Spatiotemporal Risk Assessment of Agricultural Drought Disasters in Aman Rice Growing Season in Western Bangladesh

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Abstract

Agricultural drought (AGD) is among the most well-known and devastating natural disasters on the globe, wreaking havoc on rain-fed agricultural countries, including Bangladesh. The Penman-Monteith (P-M) equation and a crop coefficient model were used to assess the spatial and temporal variability of the rainfed Aman rice season in western Bangladesh between 1980 and 2017. To reveal the spatiotemporal changes in drought during the Aman rice growing phases in western Bangladesh, the crop water deficit index (CWDI) was developed for AGD evaluation. In addition, based on risk formation theory, this study intends to construct a drought disaster risk index (DDRI) for rain-fed Aman rice for various growth phases. The results revealed that the crop water deficit was found to be the lowest in the vegetative phase and the highest in the ripening phase. Among all the areas, the CWDI was highest in the Rangpur and Rajshahi regions. Drought risk was relatively higher in the late phase of the crop growing period due to high temperatures, inadequate rainfall, climatic characteristics, and geographical setting. Precipitation, evapotranspiration, and a rapidly changing climate all contributed to variations in crop water deficits in the study region. Crop yields were reduced in all sub-areas. Spatially, higher values of DDRI were observed in the northern areas of western Bangladesh. New adaptive measures and policies are essential to improve the adaptability and mitigation capacity of AGD risk. Finally, this study suggests that farm-level adaptation, cropping patterns, and drought-resistant crops should be introduced in the study region.

1. Introduction

Drought, particularly agricultural drought (AGD), is a more intricate and poorly understood natural hazard than the others (Hu et al. 2021a). It is an insidious natural hazard that is defined as a prolonged period of much lower precipitation than average. Drought raises water and food security concerns, resulting in lower agricultural crop yields and economic losses around the world (Zinat et al. 2020; Kamruzzaman et al. 2019a). Furthermore, due to changes in land use patterns, climate change has recently intensified drought frequency and severity (IPCC 2007; Islam et al. 2017, Kamruzzaman et al. 2019b). Droughts have become more common in recent decades as a result of global climate change (Wang et al. 2017; Shahfahad et al. 2022). Bangladesh, as an agricultural country, is striving to adjust to changing climate conditions in addition to the problems of an increasing population and ensuring food security (Rosenzweig et al. 2014). Hence, in developing an agro-adaptation and mitigation strategy that can help to mitigate the negative effects of climate change, a detailed understanding of the potential threats of drought to agriculture activities is essential.

The Palmer drought severity index (PDSI), standardized precipitation evapotranspiration index (SPEI), standardized precipitation index (SPI), soil moisture index (SMI), and effective draught index (EDI) are among the drought indices used to evaluate drought events (Shahid and Behrawan 2008; Islam et al. 2017; Kamruzzaman et al. 2019b). These indicators rely on a small number of factors, such as rainfall and temperature, to simplify data collection and allow for speedy drought evaluation; nevertheless, they are unable to identify the severity of the drought's influence on agricultural productivity. The vast majority of previous drought studies have concentrated on the spatiotemporal aspects of drought as measured by
meteorological indices (Hu et al., 2021b). However, no previous study has focused on using the AGD index to characterize AGD in Bangladesh. Crop water deficit index (CWDI) has been widely used as an AGD tool to evaluate changes in crop drought stress over time (Yang et al. 2017; Gao et al. 2019; Zhang and Wang 2017). A study by Gao et al. (2019), found that the risk of drought is highest during the sowing-seedling and tassel-milking phases of summer maize, and that the northern region of the HRB (Huaihe River Basin) is more susceptible to drought. The total CWDI is comprised of five consecutive weighted 10-day CWDIs. Depending on the amount of precipitation and how much water is needed, the CWDI is calculated. Both its accuracy in depicting drought from the perspective of wheat growth phases and its applicability in wet regions are key advantages of the CWDI. The noncumulative CWDI was used in this study to show how the combined effects of plants and meteorological conditions affect agricultural water stress.

Rice, Bangladesh's primary food, is extremely vulnerable to climate change and disasters linked to climate change like floods and droughts (Yu et al. 2010). In Bangladesh, three varieties of rice are farmed, with Aman rice accounting for more than 40% of the total planted rice area and approximately 50% of the rain-fed rice area. The Aman rice variety is typically planted in July–August and harvested in November–December, whereas the others (Boro and Aus rice varities) are farmed throughout the year (Ghose et al. 2021). Rahman and Lateh (2015) state that unfavorable conditions in emerging countries like Bangladesh may worsen. As a result, rain-fed rice cultivation has become extremely fragile in the country, particularly in the northwest. Water stress affects transplanted amaranth during the reproductive stage or early ripening stages, lowering crop yields. Using a crop growth simulation model, a yield of 7.218 t/ha was predicted with early transplanting on June 1 and low water stress during flowering and maturity stages, whereas yield reductions of 46%, 37%, and 73% were predicted with high water stress during flowering and maturity stages (Mahmood et al. 2004). Drought is only included as a factor in this study during the entire Aman rice growing stage as it is more vulnerable to climate change. Drought-induced instability in Aman rice production continues; it will ultimately have an impact on agricultural productivity and constitute a serious food safety risk. As a result, assessing drought risk and its impact on crop productivity in the context of climate change is extremely crucial.

In the earlier cited works, most of them talked about climate change situations, where seasonal and spatial variations in water deficit and long-term drought, including wet/dry phases and drought-prone areas, as well as drought duration through time, were studied (Kamruzzaman et al. 2019a, b). Previous drought assessments were based primarily on atmospheric, hydrologic, and soil parameters, according to reviews of the past literature. As one of the most important criteria, crop physiological water deficit has only been used infrequently in assessing the risk of an AGD catastrophe occurring. Thus, assessing AGD risk from Aman rice growth stages is crucial for increasing crop yield. Nonetheless, there is a scarcity of studies on spatiotemporal variations and drought risk assessments during the Aman rice growth period in western Bangladesh. This work used meteorological information from 7 stations in western Bangladesh from 1980 to 2017 to analyze AGD using the CWDI, in order to fill the previous research gap. The main purposes of this study are to (1) analyze the spatiotemporal characteristics of drought throughout the Aman rice development phase in the western region and (2) quantify the AGD risk using a drought
disaster risk (DDRI) model during the Aman rice growth phase. The novel aspect of this research is that it uses risk formation theory to construct a DDRI and categorise AGD according to the Aman rice growing phase based on variations in water supply and demand as reflected by the CWDI in western Bangladesh. This research could help researchers better understand the rain-fed Aman rice distribution pattern, as well as develop disaster mitigation and adaptation techniques in western Bangladesh.

2. Materials And Methods

2.1 Study area description

Bangladesh is one of the world’s most drought-prone countries. The most severe drought in Bangladesh’s history happened in the western half of the country. It is separated into two parts: The north-western region (240.30 - 26040 N, 880.01-890.90 E) and the south-western region (220.52 -230.90 N, 880.20 -90030 E) (Islam et al. 2017). The northwestern stations are Rangpur Bogra, Rajshahi and southwestern stations are Faridpur, Satkhira, Khulna, Barishal. Aman rice production is the highest in this region of the country. With an average rainfall of less than 1500 mm annually and summertime humidity of less than 50%, Bangladesh's western zone is the driest. In the summer, it is the warmest climatic zone. The typical maximum temperature in summer exceeds 35°C, while rainfall is substantially lower. It also gets a lot less rainfall than the rest of the country. The excesses of the zones to the north are softened in the south-western zone. The annual rainfall varies from 1,500 to 1,800 mm (Islam et al. 2019).

2.2 Data source and quality check

Climate data

Seven stations in Bangladesh’s western area provided daily meteorological data (Fig. 1). These seven stations have been selected as the study area because of their climatic characteristics. The study area was chosen for a variety of reasons, including rainfall patterns, temperature variability, hydrological characteristics, and historical drought records. This study used daily maximum, minimum, and average temperatures, solar radiation, sunshine hours, rainfall, static pressure, and wind velocity from 1980 to 2017. It should be emphasized that the research is based on data from the period 1980 to 2017. The information was obtained from the Bangladesh Meteorological Department (BMD). The quality control of these datasets was verified using quality control tests such as the Chi-Squire test and the Grub test. BMD staff confirmed the accuracy and validity of the dataset. In the case of missing data on rainfall, temperature, and humidity, those were collected from the nearest station, and a well-developed method was applied to make them accurate.

Crop data

To get information on the Aman rice growing season, daily crop data such as farmed area, crop yield, and pheno-phase were gathered from the Bangladesh Bureau of Statistics (BBS 2019). Phenophase data of
Aman rice was collected from agrometeorological stations in Bangladesh throughout the research period, while yield data was collected from the crop database in the Statistical Year Book Bangladesh-2018.

**Socio-economic data**

The socio-economic data from the period of 1980 to 2011, including GDP, population, total power of agricultural machines, effective irrigation area, disaster area, and plowed area, are collected from the statistical yearbooks of the Census (2011) of Bangladesh.

### 2.3 Calculation of CWDI

This study uses the crop water deficit index (CWDI) to detect drought during the Aman rice growing season. The Agricultural Water Deficit Index (CWDI) is an effective method for determining deficits in crop water and it’s frequently used in agricultural drought analyses (Yang et al., 2017; Jhajharia et al., 2012; Gao et al., 2019). The CWDI is determined by subtracting the crop water requirement from the water demand at the very same phase (Gao et al., 2019; Hu et al., 2021a). Eq. (1) shows how to calculate the CWDI for a discrete 10-day period:

\[
CWDI_i = \begin{cases} 
\frac{ET_i - P_i}{ET_i} \times 100\% & \text{if } ET_i \geq P_i \\
0 & \text{if } ET_i < P_i
\end{cases} \tag{1}
\]

Where \(CWDI_i\) is the total water deficit index for the \(i\)th 10-day period (%), \(ET_i\) is the rice collective water need for the \(i\)th 10-day period (mm), and \(P_i\) is the cumulative precipitation for the \(i\)th 10-day period (mm), which is equivalent to crop watersupply. Five consecutive 10-day weighted CWDIs make up the total CWDI. The CWDI is determined by the quantity of rainfall and the volume of water required. The CWDI has several benefits, including the ability to properly show drought from the perspective of Aman rice development stages and the ability to be used in humid areas.

As a result, the noncumulative CWDI was chosen to expose the combined effects of plants and agricultural water demand is influenced by meteorological conditions.

\(ET_i\) was computed with the crop coefficient-\(ET_0\) method by the given equation:

\[
ET_i = K_c \times ET_0 \tag{2}
\]

The crop coefficient is \(K_c\), while the reference evapotranspiration is \(ET_0\).

The FAO P-M (Penman-Monteith) equation, given by the FAO (Food and Agriculture Organization), was used to calculate \(ET_0\) (Allen et al. 1998).

\[
ET_0 = \frac{0.408 \Delta (R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_v)}{\Delta + \gamma (1 + 0.34 h_2)} \tag{3}
\]
Where $ET_0$ is the reference evapotranspiration (mm day$^{-1}$), $\theta$ is the vapor pressure curve (k Pa° C$^{-1}$), $Rn$ is the net radiation at the crop surface (MJ m$^2$ day$^{-1}$), $G$ is the soil heat flux density (MJ m$^2$ day$^{-1}$), $\psi$ is the psychrometric factor, which should be 0 according to the FAO standard, $T$ denotes the daily average atmospheric temperature at a height of 2 meters (°C), $u$ (kPa).

Based on the CWDI values, north-western part of Bangladesh can be divided into three sub-regions (Fig. 1). The drought classification criteria based on the CWDI of Aman rice are shown in Table S1.

### 2.4 Drought characteristic index calculation

**Drought frequency**

The drought onset throughout the crop growth period is expressed as drought frequency (DF). Using Eq. 4, F can be obtained.

$$DF = (n / N) \times 100\% \ (4)$$

Where $N$ is the total year numbers with meteorological data, and $n$ is the number of drought years.

**Drought station ratio**

The drought station ratio ($P_j$), which is used to assess drought-affected areas, is calculated as follow:

$$P_j = (m / M) \times 100 \% \ (5)$$

The overall number of climatic sites is $M$, the amount of drought sites is $m$, and the year is $j$.

**Yield reduction rate**

Eq. 6 is used to calculate the rate of rice yield reduction.

$$R = (CY / TY) \times 100\% \ (6)$$

where The yield decrease rate is $R$, the climatic yield is $CY$, and the time trend yield is $TY$. $CY$ is a variable that represents the annual variation in wheat production due to climatic circumstances, and it may be expressed using Eq. 7.

$$CY_i = AY_i - TY_i \ (7)$$

Where $CY$ is for climatic yield, $AY$ stands for actual wheat yield per unit area, $TY$ stands for temporal trend yield, which can be estimated using the 5-year rolling average actual yield, and $i$ stands for the year. Positive (negative) $CY$ values indicate increases (decreases) in wheat production due to favorable (unfavorable) environmental conditions.

### 2.5 Drought disaster risk assessment model
Eq. 8 was used to compute the drought disaster risk index (DDRI) for the Aman rice growth period in western Bangladesh:

\[
DDRI = (DH \times DH_w) + (DS \times DS_w) + (ED \times ED_w) - (PL \times PL_w) \quad (8)
\]

Here, DS is the sensitivity of Aman rice to drought; DH is the drought hazard, which is the frequency and intensity of drought; ED is the degree of exposure of Aman rice to drought; and PL is the regional production level, which is used to assess drought disaster prevention and reduction capabilities. The normalized indices are all DS, DH, PL, and ED values. The weights assigned to the DH, DS, ED, and PL are DHw, DSw, EDw, and PLw, respectively.

DH was determined with drought intensity and frequency using the methods of Zhang et al. (2016) and Islam et al. (2017). DS was reflected using the slope of the regression function between yield reduction rate and drought intensity. DH and DS were determined month by month, taking into account the crop's sensitivity to dryness throughout distinct growth periods. The ratio of Aman rice grown area to total cultivated area was used to illustrate ED. Per capita GDP, effective irrigated cultivated area, and total power of agricultural machinery were used to calculate PL. Standard treatments of DH, DS, ED, and PL were conducted, and the weights of DH, DS, ED, and PL were given using the analytic hierarchy process.

2.6 Spatial distribution analysis

In general, bayesian kriging, standard kriging, and inverse distance weighted kriging were used to generate geographic variability of AGD risk at various crop growth phases (IDW) (Islam et al. 2019; Zinat et al. 2020). When compared to alternative interpolation methods, the IDW model was chosen for spatial variability analysis for this study due to its acceptance and estimation accuracy (Islam et al. 2021).

3. Results

3.1 Interannual variation of CWDI

Drought occurrence in the reproductive stage of Aman rice is comparatively lower than any other type of rice. In this season, rainfall remains abundant at almost all metrological sites. Among all the selected study areas, the northern region is slightly prone to drought. A water deficit exists in this region (Rangpur, Rajshahi, and Bogra). CWDI mean values in the central, southern, and northern regions at the reproductive (mid) stage (Table S2). According to calculated results of the CWDI from the 1980 to 2017 period, selected study areas faced relatively higher water deficits. The reproductive phase of Aman rice is so important for crop production. At this stage of production, the water deficit becomes a little bit higher because of the rainfall pattern in Bangladesh. In recent years, the percentage of water deficit has also increased due to uneven rainfall. Water deficits and surpluses are experienced. The southern part has a water surplus rather than a water deficit. The percentage of CWDI also varies from year to year which depends on ET$_{0}$ and cumulative precipitation. The northern region of the study has a greater water deficit than the central region, which has a medium-range water deficit. In initial stage CWDI value is higher in
central region, and lower in northern region. Drought intensity level is determined through values from this CWDI (Table S3). Crop water deficit is relatively lower in initial stage of Aman rice growing season than reproductive and ripening period.

Figure 2 shows the water deficit level in the ripening season of Aman rice growth. The possibility of drought occurring is relatively higher in the late or ripening season of Aman rice, which is usually a part of the winter season. Drought generally occurs in the late winter season in Bangladesh. The drought level during the ripening season of different stations is represented in Fig. 2. CWDI mean values in the central, southern, and northern regions at the ripening (late) stage.

### 3.2 Spatial pattern of drought frequency

According to the initial or vegetative phase of the Aman rice growing season, the drought frequency at the initial stage is the highest at 10.81% and the lowest at 5.5% (Fig. 3). DF doesn't remain high for the entire period. From the vegetative to ripening stages, there was a low drought frequency in the selected study area. According to drought frequency percentage, the order of DF for a selected area is as follows: vegetative phase, reproductive phase, ripening phase. The mean drought frequency of three different phases is 8.1%, 18.5%, and 32.82%, respectively. The frequency of drought is shown in the figure by using different colors. The red zone shows the highest frequency, and the blue part shows the lowest drought frequency. Drought frequency of drought is quite high, as it is known that Bangladesh has faced a repeated number of droughts historically (Afrin et al. 2019). The high drought frequency of each station represents the number of times drought occurred in the locations from 1980 to 2017. The concentration of drought frequency is an ultimate result of climate change and uneven rainfall. The spatial distribution of drought frequency is shown on maps a, b, and c, while each frequency level ranges from 0–100%. A lower frequency percentage means a minimum number of droughts and a higher frequency means a maximum number of droughts. Droughts are more common in the northern region of Bangladesh than in the rest of the country.

### 3.3 Spatial pattern of drought intensity

Figure 4 illustrates the spatial distribution of drought intensity in a given study area. The intensity of drought is much lower. In the vegetative season of rice growing, there is no drought because of the abundant amount of rainfall. Similarly, drought intensity remains below its level in the reproductive phase. There is a very low concentration of drought that occurs in the ripening season of the Aman rice growing season. The spatial distribution of drought intensity represents how drought occurs in different selected study areas. All the evaluated drought intensity shows negative values in the map, which means there is an absence of drought in both the vegetative and reproductive seasons. Barishal, Rajshahi, and Faridpur (dark areas of the map) have comparatively higher drought intensity, Rangpur has a moderate intensity, and Barishal, Satkhira, and Khulna have the least intensity of drought (lighter parts of the map). The ripening phase of crop growth has been shown. According to all calculations, only this phase of crop
growth faces drought. Rangpur, Rajshahi, and Bogra (dark part of the map). Barishal, Khulna, and Satkhira have comparatively lower drought intensity, and the least drought intensity exists in Satkhira.

### 3.4 Drought disaster risk index

#### Characteristics of drought hazard (DH)

Each sub-area has different range of drought hazard according to calculation. Natural breakpoint classification, all station has shown on the map. From vegetative to ripening phase of Aman rice, DH were nearest to each study site. Lighter green part shows highest drought hazard in vegetative phase. Barishal, Khulna has the high probability of drought hazard. Rangpur and Rajshahi has lower DH (shown in map by red color). In ripening phase of crop, Faridpur and Satkhira has the high (shown by lighter green color) drought hazard Barishal has lowest amount of drought hazard, Rajshhi has relatively higher DH than Barishal. Rangpur and Bogra has moderate DH (Fig. 5).

#### Characteristics of drought sensitivity (DS)

Based on DS index values, the selected study area was divided into three sorts of areas. There are three levels of difficulty: high, medium, and low.

#### Characteristics of wheat exposure degree (ED) to drought

According on the ED values, the study area was sorted into three different regions. The northern ED regions are primarily found in Rajshahi, Rangpur, and Bogra, as indicated in Fig. 6. Faridpur, Barishal, Khulna, and Satkhira are the primary centers of the central and southern ED regions, respectively. The northern region has a high ED, while the central region has a low ED.

#### Characteristics of regional production level (PL)

The research area was divided into three parts based on the PL values. Northern PL regions are primarily scattered in Rajshahi, Rangpur and Bogra. The central and southern PL regions are mainly stated respectively in Faridpur; Barishal, Khulna and Satkhira. PL is high in northern region and low in central region.

### 3.5 Drought disaster risk index

The DDRI values indicate that, entire selected area has divided into three regions. As represented in Fig. 7 from the vegetative to ripening stages. There was a very significant DDRI in Rangpur, Rajshahi and Bogra (northern side), which has shown on the map by red color of vegetative phase Satkhira, Barishal and Khulna has lower drought risk (yellow part of map). In reproductive phase of Aman rice northern region basically Bogra, Rajshahi, Rangpur has comparatively high drought disaster risk. Barishal, Khulna and Satkhira has medium drought disaster risk. Lastly, at ripening period of drought risk remains higher considering other two stage of crop production, DDRI is highest in ripening stage. In ripening phase of Aman rice northern region basically Bogra, Rajshahi, Rangpur has comparatively high drought disaster
risk. Barishal, Khulna and Satkhira has medium drought disaster risk. DDRI for agricultural drought in the context of Aman rice depends on several climatic factors, crop yield reduction rate that usually affected by drought in agricultural production period.

4. Discussion

The purpose of this study is to examine the spatiotemporal changes and AGD risk in the study area (a drought-prone region). Earlier studies have looked at the spatial characteristics and risk of winter rice water consumption in the study location at various phases of the crop's growth (Hu et al., 2021a; Wang et al. 2017). Water scarcity, on the other hand, has a significant impact on rice growth at various stages (Potopová et al. 2016). Moreover, the CWDI exhibits notable geographical and regional alterations at several stages, which is consistent with findings from different studies (Yang et al. 2017; Gao et al. 2019).

In order to properly appreciate the Aman rice drought, the drought characteristics (intensity and frequency) were investigated during the crop's growing stages. Mild drought occurs in the final and last stages of crop production. There are some reasons behind this lower concentration of drought occurrences. First, select the study area's geographical location. Each of the areas gets adequate rainfall, though the northern districts are high Aman rice producing areas and require extensive irrigation as well. Second, when crops need irrigation, they almost get ready for harvest. As a result, agricultural drought does not affect the yield of rice that much. Water resources may be depleted as a result of irrigation and major over-exploitation of sub-surface water.

CWDI remains relatively lower than in the winter season, and Aman rice is usually cultivated in the rainy season. According to the Aman rice spatial patterns, drought disaster risk differed spatially at each development stage. Droughts may be distributed unevenly due to high air temperatures, wind speeds, and sun-shine hour lengths, as well as lower humidity and rainfall levels. Climate variability and drought patterns are essential physical parameters to consider when determining the consequences of climate change on the growth period of Aman rice.

Drought sites in the north and south can be targeted to reduce the chance of an Aman rice drought calamity. Furthermore, strengthening drought mitigation policies for every phase of rice growth, which is most vulnerable to drought, is critical. Identifying the spatiotemporal patterns of drought during the Aman rice growth periods provides a substantial basis for understanding climate change's consequences on rice-related drought, as well as a valuable basis for agricultural water management on the specified study site. CWDI was low in the vegetative, reproductive, and ripening stages of Aman rice, and there was little variation between years in the northern part of the field.

In order to maintain good rice production in the research area, excessive drought threats must be avoided during the ripening stages. To reduce rice-related drought at the mature stage in Bangladesh's northern region, numerous drought-resistant measures associated with water should be employed. In this study, the CWDI was used to examine the differences in drought during the rice growth seasons, which is acceptable for application in the study area. Changes in meteorological circumstances such as sunshine
hours, average wind speed, and solar radiation can cause drought features to vary (Hu et al. 2021b). In comparison to climatic variables, the CWDI balances crop water availability and demand. Moreover, crop properties, soil properties, and climate variables were all considered in this study, resulting in a comprehensive picture of the influence on the environment (Huang et al. 2017). In practice, agricultural droughts can be detected at various stages of Aman rice growth. The standardized precipitation evapotranspiration index (SPEI), the standardized precipitation index (SPI), the crop water stress index (CWSI), and the Effective drought index (EDI) have all been used to measure agricultural drought in developing countries (Islam et al. 2017; Kamruzzaman et al., 2019a, b; Zinat et al. 2020; Páscoa et al. 2017; Islam et al. 2021; Shahfahad et al. 2022).

According to the results of this study, drought risk exists at a higher level in the ripening phase of Aman rice. Two other phases have a very low amount of drought risk. Rainfall variability, a reduced need for irrigation, climatic factors, and land use patterns are some of the primary reasons for a lower drought disaster risk. Considering food production and the world's concern about food scarcity, the chance of agricultural drought must be kept to a minimum.

Drought is a slow-onset hazard that has an impact on the agriculture, economy, and ecology of western Bangladesh. Residents in northwestern Bangladesh have implemented a variety of adaptation practices, including drought-tolerant rice cultivars, domestic horticulture, and jujube crop rotations, to offset the effects of the drought. Hossain et al. (2016) report that adapting to changes in weather and climate will help agriculture in the long run by reducing the effects of drought and preventing future climate change.

In order to mitigate and adapt to drought risk in agriculture, it is necessary to take initiatives from the government and other related authorities. Implementation of the new strategy is important so that the existing probability of an occurring drought will be minimized and that will not affect the agricultural sector much. Agricultural drought intensity can be controlled through new policy implementation or existing policy improvement.

5. Conclusion

For the first time in Bangladesh, during the rain-fed Aman rice growth period, the spatiotemporal characteristics and consequences of agricultural drought disasters are widely explored in this study. The major findings are as follows:

- Drought spatial characteristics in the total growth period, with higher CWDI values in the northern and southern parts, are lower during the growth phases of Aman rice. Only during the ripening period does the amount of precipitation in the northern region match the rice water requirement.
- During the mature phase, there were sporadic droughts. Drought frequency in the northern region can be as high as 40–50% of the Aman growth period, while drought frequency in the southern region can be as high as 30%.
• From 1980 to 2017, the CWDI rose significantly in all of the central and northern areas during the mature phase. During the early and middle phases, however, a slight drought intensity was noticed.
• Drought threats followed the same spatial trend as the CWDI, with the most severe droughts happening in the northern area and the least severe droughts occurring in the southern area.
• During the vegetative and reproductive phases, which were generally the same, the southern area had the lower DDRI values. The DDRI was higher in the northern areas (Rajshahi, Rangpur, and Bogra) than other areas through the crop maturity phase. The DDRI gives baseline data to assess AGD disasters in Aman rice at various phases of development.
• The study's findings provide planners and relevant stakeholders concerned with drought hazard prevention and agricultural sustainability initiatives with relevant information on AGD risk. This research can also be used to help researchers and regional decision-makers develop management plans. Using specific AGD indicators and cropping varieties, the suitable period for calculating the cumulative CWDI must be chosen.

Declarations

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The authors declare that they have no conflict of interest.

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Author's Contribution

M.M.M.F.J. and MK wrote the main manuscript text; A.R.M.T.I supervised the research; J.M and S.D critically reviewed the manuscript. All authors read and approved the final manuscript.

Availability of data and material

Data used in this study are available from the first author upon request (milonbrri@gmail.com).

Code availability
Code used in this study are available from the first author upon request (milonbrri@gmail.com).

**Ethics approval**

Not applicable

**Consent to participate**

Not applicable

**Consent for publication**

Not Applicable

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Figures
Figure 1

Location map showing the study area, western Bangladesh
Figure 2

Interannual variability in the CWDI during Aman rice growing season (initial, mid and late growth phases).
Figure 3

Spatial distribution of drought frequency (DF) during different stage of Aman rice growing season
Figure 4

Spatial distribution of drought intensity (DI) during different stages of Aman rice growing season.
Figure 5

Spatial distribution of drought hazard ($DH$) during different stages of Aman rice growing season.
Figure 6

Evaluation of production level (PL, a), drought sensitivity (DS, b), and (ED, c)
Figure 7

Spatial distribution of drought disaster risk during different stages of Aman rice growing season

Supplementary Files

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