J. Environ. Earth Sci., vol. 4, no. 1, pp. 35–40, 2014.
[11] M. Hossain, K. Roy, and D. Datta, "Spatial and Temporal Variability of Rainfall over the South-West Coast of Bangladesh," Climate, vol. 2, no. 2, pp. 28–46, 2014.
[12] M. Hashizume et al., "The effect of rainfall on the incidence of cholera in Bangladesh.," Epidemiology, vol. 19, no. 1, pp. 103–110, 2008.
[13] J. K. Basak, R. A. M. Titumir, and N. C. Dey, "Climate change in Bangladesh: A historical analysis of temperature and rainfall data," J. Environ., vol. 2, no. 2, pp. 41–46, 2013.
[14] S. Farhana, "Characterizing rainfall trend in Bangladesh by temporal statistics analysis," 4th Annu. Pap. Meet 1st Civ. Eng. Congr., pp. 978–984, 2011.
[15] Z. Hasan, S. Akhter, and A. Kabir, "Analysis of Rainfall Trends in the South-East Bangladesh," vol. 3, no. 4, pp. 51–56, 2014.
[16] M. Roy, "Time Series, Factors and Impacts Analysis of Rainfall in North-Eastern Part in Bangladesh," Int. J. Sci. Res. Publ., vol. 3, no. 8, p. 129, 2013.
[17] A. Mannana, A. M. Chowdhury, and S. Karmakar, "Long-range and short-range prediction of Rainfall and Rainy days over northwestern part of Bangladesh during Monsoon Season," in International Conference on Physics Sustainable Development & Technology (ICPSDT-2015), 2015, pp. 47–53.
[18] M. R. Rahman and H. Lateh, "Climate change in Bangladesh: a spatio-temporal analysis and simulation of recent temperature and rainfall data using GIS and time series analysis model," Theor. Appl. Climatol., pp. 1–15, 2015.
[19] S. Shahid, "Rainfall variability and the trends of wet and dry periods in Bangladesh," Int. J. Climatol., vol. 30, no. 15, pp. 2299–2313, 2010.
[20] S. H. Bari, M. T. Rahman, M. M. Hussain, and S. Ray, "Forecasting Monthly Precipitation in Sylhet City Using ARIMA Model," Civ. Environ. Res., vol. 7, no. 1, pp. 69–78, 2015.
[21] S. Banik, F. H. Chanchary, K. Khan, R. A. Rouf, and M. Anwer, "Neural network and genetic algorithm approaches for forecasting bangladeshi monsoon rainfall," in 2008 11th International Conference on Computer and Information Technology, 2008, vol. 2, no. 1, pp. 735–740.
[22] M. Alam, "Process Development for Hydrological Region- wide Integrated Water Resources Management Model in Bangladesh," Asian J. Appl. Sci. Eng., vol. 4, no. 2, pp. 137–146, 2015.
[23] B. Guha and G. Bandyopadhyay, "Gold Price Forecasting Using ARIMA Model," J. Adv. Sci., vol. 4, no. 2, pp. 117–121, 2016.
[24] M. Ranjbar and M. Khaledian, "Using Arima Time Series Model in Forecasting the Trend of Changes in Qualitative Parameters of Sefidrud River," Int. Res. J. Appl. Basic Sci., vol. 8, no. 3, pp. 346–351, 2014.
[25] D. Şchiopu, E. G. Petre, and C. Negoiňă, "Weather Forecast using SPSS Statistical Methods," vol. LXI, no. 1, pp. 97–100, 2009.
[26] IBM Corporation, "IBM SPSS Forecasting 22," p. 48, 2012.
[27] SAS Institute Inc., "The ARIMA Procedure," SAS/ETS® 13.2 User's Guid., pp. 186–298, 2014.