Bangladesh Rice J.27(2): 83-103, 2023, doi.org/10.3329/brj.v27i2.79473

Effects of Climatic Variables on Aus Rice Production in Bangladesh Using Geo Statistical Techniques

R Rushsa[1], M A Aziz[2*], M Noorunnahar[1], R Ahmed[2], M I Hossain[2], M A Qayum[2], M A A Mamun[2]

ABSTRACT

Bangladesh is a country with extreme weather conditions that is being investigated for its climatic effects on the production of rice (*Oryza sativa* L.) crops. Rice is cultivated as Aus, Aman, or Boro throughout the year in Bangladesh. The study was intended to explore the effects of climatic variables (rainfall, minimum temperature, and relative humidity) on Aus rice production in Bangladesh. Time series data of production, rainfall, minimum temperature, and relative humidity for the last decade (2011-2020) were collected from BBS (Bangladesh Bureau of Statistics), BRRI (Bangladesh Rice Research Institute), and BMD (Bangladesh Meteorological Department) to carry out the study. To make the research more specific and clear, the country was divided into four regions: the North- East, the North- West, the South-East, and the South-West. GIS (Geographic Information System) tools was used to prepare climatic mapping. The results show that rainfall and relative humidity had a significant impact on the production of Aus rice in the North-Eastern and North-Western regions, but rainfall was more effective than relative humidity in the North-Western part. Minimum temperature and relative humidity were the dominant variables in both the South-Eastern and the South-Western regions for Aus production.

Key words: Aus rice, Rainfall, Minimum Temperature, Relative humidity, GIS.

INTRODUCTION

Bangladesh is a developing country with an economic system based primarily on agriculture. The agricultural sector is significant to the country's overall economic growth and food security because of its high population density. The agricultural sector has historically played a significant role in Bangladesh (Molla *et al.* 2015). The country has an ideal climate and very fertile soil. So, a wide variety of distinct crops are produced here. The agriculture sector contributes about 13.02 percent in FY 2019–20 to the country`s Gross Domestic Product (GDP) and employs around 40.60 percent of the total labour force (BBS 2021). Rice (*Oryza sativa* L.) serves as their primary source of nutrition for more than 50% of the world's population. It also accounts for more than 60% and 25%, respectively, of Asia's and the world's cereal production and it accounts for over 30% of all the food consumed in Asia (Timmer, C.P. 2010). It is the primary source of nourishment for many of the world's highly populated nations, including China and Bangladesh, and is the main food item for a billion citizens of Asia (Jabran and Chauhan, 2015). According to Barua *et al.* (2014) it is the main food and a major proportion of the regular, balanced lifestyle of the Bangladeshi people. Rice is the staple food of around 167 million people in Bangladesh (BBS, 2017). In Bangladesh, the rice sector contributes half of the agricultural GDP and one-sixth of the national income (Elahi 2017). Rice is cultivated as Aus, Aman, or Boro throughout the year in Bangladesh. Aus, Aman, and Boro

[1]Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur 1706, Bangladesh, [2]Bangladesh Rice Research Institute, Gazipur 1701, Bangladesh
*Corresponding author's, E-mail: abdullahaziz.stat@brri.gov.bd (M A Aziz)

are successively grown from April to July, August to December, and January to May, respectively (Khondakar et al. 2022).

The climate is one of the most important factors affecting agricultural production. According to Ahmed and Alam (1999), variations in temperature and rainfall are becoming apparent due to climatic change both nationally and internationally. Floods, droughts, cyclones, and other dangers that are already more frequent in the country than ever before have been made worse by climate change and its variability. Flooding results from unpredictability in the timing and distribution of rain, while drought conditions are brought on by prolonged dry spells (Lai, et. al. 1998; Masud et al. 2014). According to projections, between 2005 and 2050, the average annual rice production in Bangladesh will decrease by 7.4% between 2005 and 2050, according to forecasts (Yu et al. 2010). Due to changing climatic situations, it has been predicted that reduction in rice productivity would become a significant issue in the future. (Yuji et al. 2009). Although technology has progressed, it has been suggested that the current patterns in climate element change may be too responsible for fully reversing yield trends (Islam et al. 2022). Since climate is the primary determinant of rice production, any changes in the climate have a significant impact on rice production (Huq et al. 1996; Karim et al. 1996; Yu et al. 2010). According to BRRI (1991), While Aman is nearly entirely rain-fed and grows in the monsoon months; Aus rice needs supplemental irrigation during the early stages of its growing season. Depending on the amount of rainfall available, Aman may also need supplemental irrigation during the flowering stage. In contrast, Boro rice is completely irrigated because it grows during the hot, dry winter and summer. (Mahmood, 1997). Only 5% of Aman rice and 8% of Aus rice are irrigated. (Ahmed, 2001; Sarker et al., 2019).

Research that aimed to investigate the relationship between climate variability (such as fluctuations in mean temperature, rainfall, relative humidity, and sunshine duration) and rice yields (such as Aus, Aman, and Boro rice varieties). The outcomes showed that humidity and rainfall have negatively affected Aus and Aman rice crops, while temperature and rainfall positively influence Boro rice yield (Islam et al. 2022). Another study was conducted to examine how Bangladesh's three different rice crops (Aus, Aman, and Boro) would be affected by climate change from 1972 to 2014. The results showed that for Aus rice, yield is positively correlated with rainfall and humidity but negatively correlated with maximum temperature. The statistically significant minimum temperature has no impact whatsoever on Aman production. The influence of the seasonal maximum average temperature is also seen to be identical and negatively connected to the yield of Boro rice (Chowdhury and Khan 2015). Different crops are affected by changes in climate variables in different ways. The average maximum temperature seems to make Aus and Aman rice production riskier while making Boro rice production less risky. The mean minimum temperature reduces the risk for Aus and Aman crops while increasing it for Boro rice. Last but not least, rainfall increases the risk of Aman rice while decreasing the risk of Aus and Boro rice (Sarker et al. 2014). The associations between the climate and crops were examined using national-level time series data. Findings showed that, except for Aus rice, the maximum temperature statistically significantly affected the production of all food crops. While the production and crop area of Aman rice were both considerably impacted by rainfall, the cropping area of Aus rice significantly benefited from it. According to statistics, humidity increased the production of Aus and Aman rice. Sunshine statistically significantly benefited only Boro rice yield (Amin et al. 2015). The production efficiency of Boro with environmental considerations is essentially identical to the production efficiency without environmental issues. The production efficiency of Aus and Aman is higher when environmental variables are used than when they are not. All types of rice production are significantly and favourably impacted by humidity. Given that temperature has a detrimental effect on production effectiveness, global warming may contribute to a decline in rice production efficiency. Only Boro production is positively impacted by rain (Hossain et al. 2013).

Aus rice varieties are typically short-duration, early-maturing varieties grown during the pre-monsoon season. In general, during April to July, which corresponds to the pre-monsoon and early monsoon period, temperatures in Bangladesh can range from warm to hot. Aus rice varieties are typically short-duration, early-maturing varieties grown during the pre-monsoon season. Minimum temperatures can range from around 20^{o}C to 28^{o}C. Minimum temperature can be important for maintaining favorable conditions during critical growth stages for Aus rice.

Besides, among the three crops, Aus, Aman, and Boro; Boro is the most significant and dominant crop, and total Boro production was 198,853 metric tons in FY 2020–21. The cultivation of Aman is also increasing day by day, and the total production for FY 2020–21 was 144,37,763 metric tons. But Aus's production is comparatively lower than that of Aman and Boro. The predicted total Aus production for the FY (2020–21) was 3,284.710 metric tons (BBS 2021). Farmers eventually started shifting to irrigated-Boro rice production, which was supported by its higher yields, and Aus rice started to lose its value. The production of rice in Boro is entirely dependent on irrigation, and the pressure of the groundwater is rising daily while the level of the water is falling. In contrast, Aus rice only needs 5% of the irrigation to be supplemented, and the groundwater pressure has to be lower than it is for Boro. Besides, the production of Aus rice has a significant relation with meteorological conditions such as temperature, precipitation, and humidity. It varies from region to region. For these reasons, it is necessary to have a sufficient understanding of Bangladesh's climate conditions and their changing patterns on a regional basis to boost Aus production.

A GIS (Geographic Information System) is a computer-based technology for storing, manipulating, analyzing, and retrieving data such as digital maps, images, or other data with spatial references, including latitude and longitude (BARC, 2001). With a small database, GIS and its accompanying maps and databases can serve a variety of general and specific functions. The ability of different data sets to be related via a shared spatial reference is an essential element of GIS (Zakaria et al., 2014). GIS (Geographic Information System) technology will help to visualize information on the maps. Because there has been no specific research conducted on a regional basis as well as using GIS for Aus.

The specific objectives of this study are: to identify the change in climatic conditions for Aus rice production using GIS mapping; to understand the impact of rainfall and minimum temperature and humidity on Aus rice (Aus) production; and to assess the change in Aus rice production under historical assumptions using trend analysis.

MATERIALS AND METHODS

Selection of study area

Secondary data on rainfall, temperature, humidity, and production were needed for the study's purpose. That's why the whole of Bangladesh was selected as the study area. Bangladesh is a South Asian nation with 64 districts that are located between 20°34' and 26°38'N and 88°01' and 92°41'E. Its total area is 147,570 km^2. The research would cover 64 districts in Bangladesh. 35 meteorological stations in Bangladesh were selected for the climate data. To make the research more specific and clear, the country was divided into four regions: the North- East, the North-West, the South- East, and the South-West.

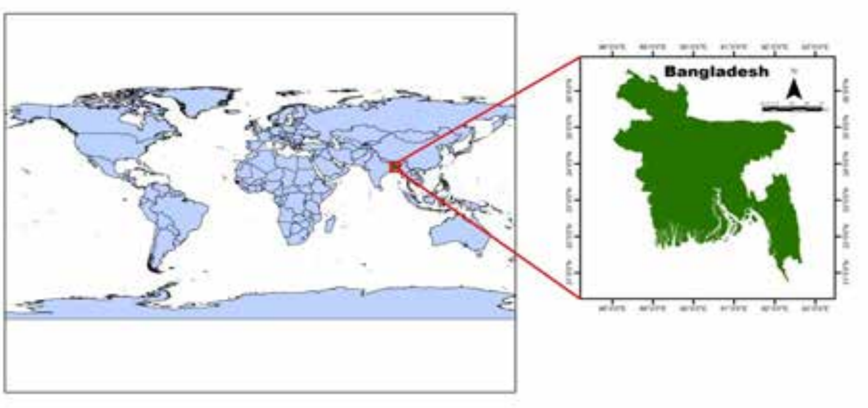

Fig. 1. Study Area: Bangladesh is selected as study area.

Districts under (Fig. 2)

- **North-Eastern Region:** Brahmanbaria, Dhaka, Gazipur, Hobiganj, Jamalpur, Kishoreganj, Manikganj, Moulavibazar, Munshiganj, Mymensingh, Narayanganj, Narsingdi, Netrakona, Sherpur, Srimangal, Sylhet and Tangail.
- **Sout-Eastern Region:** Bandarban, Chattagram, Cox's Bazar, Chandpur, Cumilla, Feni, Khagrachari, Laxmipur, Noakhali, Rangamati, Sitakunda
- **North-Western Region:** Rajshahi, Bogura, Rangpur, Dinajpur, Kurigram, Lalmomonirhat, Nilphamari, Panchagar, Thakurgaon, Gaibandha, Naogaon, Sirajganj, Chapai Nawabganj, Natore, Pabna, Kushtia, Meherpur, Jaypurhat
- **South-Western Region:** Faridpur, Madaripur, Chuadanga, Khulna, Jessore, Satkhira, Patuakhali, Barisal, Bhola, Jhenaidah, Magura, Narail, Gopalganj, Bagerhat, Barguna, Jhalakhati, Pirojpur, Rajbari, Shariatpur.

Thirty five meteorological stations of Bangladesh were selected for the climate data.

Stations under (Fig. 2)

- **North-Eastern Region:** Dhaka, Mymensingh, Sylhet, Srimangal
- **South-Eastern Region:** Chattagram, Cox's Bazar, Chandpur, Cumilla, Feni, Hatiya, Kutubdia, M.Court, Rangamati, Sandwip, Sitakunda, Teknaf
- **North-Western Region:** Tangail, Rajshahi, Bogura, Isaurdi, Rangpur, Dinajpur, Sydpur, Rangamati
- **South-Western Region:** Faridpur, Madaripur, Chuadanga, Khulna, Jessore, Satkhira, Patuakhali, Khepapura, Mongla, Barisal, Bhola

Fig. 2. Study Area: Regions and locations of meteorological stations.

Data Collection, Processing, and Tabulation Method

The information furnished in the study is based on a different database. The research was conducted using relevant secondary data from the Bangladesh Bureau of Statistics (BBS), Bangladesh Rice Research Institute (BRRI), and the Bangladesh Meteorological Department (BMD). The analysis was done for 10 years. Before 2011 there were less than thirty five meteorological stations in Bangladesh. Analyzing data prior to 2011 would not have any data coherency. To keep the analysis consistent, databases were made for the years 2011–2020. Data on Aus rice production (MT) from 2011-2020 was collected from BBS and BRRI, and climatic data on rainfall (mm), minimum temperature (^{o}C), and humidity (%) were collected from BMD for the following 10 years. To select the districts under the four regions, the map of Bangladesh was divided into four parts and manually named the North-Eastern, South-Eastern, North-Western, and South-Western regions.

The data entry (Aus production) for 64 districts was done using Microsoft Excel for 10 years. Data entry was also done for 35 meteorological stations for 10 years, and the database was updated on a daily basis. Microsoft Excel was used to calculate the average total annual rainfall, minimum temperature, and relative humidity. Furthermore, the Aus season runs from April to July. So, the following four months were selected from the meteorological database for rainfall, temperature, and humidity by filtering the whole database. After that, both production data and meteorological data were sorted into 4 regions (NE, SE, NW, and SW) using a pivot chart. A spatial analysis was done using ArcGIS 10.8 software for the meteorological dataset.

Using the spatial analyst tool in ArcGIS 10.8, maps of rainfall, minimum temperature, and humidity were created. After that, the last ten years of Aus rice production graphs were generated for each region, and they were then compared to statistics on rainfall, minimum temperature, and humidity. The effects of rainfall, minimum temperature, and humidity were then examined regionally for Aus rice production.

RESULTS AND DISCUSSION

Average Total Rainfall (Map and Trend)

In Bangladesh, average total rainfall maps (Fig. 3 and 4) for the ten years from 2011 to 2020 with a five-year gap have been prepared. The scale used to measure rainfall is in millimeters (mm). In different parts of Bangladesh, there have been numerous shifts in terms of the average annual rainfall. The average rainfall diagrams (Fig. 5) from 2011 to 2020 show Bangladesh's continuous rainfall variability. However, the regional graphs depict several scenarios of rainfall change.

Between 2011 and 2015 (Fig. 3), certain areas of Bangladesh, including Bandarban, Sylhet, Nilphamari, and Panchagar districts in the

South-East, North-East, and some parts of the North-West, experienced the highest rainfall exceeding 12000 mm. In the North-West, there was a 5000 mm decrease in average total rainfall, while Greater Barishal and Rangpur districts encountered moderate rainfall ranging from 7000 to 12000 mm

During 2016 to 2020 (Fig. 4), Sylhet in the North-East received the most rainfall exceeding 12000 mm. The North-West and South-West regions witnessed a 5000 mm decrease in overall average rainfall. Greater Dhaka, Cumilla, and Barishal districts saw moderate rainfall, ranging from 7000 to 11000 mm. These maps reveal a decline in the most rainy areas between 2016 and 2020 while witnessing an increase in regions with moderate rainfall.

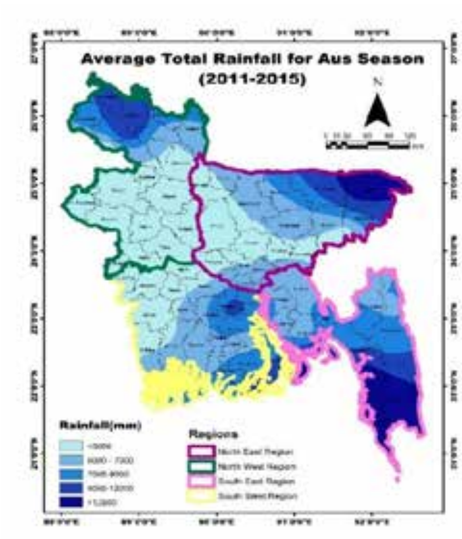

Fig. 3. Average Total Rainfall Map for Aus Season (2011-2015).

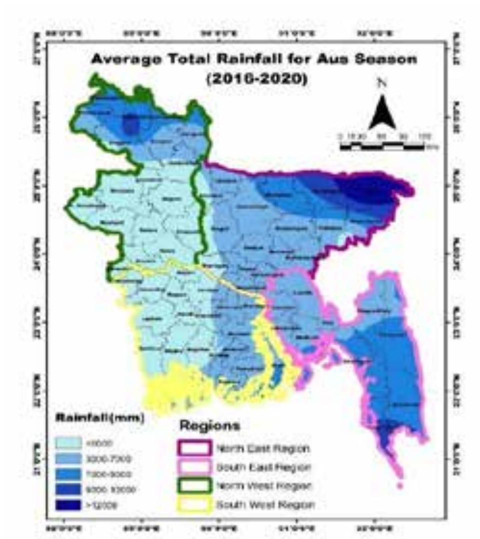

Fig. 4. Average Total Rainfall Map for Aus Season (2016-2020).

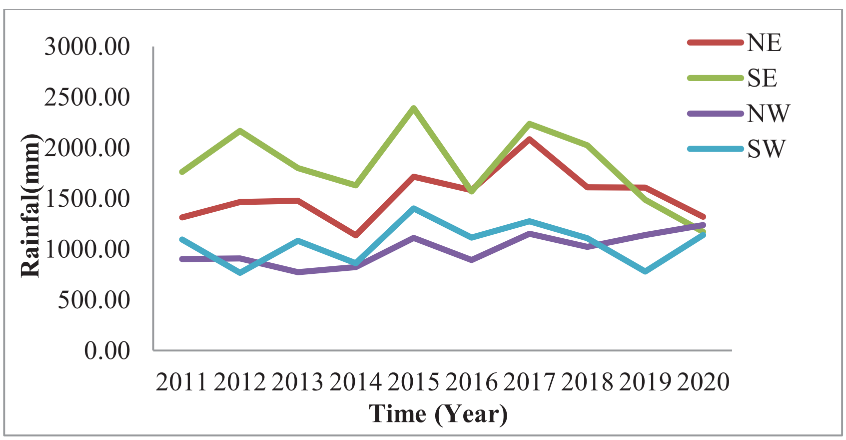

Fig. 5. Rainfall of the North-Eastern, South-Eastern, South-Western, and North-Western Region of Bangladesh

The graphs from 2011 to 2020 (Fig. 5) illustrate that Bangladesh's South-East region encountered the highest rainfall initially but experienced a decline after 2017. The trend line in the North-East region started as the second-highest but eventually rose to the top by 2020. The crossing of trend lines indicates fluctuation in rainfall amounts between 2011 and 2020, displaying periods of increase and decrease.

Average Minimum Temperature (Map and Trend)

Maps 6 and 7 show the average minimum temperature for the most recent decade, from 2011 to 2020, with a five-year gap. The scale of degrees Celsius (°C) is used to express temperature. The continuous temperature fluctuation in Bangladesh is depicted in the average minimum temperature curve (Fig. 8) from 2011 to 2020.

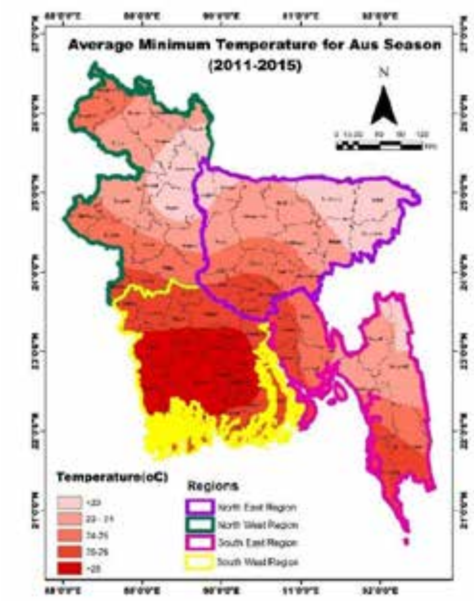

Fig. 6. Average minimum temperature map for Aus season (2011-2015).

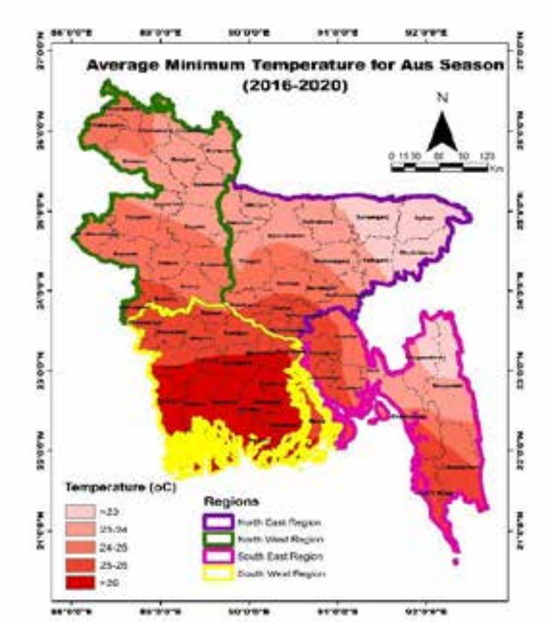

Fig. 7. Average minimum temperature map for Aus season (2016-2020).

Between 2011 and 2015 (Map 6), the South-West region of Bangladesh, encompassing greater Khulna and Barishal districts, recorded the highest average minimum temperature (>26°C). Meanwhile, the North-West and North-East regions maintained an average minimum temperature of 23 degrees Celsius.

During the 2016 to 2020 period (Map 7), a similar pattern persisted in Bangladesh's South-West region, with greater Khulna and Barishal districts experiencing the highest average minimum temperature (>26°C). Conversely, the North-West and North-East regions sustained an average minimum temperature of 23 degrees Celsius. Comparing these maps reveals that while the area with the maximum average minimum temperature remained relatively consistent from 2016 to 2020, there were notable changes in areas with moderate temperature levels.

The graphical representation from 2011 to 2020 (Fig. 8) highlights that the South-Western part of Bangladesh consistently displayed the maximum average minimum temperature, while the North-Eastern region experienced a decline in this measure. The trend lines indicate a rise in temperature for the South-Eastern region from 2012 to 2014, followed by a gradual decrease. Temperature patterns in the North-Eastern and North-Western regions fluctuated with recurrent increases and decreases, yet by the beginning of 2020, the average minimum temperature in the North-Eastern region began to decline.

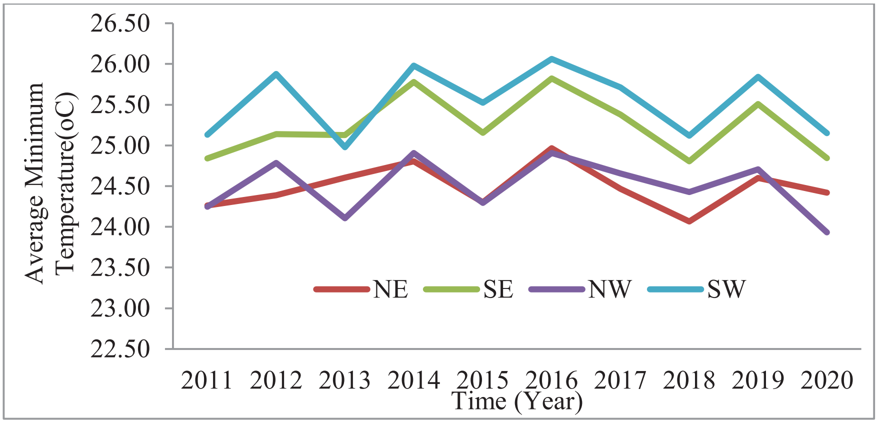

Fig. 8. Average minimum temperature of the North-Eastern, South-Eastern, South-Western, and North-Western region of Bangladesh.

Average Humidity (Map and Trend)

Average humidity maps (Figs. 9 and 10) have also been prepared for the last decade, from 2011–2020, with a five-year gap. The humidity unit is on a percentage (%) scale. The average humidity diagram (Fig. 11) from 2011–2020 shows the continuous fluctuation of humidity in Bangladesh.

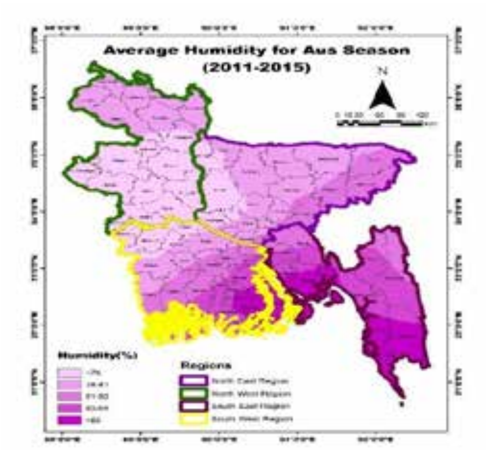

Fig. 9. Average humidity map for Aus season (2011-2015).

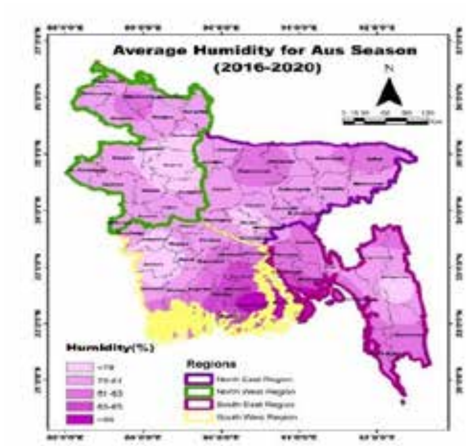

Fig. 10. Average humidity map for Aus season (2016-2020).

In the map from 2011 to 2015 (Fig. 9), the highest average humidity levels (>85%) were observed in the South-West and South-East regions of Bangladesh, encompassing Patuakhali, Noakhali, Bhola, Feni, and Bandarban districts. Conversely, the North-West regions experienced a decrease in average humidity, reaching 78%.

Similarly, according to the 2016 to 2020 map (Fig. 10), the areas with the highest average humidity (>85%) were situated in the south-western part of Bangladesh, specifically covering Patuakhali and Bhola districts. In certain districts across four regions, average humidity declined to 78%. A comparison between these maps reveals a change in the region with the maximum relative humidity between 2016 and 2020, along with an increase in the area experiencing minimum relative humidity.

The diagram representing 2011 to 2020 (Fig. 11) indicates that the South-East part of Bangladesh consistently maintained the highest average humidity, while the North-West region experienced decreased levels. The trend lines demonstrate that relative humidity predominantly prevailed in the South-Eastern region. The trend lines for the South-Western and North-Eastern regions overlap, converging to nearly the same level by the end of 2020.

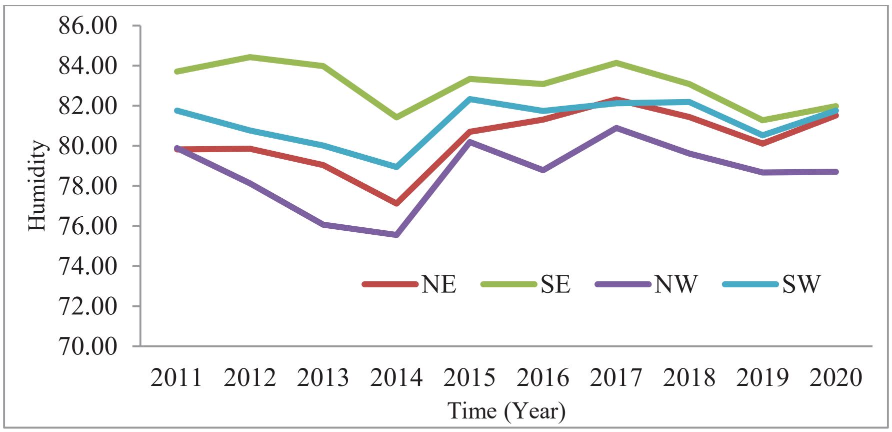

Fig. 11. Humidity of the North-Eastern, South-Eastern, South-Western, and North-Western region of Bangladesh.

Aus rice production in Bangladesh

In Bangladesh, different types of rice are grown depending on seasonal variations in the water supply. Since Aus, Aman, and Boro make up the majority of the nation's rice crop and grow in each of the three distinct seasons, rice is grown in Bangladesh all year round. The average planting and harvest dates for Aus are March or April and June or July, respectively (Sarker et al. 2012). The Aus rice production for each of the four dividing regions based on rainfall, temperature, and humidity has been estimated and shown. The production of rice in four regions of Aus is illustrated in figures from 12 to 15 For each graph, a linear trend line is constructed to illustrate the linear change in production. Figures 12 and 14 depict an upward trend in Aus rice output in the North-East and North-West regions over the past ten years, while a downward trend in production is seen in the South-East and South-West regions.

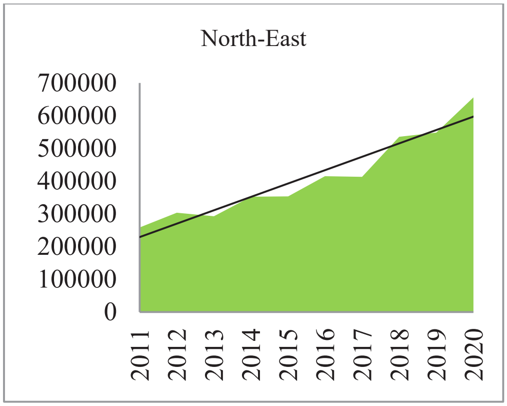

Fig. 12. Aus rice production and linear trend of the North-East region for the last decade.

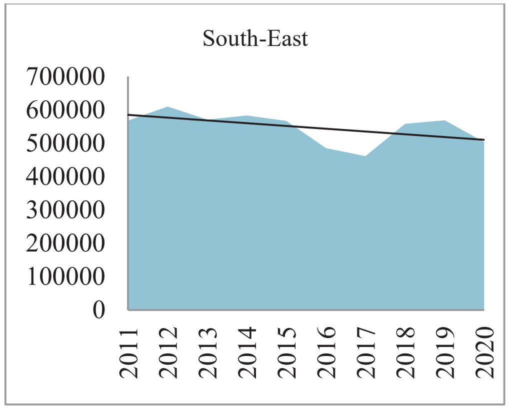

Fig. 13. Aus rice production and linear trend of the South-East region for the last decade.

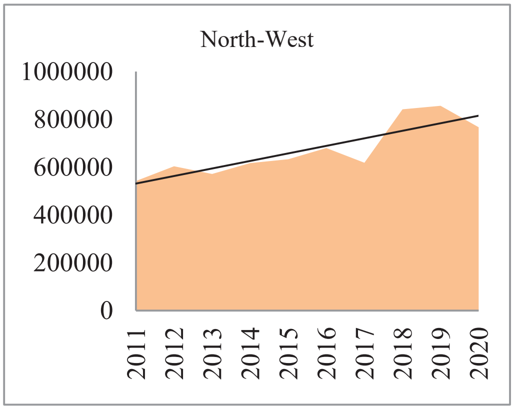

Fig. 14. Aus rice production and linear trend of the North-West region for the last decade.

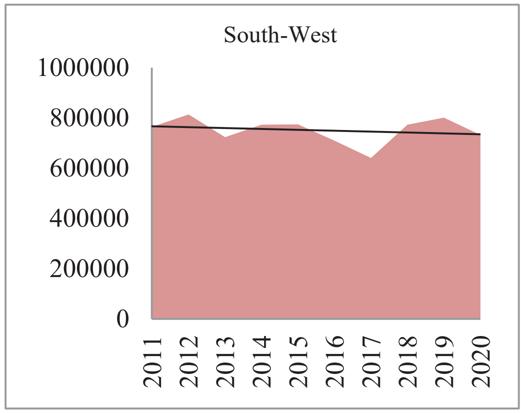

Fig.15. Aus rice production and linear trend of the South-West region for the last decade.

North-Eastern Region:

Brahmanbaria, Dhaka, Gazipur, Hobigonj, Jamalpur, Kishoreganj, Manikganj, Moulavibazar, Munshiganj, Mymensingh, Narsingdi, Netrakona, Sherpur, Srimangal, and Sylhet districts are included in the region.

The relationship between rice production and environmental factors like rainfall, Figures 16, 17 and 18 depicted temperature, and humidity in the region. The graph in Figure 16 illustrates that rice production has shown a consistent increase over time, correlating positively with higher rainfall levels. The lowest recorded rainfall occurred in 2014, followed by an upward trend from 2015 to 2017, a decline in 2018, and relatively stable levels from 2018 to 2019, before a decrease in 2020.

In contrast, the temperature graph (Fig. 17) displays an inverse trend concerning rice production, except for 2015 and 2017. The average minimum temperature initially increased from 2011, experienced a sudden drop in 2015, followed by fluctuations with a decrease in 2018 after rising in 2016 and 2017. Finally, temperatures rose again in

2019–2020. This fluctuating pattern in temperature doesn't significantly impact Aus rice production.

Fig. 18, showcasing humidity levels, exhibits an inverse trend between the periods of 2015–2017 and 2011–2013. Humidity trend lines were decreasing until 2014, then began to rise until 2019, slightly decreasing again in 2020. Despite these fluctuations, Aus rice production has increased over time. The analysis suggests that rainfall and humidity play dominant roles in influencing Aus rice production in this region. These variables exhibit a more consistent impact on production compared to the fluctuating pattern of temperatures, indicating a stronger correlation between higher rainfall/humidity and increased rice yields over time.

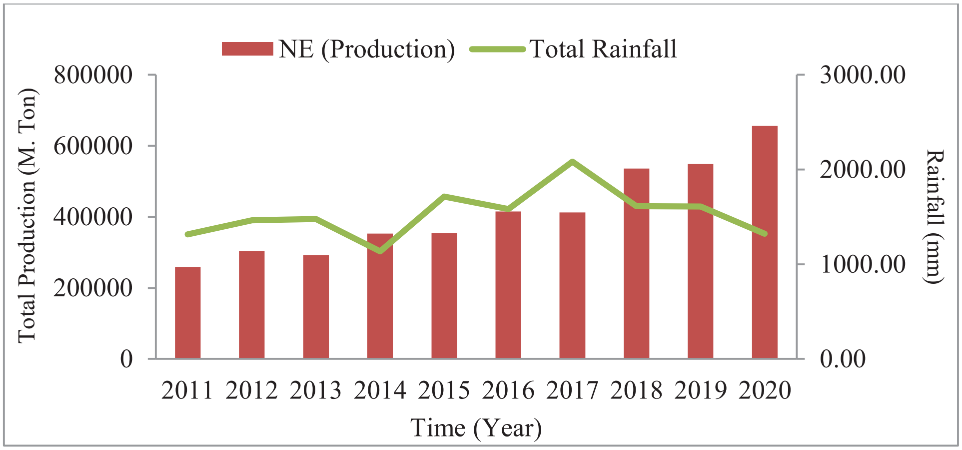

Fig.16. Combined graph of Aus rice production and rainfall in the North-Eastern region of Bangladesh for the last decade.

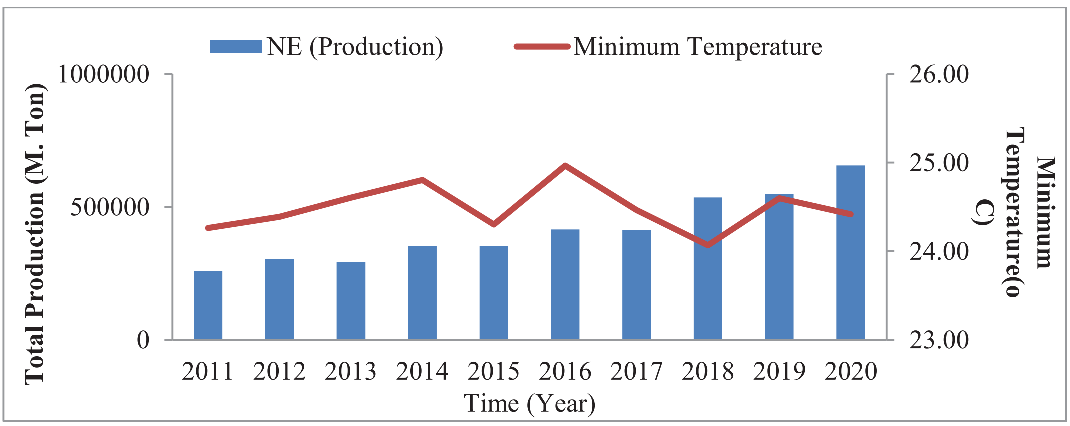

Fig. 17. Combined graph of Aus rice production and minimum temperature in the North-Eastern region of Bangladesh for the last decade.

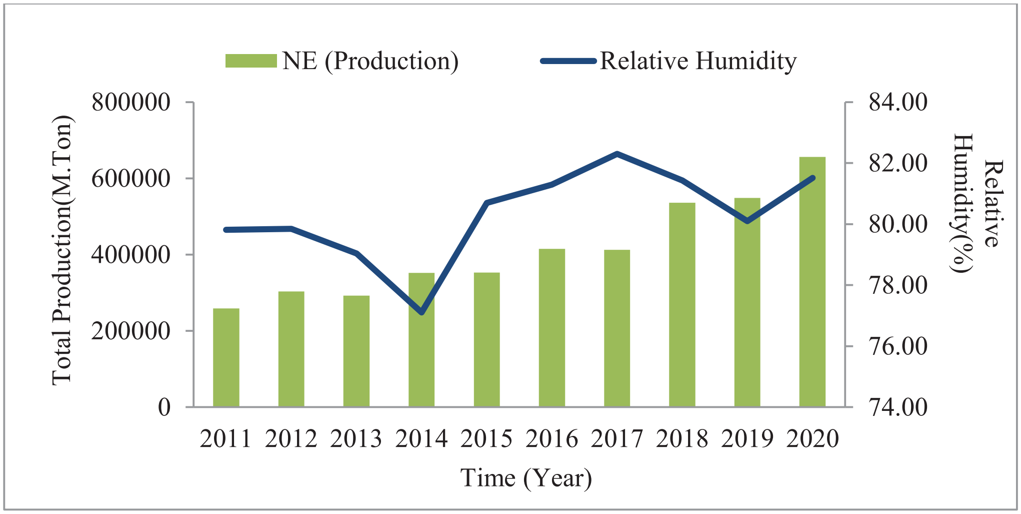

Fig. 18 Combined graph of Aus rice production and humidity in the North-Eastern region of Bangladesh for the last decade.

South-Eastern Region

Chattagram, Cox's Bazar, Chandpur, Cumilla, Feni, Khagrachari, Laxmipur, Noakhali, Rangamati, and Sitakunda districts are included in the region.

Figure 19 demonstrates a declining trend line until 2014, followed by an increase after 2016, and subsequently declining again from 2018 to 2020. Interestingly, there's little variation in production levels despite changes in rainfall, suggesting that rainfall has limited impact on the volume of Aus rice produced in this region. On the other hand, Figure 20, displaying temperature, indicates that production tends to increase with rising temperatures. However, production decreases when temperatures reach extremes, observed notably from 2016 through 2018 and 2020.

In Figure 21, the relative humidity graph shows an increase in both production and humidity until 2013. Despite a significant decline in humidity in 2014, production levels remained constant. Similar occurrences happened in 2017 and between 2017 and 2020. This graph, akin to the production vs. rainfall graph, suggests that humidity has a more pronounced impact on productivity compared to rainfall. Hence, average minimum temperature and humidity emerge as the dominant variables influencing Aus rice production in this region. Temperature fluctuations affect production, particularly when reaching extreme highs or lows, while humidity appears to have a more consistent influence on productivity.

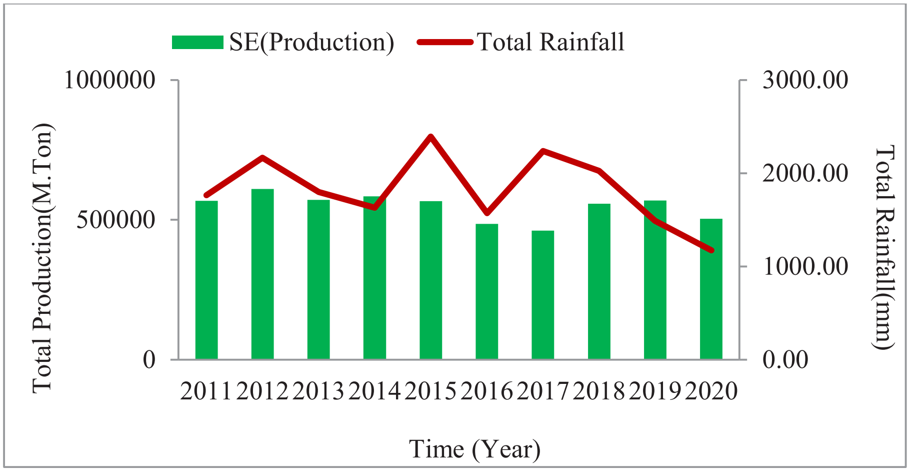

Fig. 19. Combined graph of Aus rice production and rainfall in the South-Eastern region of Bangladesh for the last decade.

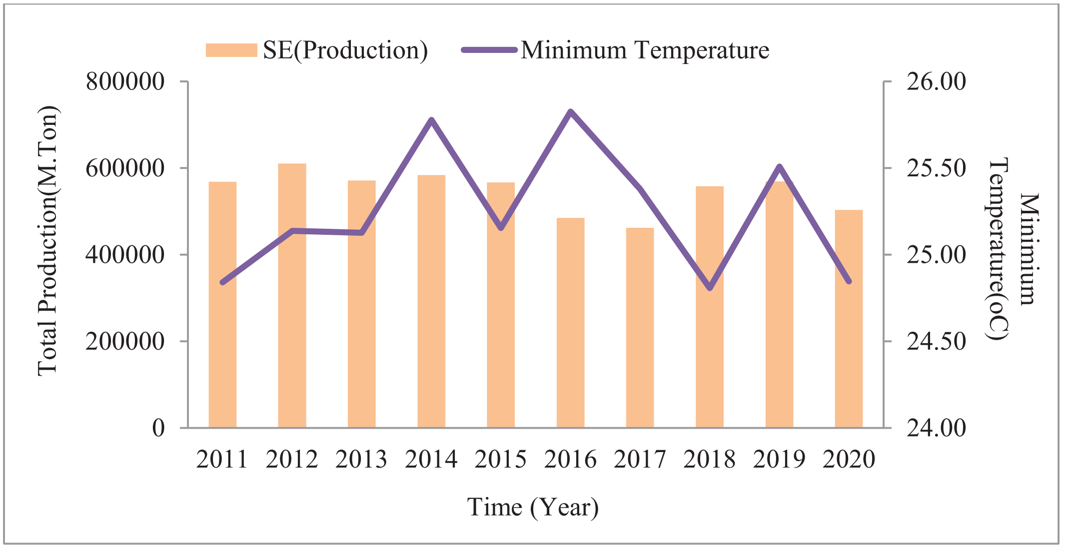

Fig. 20. Combined graph of Aus rice production and minimum temperature in the South-Eastern Region of Bangladesh for the last decade.

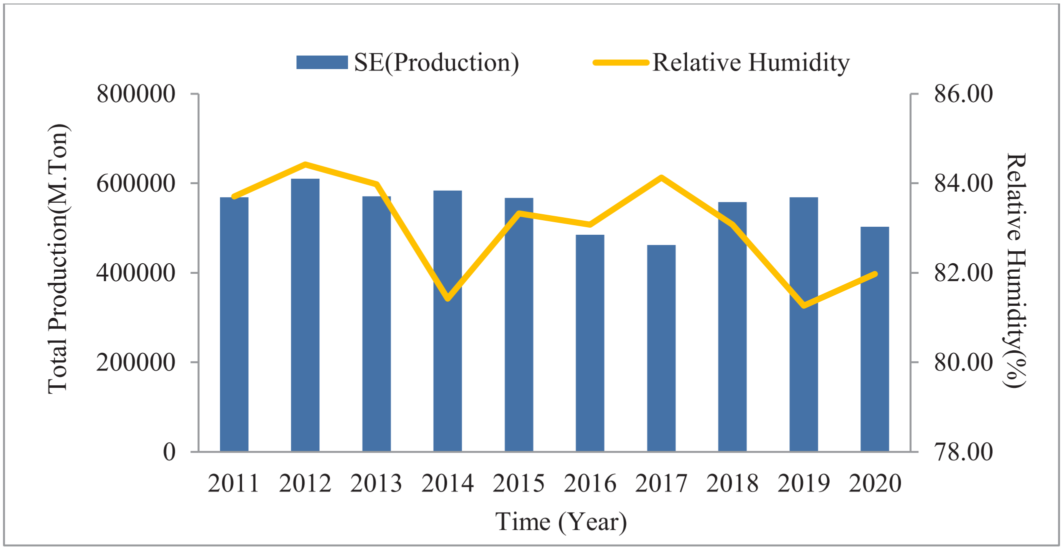

Fig. 21. Combined graph of Aus rice production and humidity in the South-Eastern Region of Bangladesh for the last decade.

North-Western Region

Tangail, Rajshahi, Bogura, Rangpur, Dinajpur, Rangamati, Kurigram, Lalmomonirhat, Nilphamari, Panchagar, Thakurgaon, Gaibandha, Naogaon, Sirajganj, Chapai Nawabganj, Natore, Pabna, Kushtia, Meherpur, and Jaypurhat districts are included in the region.

Figure 22 demonstrates an upward trend in rice production, attributed to increasing rainfall. Notably, Aus rice production peaks from 2019 to 2020, aligning with a higher trend line for rainfall during this period. The enhanced rainfall appears to positively impact Aus production, contributing to improved yields. Conversely, Figure 23, displaying temperature, doesn't display a discernible relationship between production trends in this area and changes in the average lowest temperature. Therefore, there seems to be no evident effect of temperature fluctuations on the production of Aus rice.

However, Figure 24, representing relative humidity, depicts a downward trend in humidity until 2014, followed by a subsequent rise. Concurrently, the level of production shows an upward trend. This observation indicates that relative humidity plays a significant role in Aus rice production in this region. Therefore, the analysis suggests that rainfall and humidity serve as the dominant variables influencing Aus rice production in this area. While increased rainfall positively impacts production, changes in humidity levels also have a substantial impact, with both factors contributing significantly to Aus rice yields. Conversely, temperature fluctuations do not seem to exert a notable influence on Aus rice production in this specific region.

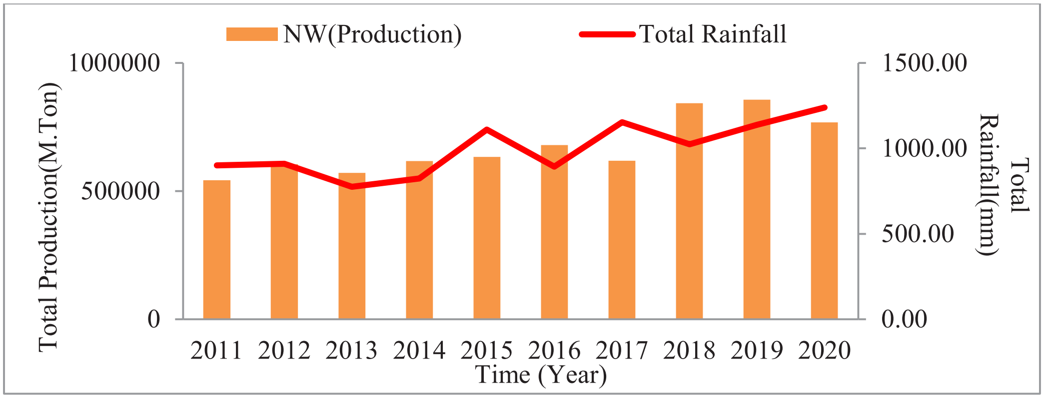

Fig. 22. Combined graph of Aus rice production and rainfall in the North-Western region of Bangladesh for the last decade.

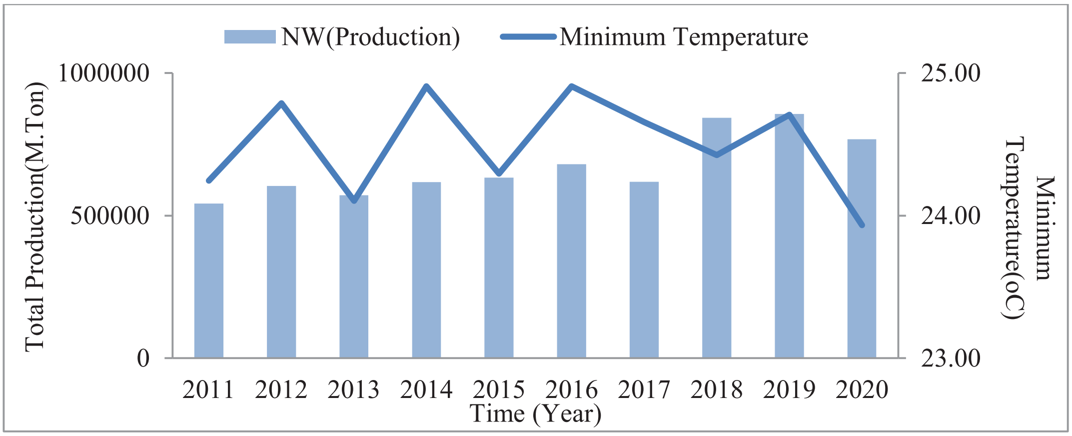

Fig. 23. Combined graph of Aus rice production and minimum temperature in the North-Western region of Bangladesh for the last decade.

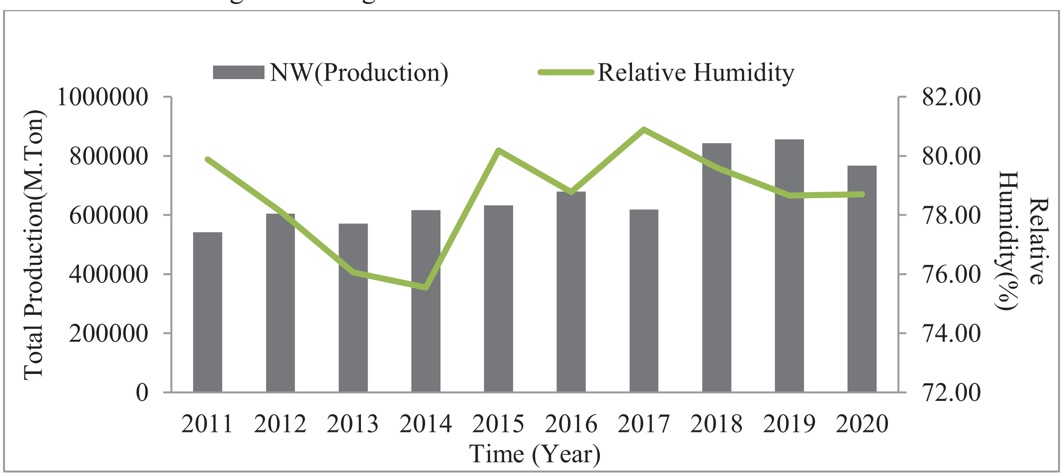

Fig. 24. Combined graph of Aus rice production and humidity in the North-Western region of Bangladesh for the last decade.

South-Western Region

Faridpur, Madaripur, Chuadanga, Khulna, Jessore, Satkhira, Patuakhali, Barisal, Bhola, Jhenaidah, Magura, Narail, Gopalganj, Bagerhat, Barguna, Jhalakhati, Pirojpur, Rajbari, and Shariatpur districts are included in the region.

Figure 25 illustrates a relatively stable Aus rice production trend over time despite fluctuations in the rainfall line, which mostly displays a downward trend. Surprisingly, these variations in rainfall seem to have limited effect on the production level of Aus rice in this context.

In Figure 26, the temperature graph reveals that Aus rice production is notably affected by temperature fluctuations in the years 2012, 2015–2017, and 2019. This suggests that, during these specific years, changes in temperature had an observable impact on the output of Aus rice.

Moreover, Figure 27, representing humidity, indicates a decline in humidity from 2011 followed by an increase after 2015. Until 2014, humidity did not seem to significantly impact the output of Aus rice. However, from 2015 through 2020, there was a noticeable influence of humidity on Aus rice production, implying that humidity levels began to play a more substantial role during this period. As a result, the analysis suggests that average minimum temperature and humidity emerge as the dominant variables influencing Aus rice production in this region. Temperature fluctuations seem to affect production in specific years, while humidity levels, particularly from 2015 to 2020, have a more pronounced impact on Aus rice yields. Despite fluctuations in rainfall, it appears to have limited effect on the production of Aus rice in this particular area compared to the significant influence of temperature and humidity on production levels.

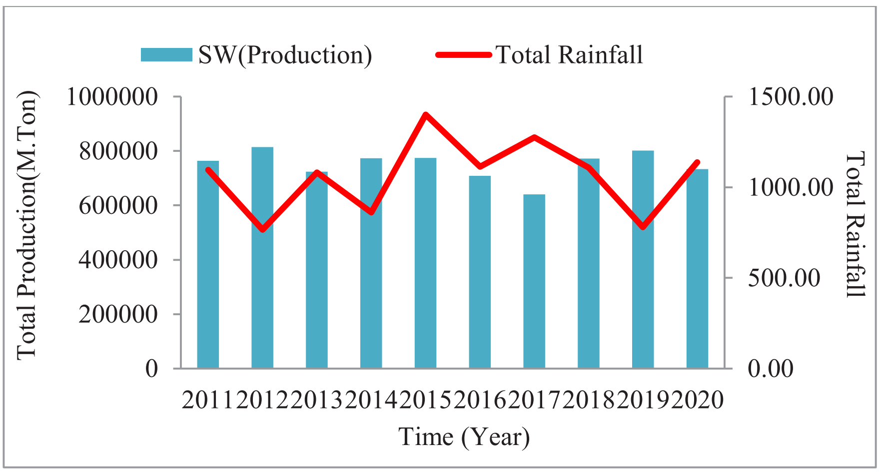

Fig. 25. Combined graph of Aus rice production and rainfall in the South-Western region of Bangladesh for the last decade.

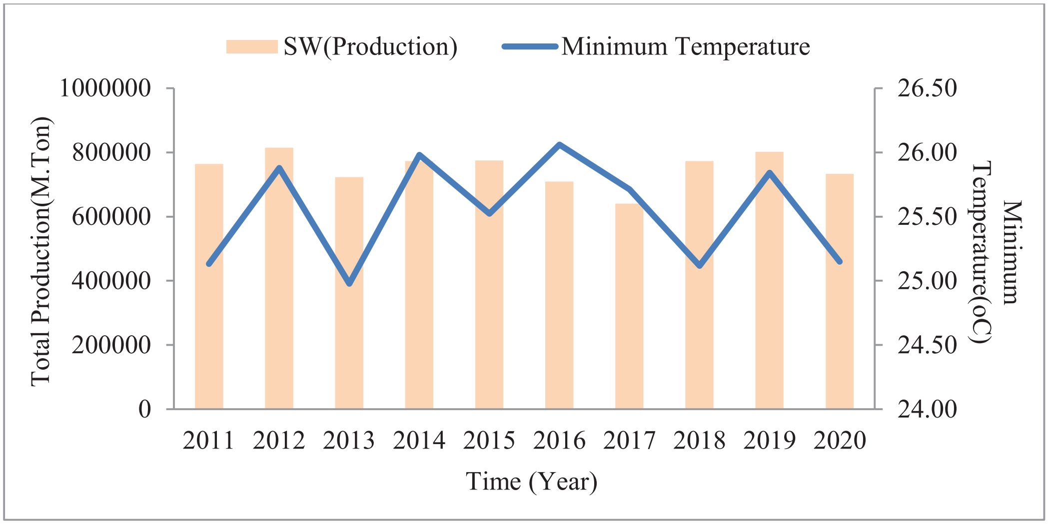

Fig. 26. Combined graph of Aus rice production and rainfall in the South-Western Region of Bangladesh for the last decade.

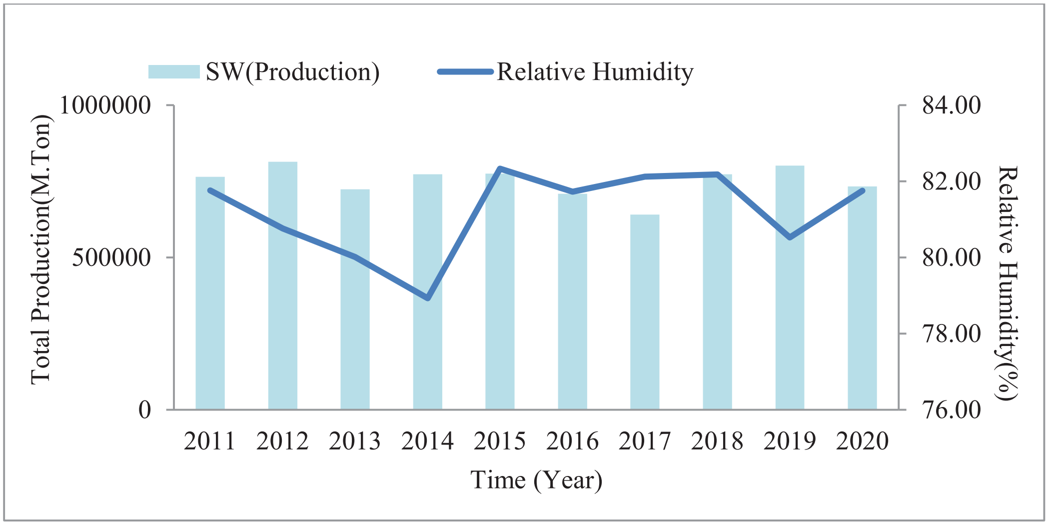

Fig. 27. Combined graph of Aus rice production and rainfall in the South-Western Region of Bangladesh for the last decade.

The impacts of climate change are evident in Bangladesh, with observable changes including rising temperatures, erratic rainfall patterns, and an escalation in extreme climate-related events such as floods, droughts, cyclones, sea-level rise, salinity, and soil erosion (*Asaduzzaman et al.,* 2010; *Yu et al*., 2010; Hossain and Deb, 2011). These factors notably affect the agricultural sector, especially rice production, occurring almost annually and often multiple times in a year (MoEF, 2005; *Yamin et al.,* 2005). Bangladesh's climate is characterized by high temperatures, heavy rainfall, elevated humidity levels, and distinct seasonal fluctuations (Sikder and Xiaoying, 2014).

Projections for the region indicate that climate change will contribute to increased circulation during the monsoon season, higher surface temperatures, and a heightened frequency and intensity of heavy rainfall events (Murshed et al., 2011). The Southwest agricultural region faces challenges during dry months due to water shortages and severe moisture stress (Faruque and Ali, 2005). Drought occurrences are frequent in Bangladesh's Northwest (Shahid, S. 2010). Moreover, there has been an observed increase in rainfall during the monsoon seasons in the western parts of the country (Shahid, S. 2010). Salinity intrusion poses a significant risk, particularly impacting the southern regions (Lal, M. 2011; Shahid et al., 2006). Crops heavily reliant on rainfall will be adversely affected by the year-to-year variation in rainfall, causing disruptions in irrigation systems (Shahid, S. 2011). These climate-related changes have substantial consequences on agriculture, particularly for rain-fed crops, posing challenges for food security and livelihoods in various regions of Bangladesh.

Region-wise Comparison of Aus Production

In addition, production in the Southern region was comparatively lower than in the Northern region. Eight districts were randomly selected from the area where production of Aus was high, and the comparison is shown in the following pie chart.

Table 1. Comparison of the Region-wise Aus Production.

Region	NE		SE		NW		SW	
District	Mymensingh	Sylhet	Chattagram	Noakhali	Rangpur	Rajshahi	Barishal	Khulna
Production (MT)	34338	197358	87523	80022	50325	134357	20507	6677
Percentage (%)	37.91		27.42		30.22		4.45	

Source: BBS, 2020

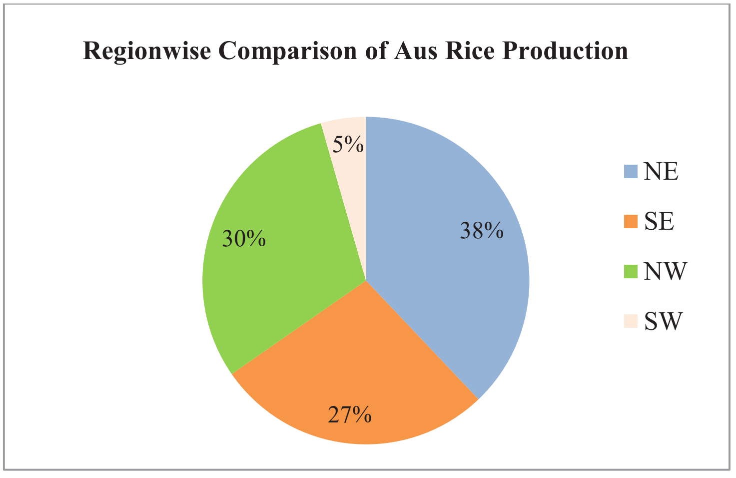

Fig. 28. Aus rice production region (Comparative analysis).

From the pie chart, in the North-Eastern region, production of Aus rice was 38% of the total selected area, and it was the highest among other regions. The North-Western, South-Eastern, and South-Western regions occupied 30%, 27%, and 5%, respectively.

The analysis of production vs. climatic variables (rainfall, minimum temperature, and humidity) graphs from the previous chapter reveals that rainfall and relative humidity had a significant impact on the production of Aus rice in the North-Eastern region. In the case of the South-Eastern part, minimum temperature and relative humidity were the dominant variables for Aus production. In the North-Western part, production of Aus rice followed the same pattern as the North-Eastern region, but the effect of rainfall was greater than the effect of relative humidity for this region, as rainfall followed an increasing trend from 2011 to 2020. Minimum temperature and relative humidity were important factors in the production of Aus rice in the south-western region.

CONCLUSION

The production of Aus rice in Bangladesh is significantly influenced by three key climatic variables: rainfall, minimum temperature, and humidity. However, their impact on Aus rice production varies across different regions in the country. Analysis of maps and trend lines indicates variations in these variables among regions, showcasing distinct influences on Aus rice production.

In the North-Eastern and North-Western regions, rainfall levels were relatively higher compared to the South-Eastern and South-Western regions. Conversely, the South-Eastern and South-Western parts experienced more favourable conditions in terms of minimum temperatures. Relative humidity was observed in all regions, particularly prominent in the South-Western part of Bangladesh.

Rainfall and relative humidity played a crucial role in augmenting Aus rice production in both the North-Eastern and North-Western regions. However, in the South-Eastern and South-Western regions, minimum temperature and relative humidity emerged as the primary factors influencing Aus rice production.

Interestingly, rainfall had a lesser impact on Aus rice production in the South-Eastern and South-Western regions compared to the other areas. Production levels were comparatively lower in the Southern region, which could potentially be attributed to the presence of salinity in the soil and water, along with the occurrence of natural calamities. Addressing salinity issues in soil and water could be crucial in increasing Aus rice production in these regions.

Moreover, the importance of minimum temperature seemed less pronounced in the North-Eastern and North-Western regions for Aus rice production. This could potentially be associated with the effects of climate change, drought, and CO_2 emissions. Further research is needed to comprehensively understand and address these challenges, aiming to enhance Aus rice production in these areas. Finding solutions to these issues through comprehensive research will be vital in sustaining and improving Aus rice production in Bangladesh.

ACKNOWLEDGEMENTS

We would like to express our sincere gratitude to Dr. Mohammad Nazmol Hasan, Professor and Dean, Faculty of Agricultural Economics and Rural Development, Bangabandhu Sheikh Mujibur Rahman Agricultural University, Gazipur for arranging internship programme to gather practical experience for the students. We also would like to extend thanks to the Department of Statistics, Bangladesh Rice Research Institute, Gazipur and all of the individuals who gave their time and support to this study specially Kamini Roy, Anamika Khatun and Hasibur Rahaman Mihir. Additionally, we are grateful of the reviewers' insightful feedback and recommendations, which significantly enhanced the impact and clarity of our findings.

STATEMENTS AND DECLARATIONS

This is an original work and not published full or partial part of the paper any journal. No funds, grants, or other support was received to conduct this study and the authors have no relevant financial or non-financial interests to disclose.

CONFLICT OF INTEREST

No potential conflict of interest was stated by the researchers (authors).

REFERENCES

Ahmed, R. 2001. *Retrospect's of the Rice Economy of Bangladesh*. University Press Limited, Dhaka.

Ahmed, A U and M Alam. 1999. Development of climate change scenarios with general circulation models. *Vulnerability and adaptation to climate change for Bangladesh*, 13-20.

Amin, M R, J Zhang and M Yang. 2014. Effects of climate change on the yield and cropping area of major food crops: A case of Bangladesh. *Sustainability*, 7(1): 898-915.

Asaduzzaman M, C Ringler and J Thurlow. 2012. Investing in crop agriculture in Bangladesh for higher growth and productivity, and adaptation to climate change.

BARC (Bangladesh Agricultural Research Council). 2001. Ministry of Agriculture, Government of the People's Republic of Bangladesh, Dhaka.

BBS (Bangladesh Bureau of Statistics). 2017. The Yearbook of Agricultural Statistics of Bangladesh. Statistics Division, Ministry of Planning, Government of People's Republic of Bangladesh, Dhaka.

BBS (Bangladesh Bureau of Statistics). 2021. The Yearbook of Agricultural Statistics of Bangladesh. Statistics Division, Ministry of Planning, Government of People's Republic of Bangladesh, Dhaka.

BRRI (Bangladesh Rice Research Institute). 1991. Rice Yield and Environmental Data. BRRI, Dhaka, Bangladesh.

Barua, R, M N Islam, A Zahan, S Paul and Shamsunnaher. 2014. Effects of spacing and number of seedlings hill-1 on the yield and yield components of BRRI dhan47. *J. Eco-Friendly Agric.*, 7(06): 65-68.

Chowdhury, I U A and M A E Khanin. 2015. The impact of climate change on rice yield in Bangladesh: a time series analysis. *Russ. J. Agric. Socio-Econ. Sci.*, 40(4): 12-28.

Elahi, S H. 2017. Impact of improved rice and jute varieties adoption of farmer's well-being (livelihood) in rural Bangladesh. *Bangladesh J. Agric. Res.*, 41(1): 70-81.

Faruque, H S M and M L Ali. 2005. Climate change and water resources management in Bangladesh. *Climate Change and Water Resources in South Asia*. Balkema Press (Taylor and Francis Group), Leiden, 231-254.

Hossain, M and U Deb. 2011. Crop agriculture and agrarian reforms in Bangladesh: present status and future options. *Sixth Five Year Plan of Bangladesh, 2015*, 1-24.

Hossain, M K, A A Kamil, T A Masron and MA Baten. 2013. Impact of environmental factors on efficiency of rice production in Bangladesh. *J. Appl. Sci.*, 13(4): 564-571.

Huq, S, A U Ahmed and R Koudstaal. 1996. Vulnerability of Bangladesh to climate change and sea level rise. In: Downing TE (ed.), *Climate Change and World Food Security*. NATO ASI Series, 137. Springer-Verlag, Berlin, Heidelberg.

Islam, A R M, I A Nabila, M Hasanuzzaman, M Rahman, A Elbeltagi, J Mallick and S C Pal. 2022. Variability of climate-induced rice yields in northwest Bangladesh using multiple statistical modeling. *Theor. Appl. Climatol.*, 147(3): 1263-1276.

Jabran, K and B S Chauhan. 2015. Weed management in aerobic rice systems. *Crop Prot.*, 78: 151-163.

Karim, Z, S G Hussain and M Ahmed. 1996. Assessing impact of climate variation on food grain production in Bangladesh. *J. Water Air Soil Pollut.*, 92: 53-62.

Khondakar, A, J Dong, Z Li, X Deng, M Singha, M Rahman and X Xiao. 2022. Spatiotemporal pattern of the dynamics in area, production, and yield of Aus rice in Bangladesh and its response to droughts from 1980 to 2018. *J. Geogr. Sci.*, 32(10): 2069-2084.

Lal, M. 2011. Implications of climate change in sustained agricultural productivity in South Asia. *Reg. Environ. Change*, 11(Suppl 1): 79-94.

La,l M, P H Whetton, A B Pittock and B Chakraborty. 1998. The greenhouse gas-induced climate change over the Indian subcontinent as projected by general circulation model experiments. *Terr. Atmos. Oceanic Sci.*, 9(4): 673-690.

Mahmood, R. 1997. Impacts of air temperature variations on the Boro rice phenology in Bangladesh: Implications for irrigation requirements. *Agric. For. Meteorol.*, 84: 233-247.

MoEF (Ministry of Environment and Forest). 2005. National Adaptation Program of Action (NAPA). Government of the People's Republic of Bangladesh.

Molla, M M U, S A Sabur and I A Begum. 2015. Financial and economic profitability of jute in Bangladesh: A comparative assessment. *J. Agric. Nat. Res. Sci.*, 2(1): 295-303.

Murshed, S B, A K M S Islam and M S A Khan. 2011, January. Impact of climate change on rainfall intensity in Bangladesh. *Proc. 3rd Int. Conf. Water Flood Manag.*, 8-10.

Sarker, M A R, K Alam and J Gow. 2014. Assessing the effects of climate change on rice yields: An econometric investigation using Bangladeshi panel data. *Econ. Anal. Policy*, 44(4): 405-416.

Sarker, M A R, K Alam and J Gow. 2019. Performance of rain-fed Aman rice yield in Bangladesh in the presence of climate change. *Renew. Agric. Food Syst.*, 34(4): 304–313.

Shahid, S. 2010. Rainfall variability and the trends of wet and dry periods in Bangladesh. *Int. J. Climatol.*, 30(15): 2299-2313.

Shahid, S. 2011. Impact of climate change on irrigation water demand of dry season Boro rice in northwest Bangladesh. *Climatic Change*, 105(3-4): 433-453.

Shahid, S, X Chen and MK Hazarika. 2006. Evaluation of groundwater quality for irrigation in Bangladesh using geographic information system. *J. Hydrol. Hydromech.*, 54(1): 3-14.

Timmer, C P. 2010. The changing role of rice in Asia's food security.

Yu, W H, M Alam, A Hassan, A S Khan, A C Ruane, C Rosenzweig, D C Major and J Thurlow. 2010. Climate Change Risk and Food Security in Bangladesh. *EarthScan*, London.

Yuji, M, T Kiyoshi, H Hideo and M Yuzuru. 2009. Impact assessment of climate change on rice production in Asia in comprehensive consideration of process/parameter uncertainty in general circulation models. *J. Agric. Ecosyst. Environ.*, 131: 281-291.

.