Asian Journal of Probability and Statistics

Volume 22, Issue 2, Page 19-26, 2023; Article no.AJPAS.98602
ISSN: 2582-0230

An Application of ARIMAX Model to Examine the Effect of Climatic Factors on the Annual rice Production in Bangladesh

Md. Roshidul Islam [a#*] and Arman Hossain Chowdhury [a++]

[a] Department of Statistics, Begum Rokeya University, Rangpur, Bangladesh.

Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AJPAS/2023/v22i2480

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/98602

Original Research Article

Received: 08/02/2023
Accepted: 10/04/2023
Published: 15/04/2023

Abstract

Rice is the world's third main crops and around 160 million of people in Bangladesh consume it as a staple food. As a climate vulnerable country, the effect of climatic factors on rice production in Bangladesh is noticeable. Therefore, the study aimed to examine the impact of climatic factors on annual rice production in Bangladesh. We compiled a yearly dataset including rice production, mean temperature (˚C), relative humidity (%) and precipitation (mm/day) from 1981 to 2020. The entire data were analyzed by using Autoregressive Integrated Moving Average with Explanatory Variables (ARIMAX) model. We found that mean temperature had a negative impact on the rice production (β = -13518243, 95% CI: -19868503, -7167982). Relative humidity had both positive impact on the rice production (β = 1824456, 95% CI: 1418585, 2230327). Precipitation had both positive and negative impact on the rice production. In conclusion, mean temperature, relative humidity, and precipitation are three factors that may have an

[#] Associate Professor;
[++] Research Student;
**Corresponding author: Email: mroshid.brur@gmail.com;*

influence on the annual rice production in Bangladesh. Since Bangladesh has a hot, humid environment, it is therefore advised that breeders create rice types that use less water and are more effective in high temperatures.

Keywords: ARIMAX; rice; mean temperature; relative humidity; precipitation; Bangladesh.

1 Introduction

Bangladesh is the most climate vulnerable country in the world [1]. Climate variability and severity are influenced by variations in temperature and precipitation patterns [2]. The proliferation of green revolution technology is partly to blame for Bangladesh's output of foodgrains—primarily rice—growing faster than the country's population [3]. Rice is the major source of food for more than half of the world's population and its availability affects local economy and way of life [4]. Bangladesh is mostly an agricultural country and the crop production drives the majority of the economy of the country. Food production is especially vulnerable to climate change since the agricultural yields are directly affected by weather patterns (temperature and precipitation patterns). Even little increases in temperature will reduce the number of crops harvested in tropical areas. Higher increase in temperature will cause significant decreases in cereal output (e.g., rice, wheat) over the world [5]. Natural variation in precipitation is an important key element for both urban and agricultural water security as well as flood and drought forecasting which impact the rice production [6–8].

Several previous studies used several simulation techniques to evaluate the impact of climate on rice production [9–11]. Some previous studies used ordinary least squares and median (quantile) regression methods for assessing the impact of climate on rice production [12]. Time-series modeling is a prominent forecasting technique for understanding the dynamic relationship between relevant variables. The Autoregressive Integrated Moving Average with Explanatory Variables (ARIMAX) model is a robust time series model for examining the relationship between climate variable and annual rice production. And currently no study used this model for assessing the relationship between climate variable and annual rice production. Therefore, this study aimed to examine the impact of climatic factors on rice production in Bangladesh using the ARIMAX model.

Finally, the results of this study will assist policymakers and development experts to improve strategic planning and guaranteeing food security. In addition, it's important to look at potential future scenarios in order to assess how the climate may affect rice production in the future.

2 Materials and Methods

2.1 Data collection

Data on annual rice production from 1981 to 2020 were gathered from the FAOSTAT website [13]. The climate variables including mean temperature (˚C), relative humidity (%) and precipitation (mm/day) were collected from the NASA Langley Research Center (LaRC) website [14]. The data set do not contain any missing values.

2.2 ARIMAX model

The Autoregressive Integrated Moving Average (ARIMA) is a traditional time series forecasting model which consist of three parameters. The ARIMA (p, d, q) defines the parameters p and q which represent the lag order in the autoregressive, AR(p) component and the moving average, MA(q), respectively, while d defines the differentiation level for stationarity [15,16].

The autoregressive order p in a ARIMA model explain the p time prior observations with the random error which predicts the future value of a variable. On the other hand, the moving average order q explain the prior errors of the dependent variable [17]. The ARMA (p, q) model can be written mathematically as follows:

$$Y_t = C + \mu + \emptyset_1 Y_{t-1} + \emptyset_2 Y_{t-2} + \emptyset_3 Y_{t-3} + \emptyset_4 Y_{t-4} \ldots\ldots + \emptyset_p Y_{t-p} + \theta_1\varepsilon_{t-1} + \theta_2\varepsilon_{t-2} + \theta_3\varepsilon_{t-3} + \theta_4\varepsilon_{t-4} + \cdots + \theta_q\varepsilon_{t-q} + \varepsilon_t \quad (1)$$

Where, Y_t and ε_t are the observed value and random shock terms at time t, $\emptyset_i$ (i = 1,2,3,4....), c denotes the constant terms and μ denotes the series' mean, θ_j (j = 1, 2, 3... q).

Based on the above information, the general equation of the ARIMA (p, d, q) model can be written as

$$y'_t = c + \emptyset_1 y'_{t-1} + \emptyset_2 y'_{t-2} + \ldots + \emptyset_p y'_{t-p} + \theta_1\varepsilon_{t-1} + \theta_2\varepsilon_{t-2} + \ldots + \theta_q\varepsilon_{t-q} + \varepsilon_t \quad (2)$$

Where, y'_t denotes the differenced time series for stationarity, $\emptyset_1, \emptyset_2 \ldots \emptyset_p$ represents the coefficients of autoregressive (AR) terms and $\theta_1, \theta_2 \ldots \theta_q$ denotes the coefficients of moving average term.

The ARIMA model which includes several climate factors such as mean temperature, relative humidity, precipitation and so on as exogeneous or explanatory variables is mostly known as the Autoregressive Integrated Moving Average with Explanatory Variables (ARIMAX) model. The general equation of the model can be defined as

$$y_t = \beta_0 + \beta_1 x_{1,t} + \cdots + \beta_k x_{k,t} + \eta_t \quad (3)$$

where, y_t indicates the outcome variable for the time series; $x_{1,t} \ldots x_{k,t}$ are the climate factors or exogenous variables of the time series that could explain y_t and $\eta_t$is the random shock term from the regression model which describes the ARIMA model (eq. 2) [18].

2.3 Statistical data analysis

The ARIMAX model and the statistical analyses were performed using the Rstudio (Version 4.2.1) [19]. The time series data were processed by using the 'tseries' and stats packages. The 'forecast' package was used to fit the ARIMAX model using the auto.arima function. We used 'ggplot2' package for creating the figures.

3 Results

In Bangladesh, the maximum rice was produced in 2020 (54,905,891 tons), whereas the lowest was in 1962 (13,304,520 tons). The amount of rice on average produced annually was 29,960,847.08 tons. The results exhibit a significant degree of variation and an increasing linear trend. The Augmented Dickey Fuller (ADF) test verified that the data are not smooth (Fig. 1).

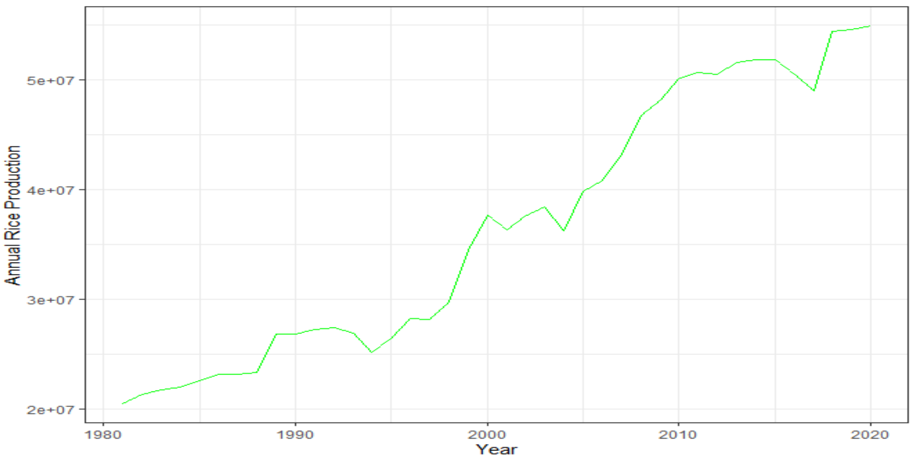

Fig. 1. Time series plot of Annual Rice Production data from 1981 to 2020

The maximum annual mean temperature in Bangladesh was 26.79 ˚C in 1994 while the minimum annual mean temperature was 25.06 ˚C in 2018. Maximum relative humidity was 81.62 % in 2017 while minimum was 61.38% in 1994. The average annual relative humidity was found 71.72%. The maximum annual precipitation in Bangladesh was 13.47 (mm/day) in 2017 and the minimum was 1.91 (mm/day) in 1992. On average the annual precipitation was 4.80 mm/day (Fig. 2).

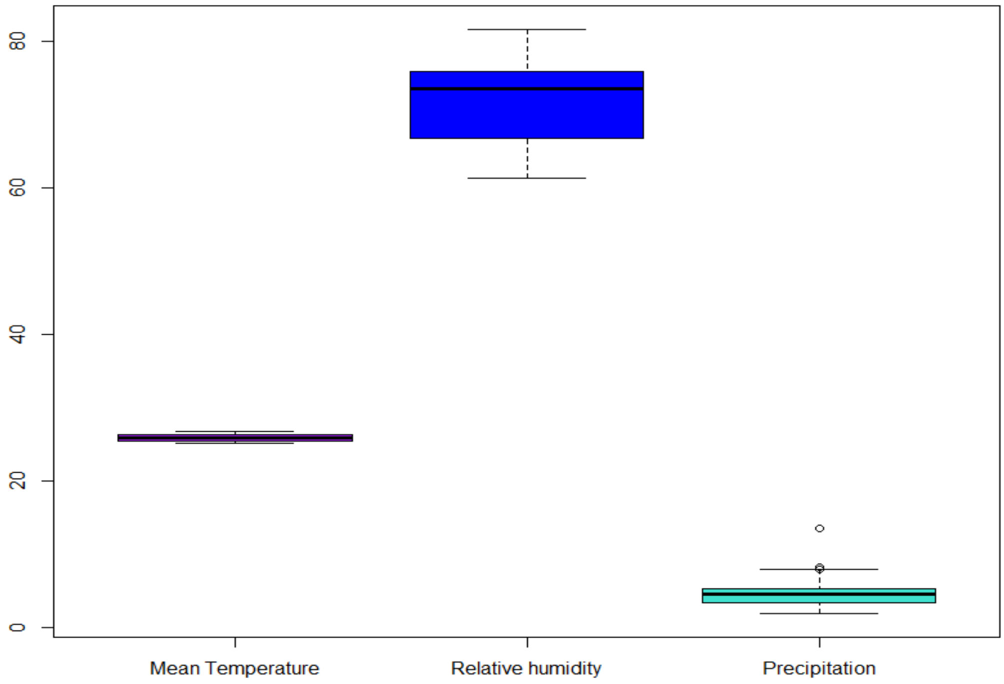

Fig. 2. Boxplot of the climate data variables

The cross-correlation between annual rice production and climatic factors was determined from lag 0 to 15. The only positive lags were considered in the study. Because only positive lags can explain the relationship between annual rice production and climate variables [20]. The mean temperature at lag 4 showed a significant association with rice production. Relative humidity at lag 3 and 4 showed significant relationship with the annual rice production in Bangladesh. Precipitation at lag 0 and 1 showed a significant relationship with the annual rice production in Bangladesh (Fig. 3).

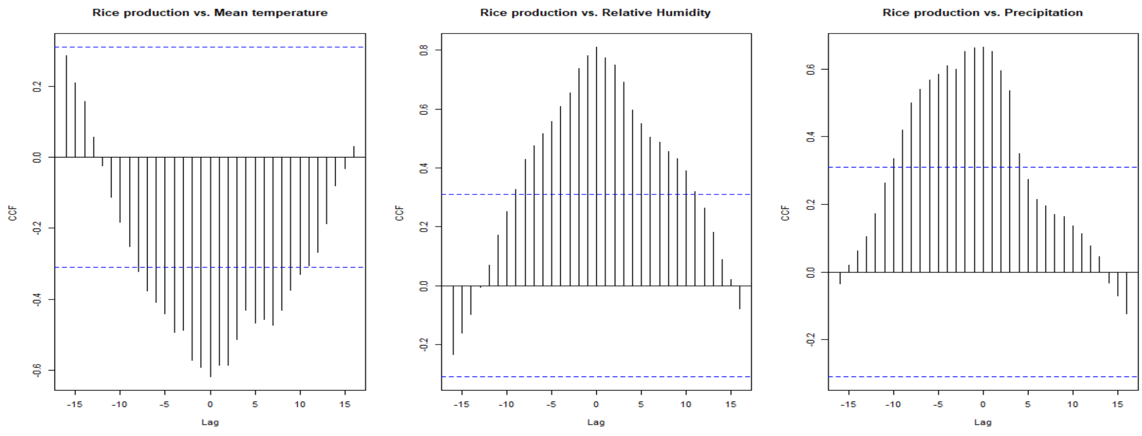

Fig. 3. Cross-correlation between annual rice production and climate variables in Bangladesh
CCF: Cross-Correlation Function

The above significant climate variables from cross-correlation were used as covariates in the ARIMAX model at different lags. For instance, mean temperature at lag 4 was used as covariates for the ARIMAX model. Similarly, the lagged relative humidity and precipitation were used and their impact on the rice production was shown in Table 1.

Table 1. Estimated parameters with 95% confidence intervals of significant climate factors of ARIMAX(0,1,0) models

Factors	Coefficients (β)	Lower 95% CI	Upper 95% CI	P-value
Mean temperature (4)	-13518243	-19868503	-7167982	p<0.01
Relative Humidity (2)	1847636	1467808	2227463	p<0.01
Relative Humidity (3)	1824456	1418585	2230327	p<0.01
Precipitation (0)	-546386	-814413.7	-278358.5	p<0.01
Precipitation (1)	329150	24106.83	634194	p<0.01

CI: Confidence interval

Table 1 illustrates that mean temperature at 4 (i.e., after 4 years) negatively impact the annual rice production (β = -13518243, 95% CI: -19868503, -7167982). Relative humidity at lag 2 had a positive impact on rice production (β = 1847636, 95% CI: 1467808, 2227463) and also positively impact the rice production at lag 3 (β = 1824456, 95% CI: 1418585, 2230327). The precipitation at 0 (i.e., same year) negatively impact the rice production (β = -546386, 95% CI: -814413.7, -278358.5) and positively impact the rice production at lag 1 (β = 329150, 95% CI: 24106.83, 634194).

4 Discussion

The study mainly examined the effect of climatic factors on the annual rice production in Bangladesh. Bangladesh has a hot, humid climate that is affected by pre-monsoon, monsoon, and post-monsoon circulations. Tropical cyclones and high precipitation are common in Bangladesh. In the past, temperatures in Bangladesh have ranged from 15°C to 34°C annually, with a mean temperature of roughly 26°C [21].

In our study, we found that climate variables have both positive and negative impact on the annual rice production. For example, the mean temperature had a negative impact on the annual rice production in Bangladesh which is similar to some previous studies [22,23]. If the mean temperature is increased, the production of rice will be decreased. And according to Baig and Amjad (2014), shifting variations in rainfall and temperature patterns are the primary climatic elements that have an impact on rice production [24]. Relative humidity had positive impact on the annual rice production which is in line with some previous studies [25]. We found that precipitation had both positive and negative impact on the rice production which is in line with some previous studies. According to our results, precipitation at same year can reduce the annual rice production but precipitation at lag 1 (i.e., after 1 year) can increase the rice production.

In this study, we examined that climate factors are both positively and negatively associated with annual rice production in Bangladesh. The results from our study will be helpful for the government and policymakers to take effect strategies in planning and guaranteeing the food security as well as to increase the rice production in Bangladesh.

5 Conclusion

The main objective of the study is to examine the impact of climatic factors on the annual rice production in Bangladesh. The statistical analyses were performed to determine the impact of climatic variables on rice production for the time period 1981 to 2020. The study found that climate factors have both positive and negative impact on the rice production. Since Bangladesh has a hot, humid environment, it is therefore advised that breeders create rice types that use less water and are more effective in high temperatures.

6 Limitations

This study used the traditional time series ARIMAX model to analyze the impact of climate factors on the annual rice production in Bangladesh. Hence, one of the limitations of the study is that several machine learning models such as random forest, artificial neural networks, support vector machines and so on were not applied but which are more efficient and robust. These should be applied further based on the adequacy of the data.

Competing Interests

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here (Please copy paste the total link in your browser address bar)
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