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School of Mathematical Sciences,
Tribhuvan University, Kathmandu, Nepal

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Forecasting Annual Mean Temperature and Rainfall in Bangladesh Using Time Series Data

Keya Rani Das[1*], Preetilata Burman[2], Linnet Riya Barman[3], Mashrat Jahan[4], Mst. Noorunnahar[5]

[1,5]*Dept. of Statistics, Bangabandhu Sheikh Mujibur Rahman Agricultural University Gazipur, Bangladesh.*

[2,3]*Faculty of Agricultural Economics and Rural Development, Bangabandhu Sheikh Mujibur Rahman Agricultural University Gazipur, Bangladesh*

[4]*Dept. of Agricultural Economics, Bangabandhu Sheikh Mujibur Rahman Agricultural University Gazipur, Bangladesh*

Email: [1]*keyadas57@bsmrau.edu.bd*, [2]*preetypbs@gmail.com*, [3]*linnetriya@gmail.com*, [4]*mjahan.aec@bsmrau.edu.bd*, [5]*noorunnahar.stt@bsmrau.edu.bd*

*Corresponding author: Keya Rani Das

Abstract: *Our ability to grow crops is significantly impacted by the weather. Therefore, it is important to make predictions about the weather. Because of its reliance on stable weather conditions, agriculture is highly susceptible to the effects of climate change. Countries like Bangladesh, whose economy is based on agriculture, will be more severely affected by the effects of climate change than others. For this reason, it is crucial to develop a robust forecasting tool to determine the implications of climatic variables, especially temperature and rainfall. In this study, we project the average annual rainfall and temperature in Bangladesh using the Auto-Regressive Integrated Moving Average (ARIMA) model for the next decade, from* 2023 *to* 2032. *Bangladesh's precipitation and temperature records from the past* 60 *years were compiled and analyzed with the help of the R programming language. Annual mean temperatures are forecasted to fall between* 24.9 *and* 26.3 *degrees Celsius, while annual mean rainfall is forecasted to fall between* 1,550 *and* 2,650 *millimeters.*

Keywords: *Rainfall, Temperature, Agricultural production, Bangladesh, ARIMA.*

Introduction

Agriculture is the backbone of the economies of many developing countries because it provides people with both food and income. Since this sector is highly vulnerable to climate change, Bangladesh, one of the rising developing nations, is in particular jeopardy. Farmers use weather forecasts and climatological trends to determine which crops to plant and when. Climate has a major impact on how often pests need and diseases occur, how easily farmers can get their hands on water, and how much fertilizer they need to use. However, climatic change and variability have an effect on agricultural output and standard of living. Recent climate changes have had multiple effects on crop yields (Lobell et. al, [21]). The threat that climate change posed to small and medium-sized rainfed farmers was significant (Ashalatha et. al, [4]).

Bangladesh typically experiences subtropical monsoon weather. The highest temperature ever recorded in the summer is 37 C (98 F), while there are few spots where it can occasionally reach 41 C (105 F) or more. Between July and October, we get about 80% of our annual precipitation. Precipitation totals typically fall between 1429 and 4338 millimeters per year on average (BBS, [7]).

The effects of the climate affect many facets of agricultural production (Iizumi&Ramankutty, [16]). The primary climatic factors affecting agricultural production include rising temperatures, changed precipitation patterns, and an increase in atmospheric CO2 concentration (Neenu et. al, [26]). In terms of agriculture, temperature and rainfall are two of the most important climatic parameters. Understanding how temperature and precipitation variations impact crop output is a crucial first step in developing policy and agricultural management choices.

A significant economic factor is the timing of rainfall (Torres et. al, [36]). The effect of rainfall on agricultural productivity could be asymmetric (Mitra, [35]). Long-term changes in natural rainfall patterns might pose a problem for the world's current farming methods (Wei et. al, [38]). Rainfall's impact on crop production can be explained by either its seasonal average quantity or its temporal distribution. Rainfall unpredictability affects food accessibility per capita and raises the percentage of the overall malnourished population in developing countries (Kinda & Badolo, [18]). Rainfall does not directly affect production because it is dependent on the environment, but there are many other factors that do (Yudin et. al, [24]). Precipitation is also responsible for loss of soil nutrients.

It was discovered that brief hot spells can lower the number of seeds or grains that might otherwise contribute to crop yield (Wheeler et. al, [39]). These results imply that temperature rises brought on by climate change may have a significant influence on agricultural yields, which may have consequences for the world's food supply. Depending on how each crop species is affected, heat stress has a negative impact on normal plant growth and development (Bhattacharya, [8]). The pace of phenological development was accelerated by warm temperatures (Hatfield & Prueger, [13]). The benefits of increased planting density for yield are diminished by higher temperatures (Wang et. al, [37]). Efficiency is considerably reduced by increases in yearly temperature fluctuation and long-term temperature (Rahman & Anik, [31]). Yields were reduced by temperatures outside or inside the ideal range (18–22 °C) (Jannat et. al, [17]). In Bangladesh, rising temperatures were linked to declines in the value of small farms (Hossain et. al, [14]). All of Bangladesh's primary food crops' production and cropping areas were negatively impacted by the maximum temperature. But in certain cases, crop yields have typically increased when temperatures have increased. The net crop revenue from crop cultivation in Bangladesh will grow as the temperature and rainfall rise (Hossain et. al, [15]). Crop yields are increased through climate-smart agriculture, which also makes it easier to produce crops in a secure environment (Liliane & Charles, [19]). The production of annual crops like wheat and groundnuts can be drastically reduced by brief high-temperature events that occur at various periods close to blooming (Challinor et. al, [10]). Wheat yields are reduced by around 3–10% for every 1°C increase in temperature throughout the growing season (You et. al, [43]).

In the study district in Ghana, the unpredictable rainfall and rising temperatures have a significant beneficial influence on maize output, underscoring the necessity for ongoing adaptation strategies such cultivating high yielding and drought tolerant maize varieties to improve family food security (Baffour-Ata et. al, [6]). Zhao et. al. [45] discovered that rising temperatures have a detrimental effect on the world's wheat, rice, maize, and soybean crops. According to a study by Lobell and Field, [20] rising temperatures cause a decline in worldwide wheat, maize, and barley yields. According to Schlenker and Roberts, [33] research, maize, soybean, and cotton yields in the US are severely harmed by temperatures that are higher than a particular point. Maize, rice, and soybean crops all benefited from higher minimum temperatures (Yin et. al, [41]). Rainfall has a detrimental impact on rice output during the heading, flowering, ripening, and reproductive stages. Rice breeders should create rice types that use less water and are more productive in hot weather (Abbas & Mayo, [1]). Since there are so many negative impacts of rainfall and temperature fluctuations all over the world like this, it is even more important for Bangladesh to come up with a good forecasting method.
Crops, animals, and pests are all vulnerable to changes in temperature and precipitation patterns, which can have an effect on agricultural output. Predicted shifts in the climate must be taken into account so that farmers and ranchers can adapt and increase their resilience. Climate variability and changes in the frequency of severe events are essential for the yield, its stability, and quality (Porter & Semenov, [28]). That's why it's crucial to know how precipitation and temperature will affect agricultural output. The purpose of this study is to predict annual mean precipitation and temperature for the period 2023-2032 in an effort to alleviate a major agricultural problem.

Methods

The aim of this research is to predict rainfall and mean temperature for the next 10 years from 2023 to 2032. Both forecasting is done using ARIMA. Rainfall and mean temperature records of Bangladesh for the past sixty years (1961-2021) were collected from the Climate Change Knowledge Portal of World Bank (World Bank, [40]). Analysis was done in RStudio with the help of auto.arima() function. In this analysis, lubridate, ggplot2, dplyr, and forecast packages were applied. There are no missing values in this data set. The study is conducted with non-stationary time series data. The Auto-Regressive Integrated Moving Average (ARIMA) model is used to forecast annual mean rainfall and temperature trends in Bangladesh.

ARIMA Model

The Autoregressive (AR) model can be effectively coupled with Moving Average (MA) models to form a general and useful class of time series models called Autoregressive Moving Average (ARMA) models. However, they can only be used when the data are stationary. This class of models can be extended to non-stationary series by allowing differencing of the data series. These are called the Autoregressive Integrated Moving Average (ARIMA) model (Anderson & Theodore, [3]). Thus, an ARIMA model is a combination of an Autoregressive (AR) process and a Moving Average (MA) process applied to a non-stationary data series. The three essential elements of the ARIMA model are autoregressive, integrated, and moving average, which drives the evaluation and selection of coefficients iteratively and recursively. These three elements are known as p, d, and q, respectively (Aborass et al, [2]).

The general non-seasonal model is known as ARIMA (p,d,q):

AR:p =order of the autoregressive part

I:d = degree of differencing involved

MA:q =order of the moving average part

The equation forth simplest ARIMA (p,d,q) model is as follows:

$$Y_t = c + \varphi_1 Y_{t-1} + \varphi_2 Y_{t-2} + \ldots + \varphi_p Y_{t-p} + e_t - \theta_1 e_{t-1} - \theta_2 e_{t-2} - \ldots - \theta_p e_{t-p} \qquad (1)$$

Where, Y_t = Climatic factor (Annual mean rainfall and temperature)

Y_{t-1}, Y_{t-2},…,Y_{t-p} = Climatic factor (Annual mean rainfall and temperature)at time lags t-1,t-2,…,t-p ,respectively.

The Box Jenkins Methodology

The Box Jenkins methodology is used to find the best-fitted model of time series data for both Univariate and Multivariate ARIMA models (Ljung & Box, [22]). Box-methods Jenkin's have four steps. First, it is necessary to determine whether or not the variables are stationary. The unit root test is used to ensure stationarity. To check the unit root and stationarity of the data, the augmented Dickey-Fuller (ADF) test and the Kwiatkowski, Phillips, Schmidt, and Shin (KPSS) test can be used. If the data is not stationary, it is transformed to be stationary by comparing the original data series. The second step is to develop a preliminary model that specifies the appropriate values of p, d, and q. The AutoCorrelation Function (ACF) and Partial Auto Correlation Function (PACF) plot to assist us in determining the order of the MA and AR processes respectively. The third step is to estimate the model's parameters using likelihood methods such as AIC, AICc, and BIC. Finally, the best-fitted model must be validated by testing the parameters and residuals of the chosen model. The residuals are examined using the ACF and PACF plots, as well as the (Box & Jenkins, [9]) statistics.

Decomposition of Time Series Data

To break down time series data into its component parts, decomposition of data is used. Using RStudio, simple additive decomposition has been performed. It goes like this:

$$Y_t = S_t + T_t + R_t \qquad (2)$$

Where, S = Seasonal Variation

T = Trend or cyclic component

R = Residual or error component

Results and Discussion

Annual Mean Rainfall

The time series plot (figure 1) shows stationary and the parameter values of p, d and q found for the ARIMA model are 0, 1 and 2. The final model chosen with the aid of the "auto.arima()" function is ARIMA (0,1,2).

Fig.1: *Time series plot of yearly rainfall in Bangladesh*

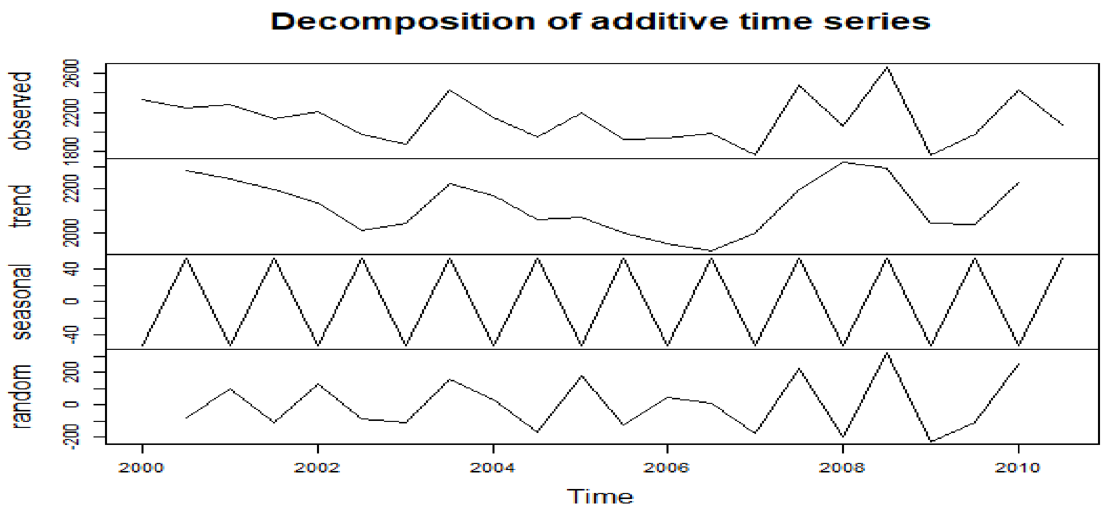

Fig.2: *Decomposition of additive time series of annual mean rainfall data in Bangladesh*

In figure 2, four types of plots are shown. first one is for the observed raw data, the second one shows the trend of the data, the third one depicts the seasonal variation and the last one shows a random component. No specific trend shows in the above plot.

Table 1

Parameter estimation of ARIMA (0,1,2) model

Parameter	Coefficients	St. Error	z value	Pr(>|z|)
MA1	-1.1073	0.1238	-8.9449	<2e-16 ***
MA2	0.2164	0.1250	1.7318	0.0833*

*** *means significant at* 1%, ** *means significant at* 5% *and* * *means significant at* 10% *level of significance*.

The model selection criteria as Akaike Information Criteria (AIC), lowest Corrected Akaike Information Criteria (AICc), Bayesian information criterion (BIC) values are listed in the following table for the yearly average rainfall data.

Table 2

Performance criteria of ARIMA (0,1,2) model

Criteria	ARIMA(0,1,2)
log likelihood	-420.88
$sigma^2$	72730
AIC	847.77
AICc	848.2
BIC	854.05

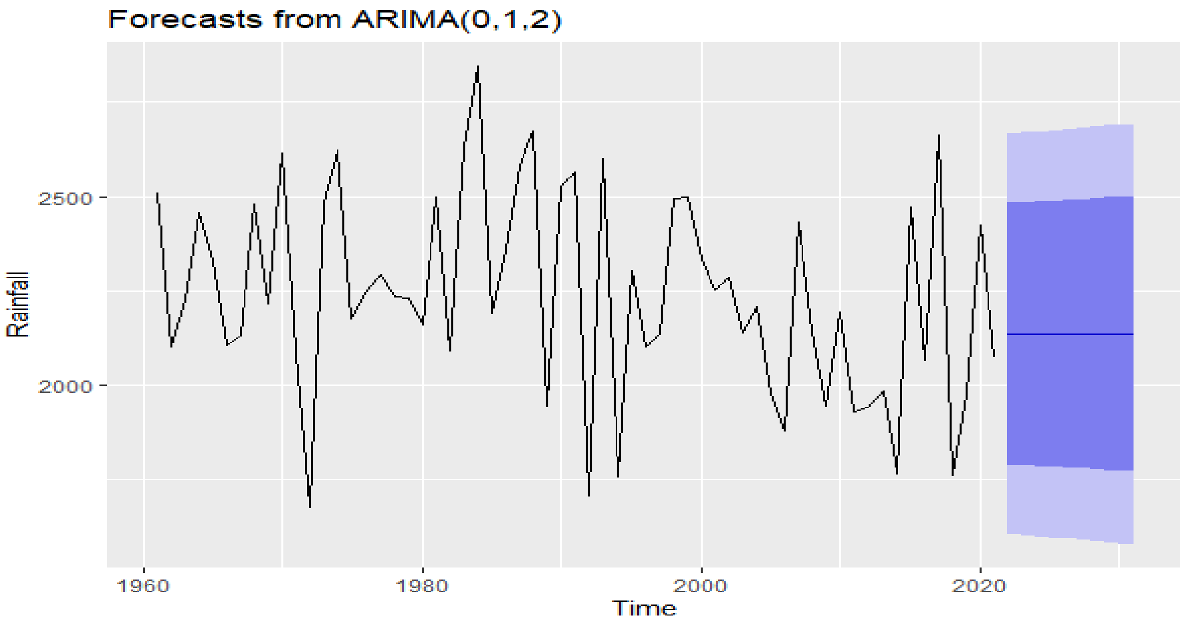

Fig.3: *Forecasting yearly average rainfall in Bangladesh*

Figure 3 focuses the forecasted values of yearly average rainfall in Bangladesh for the next ten years from 2022 to 2032. By using ARIMA(0,1,2) model the deep blue shade in the forecasted part shows 80% confidence interval and light blue shade shows 95% confidence interval for the rainfall in Bangladesh. From the 95% confidence interval it depicts the forecasted average annual rainfall is around 1550 mm to 2650 mm.

Annual Mean Temperature

The parameter values for the ARIMA model are determined to be 0, 1, and 2 according to the time series plot in Figure 4. The final model chosen with the aid of the "auto.arima ()" function is ARIMA (0,1,2).

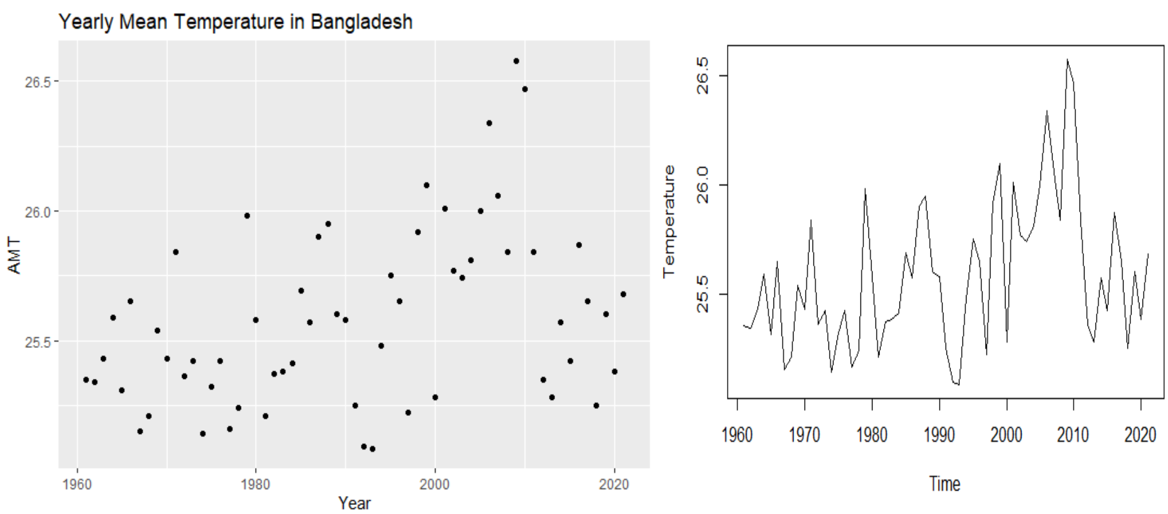

Fig.4: *Time series plot of yearly mean temperature in Bangladesh*

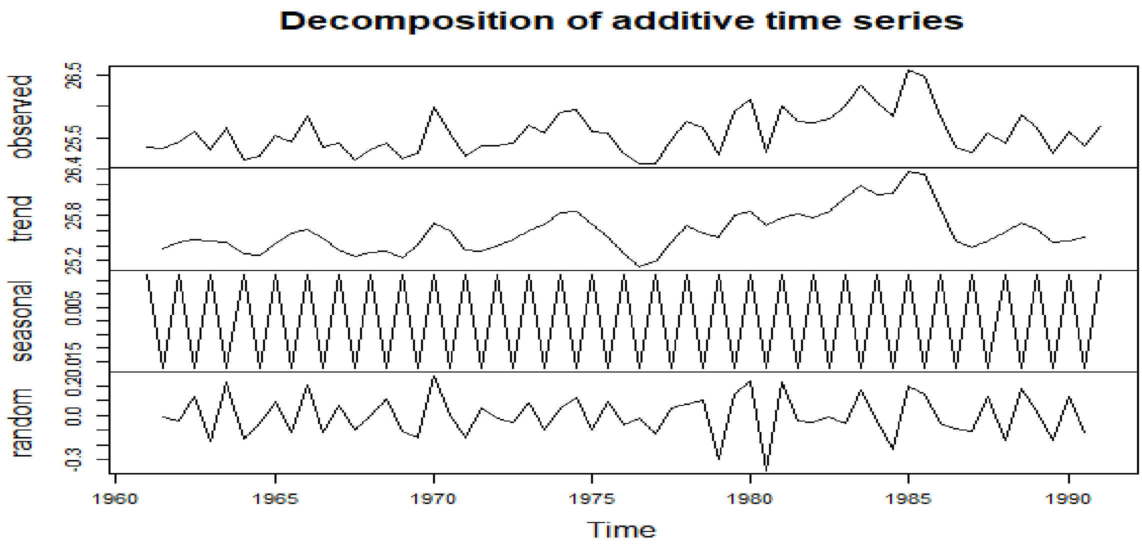

Fig.5: *Decomposition of additive time series of annual mean temperature data in Bangladesh*

Figure 5 displays four different types of plots, the first of which is for the observed raw data, the second of which indicates the data's trend, the third of which shows the seasonal fluctuation, and the fourth of which displays random components. For this data, there is no specific trend in the figure 5.

Table 3

Parameter estimation of ARIMA (0,1,2) model

Parameter	**Coefficients**	**St. Error**	**z value**	**Pr(>|z|)**
MA1	–0.4816	0.1363	–3.5336	0.0004***
MA2	–0.3270	0.1577	–2.0732	0.03816**

*** *means significant at* 1%, ** *means significant at* 5% *and* * *means significant at* 10% *level of significance.*

For the yearly average temperature data, the model selection criteria such as Akaike Information Criterion (AIC), lowest Corrected Akaike Information Criteria (AICc), and Bayesian information criterion (BIC) values are provided in the table below.

Table 4

Performance criteria of ARIMA (0,1,2) model

Criteria	**ARIMA(0,1,2)**
log likelihood	-12.56
$sigma^2$	0.09063
AIC	31.11
AICc	31.54
BIC	37.4

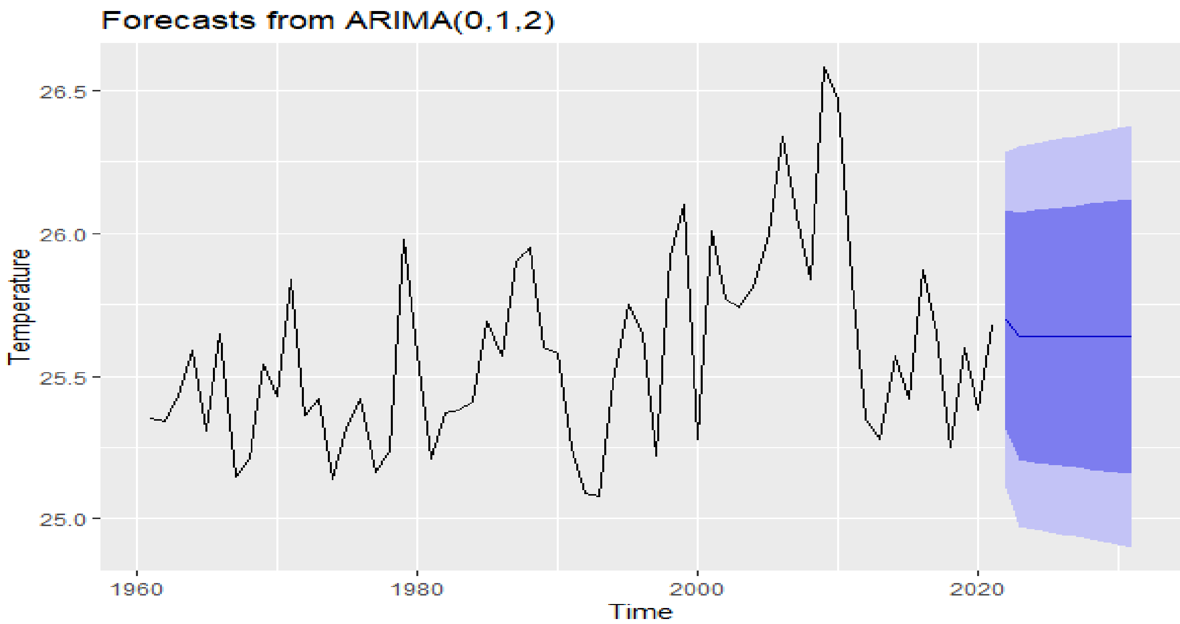

Fig.6: *Forecasting yearly average temperature in Bangladesh*

Figure 6 depicts the anticipated values of yearly average mean temperature in Bangladesh over the next 10 years, from 2023 to 2032. Using the ARIMA(0,1,2) model, the deep blue shade in the predicted portion represents an 80% confidence interval while the light blue shade shows a 95% confidence interval for the temperature in Bangladesh. According to the 95% confidence interval, the anticipated average annual mean temperature ranges between 24.9 ^{0}C and 26.3 ^{0}C.

Over the years, researchers have tried to pin down the best approach to studying climate change's impact on farm yields. The yield of crops is greatly affected by weather fluctuations over time (Yirdew & Yeshiwas [42]). Extreme heat and rain events have been demonstrated to significantly lower crop yields (Powell & Reinhard, [29]). But, accurate weather predictions can reduce planting-stage wages by reducing prior out-migration and can amplify the negative effects of bad meteorology on crop production wages (Rosenzweig & Udry, [32]). In addition, rainfall has both a short-term and long-term negative and considerable influence on agriculture productivity (Zahoor et al, [44]). Again another pair of researchers say that rainfall and economic growth in general appear to be growing in tandem. Temperature, unlike rain, has little effect on agricultural productivity (Erkan&Diken, [11]). But it has been found that more so than rainfall, temperature has an influence on crop productivity (Ochieng et al, [27]). Cotton production is growing in relation to rainfall (Ghanwat et al, [12]) whereas rainfall had little effect on coffee output (Msuya & Mahonge, [25]). With global warming, it is predicted that average temperatures would rise and heat waves will occur more frequently (Asseng et. al, [5]). For most nations, the impacts of heat are equal to or greater than those of water stress (Siebert et al, [34]). Crop performance suffers as a result of rising global temperatures (Zhu et al, [46]). The studies repeatedly demonstrate that agricultural yields are significantly impacted by temperature.

Short- and long-term stresses can significantly influence growth and yield processes when stress occurs at sensitive stages (Prasad et al, [30]). So regulated, steady growth in climatic factors is sometimes good for agricultural production. Bangladesh has witnessed extremes in rainfall and temperature during the previous few decades, affecting both the environment and the agricultural economy. Masum et al, [23] used the ARIMA model to predict and forecast rainfall and temperature in Chattogram, Bangladesh from 1953 to 2070 considering seasonal variations. (Aborass et al. [2]) applied the Box-Jenkins ARIMA methodology and comparative study of ETS model for rainfall forecasting at Birzeit for the period which extended from September -2003 to August-2021. This study predicts annual mean rainfall and temperature with the ARIMA (0,1,2) and ARIMA (0,1,2) model respectively.

Concluding Remarks

The two most important climatic factors are rainfall and temperature. Studies have shown that deviations in temperature from the ideal range can have a significant impact on a country's agricultural output. In a similar vein, inadequate or excessive precipitation will reduce agricultural output. A nation should take adequate measures to prepare for such critical climate elements. Floods, cyclones, droughts, and other extreme weather are becoming more frequent, wreaking havoc on farmlands and agricultural production in Bangladesh, one of the nation's most vulnerable to global warming. The consequences of global change, such as low land submergence, severe floods, cyclones, tidal waves, coastal flooding, and poor socioeconomic situations, especially with regards to everyday living and food security, are having a profound effect on the physical and chemical processes in these areas. Many factors, including but not limited to rising sea levels, rising temperatures, saline intrusion, shrinking cultivable landmass, limited access to clean water and sanitary conditions, infrastructure, plant diseases, limited energy sources, and so on, are making this worse. With increasing temperature and precipitation swings, farmers in Bangladesh can benefit from up-to-date and reliable weather forecasts in order to better manage crops in the field. The 10-year rainfall and mean temperature forecasts from 2023 to 2032 can help farmers make long-term plans and adjustments to their agricultural production processes. Even if climatic conditions may fluctuate due to a number of variables, this prediction will hopefully help them have a secure agricultural production process and avoid the difficult periods. If farmers had access to weather predictions, it might have prevented some of the damage that has been done. These climate services will help the agricultural sector prepare for and respond to extreme weather events, as well as adapt to the long-term effects of climate change. Therefore, this type of forecasting method is essential for ensuring the reliability of agricultural output.

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