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Optimization of Irrigation Water to Maximize Transplanted Aman Rice Production in Selected Areas of Bangladesh

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ABSTRACT

In rainfed and irrigated agriculture, optimization of irrigation scheduling is very essential to maximize the crop production using the limited of agricultural water resources. A study was conducted to estimate requirement of irrigation and its scheduling of T. Aman (wet season) rice in the Northwest and Southeast region of Bangladesh using CROPWAT model. This paper utilized the daily rainfall and reference evapotranspiration data sets, obtained from seven weather stations for the period of 1981 to 2015. Effective rainfall and reference crop evapotranspiration (ET_o) were calculated using the USDA Soil Conservation method and Penman-Monteith method, respectively. The simulation model of this explored the appropriate transplanting date to utilize maximum rainwater and to avoid supplemental irrigation. Four transplanting dates 15 July, 30 July, 15 August and 30 August were considered for transplanting T. Aman rice in the study areas. The optimization results showed that the water requirement was lower of the rice crop transplanting on 15 July in all locations due to higher effective rainfall. No supplemental irrigation was required for T. Aman cultivation transplanted on 30 July in Rangpur, Dinajpur, Bogura and Mymensingh regions since rainfall was sufficient to meet the demand of the crop. Therefore, this period was found for suitable and recommended for transplanting of T. Aman rice in these four locations. Transplanting after 30 July in these four locations needed supplemental irrigations. This study also revealed that 30 July transplanting required one supplemental irrigation in Jashore and Rajshahi regions due to insufficient rainfall. This period was also considered as the appropriate transplanting time in these two locations. However, in Pabna, one supplemental irrigation must be applied for T. Aman even transplanting on 15 July owing to in adequate rainfall. Irrigation requirement and number of irrigations were gradually increased with delaying the transplanting time. Early transplanting demanded less irrigation than late transplanting.

Key words: CROPWAT model, crop water requirement, effective rainfall, crop water requirement, irrigation scheduling, T. Aman, transplanting date

INTRODUCTION

Rice is cultivated in three seasons namely Aus, Aman, and Boro in Bangladesh. T. Aman rice is grown under rainfed condition in wet season. T. Aman rice is one of the major crops of Bangladesh and contributed about 48% of the total rice production (BBS, 2019). T. Aman rice is transplanted from July to August and harvested during October to December. The biggest consumer of the world's water resources is agriculture, as irrigated agriculture uses about 70% of the world's ground and surface fresh waters (Michelon *et al*., 2020). This water amount is insufficient to address actual irrigation needs and is expected to decline in the next decades in the arid and semi-arid regions

Both rain fed and irrigated agriculture require greater water use efficiency although deteriorating water resources and growing food requirements (FAO,1988). In hydrological cycle, rainfall and evapotranspiration are the most significant components which contributed food production (Smith, 1992).This threatened resource is recurrently wasted due to in efficient water management practices in agriculture and resulting low water productivity (Tarjuelo *et al*., 1996). Agricultural production in South Asia

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may be reduced up to 30% by 2050s if appropriate utilization of water use is not taken under prime consideration (Calzadilla *et al*., 2011). It is estimated that the freshwater supply in the agricultural sector is likely to decline 8–10% globally owing to increasing struggle in various sectors such as agriculture, urban and industrial sectors (Toung *et al*., 1994). Additional, plethora of Asian countries, per capita water availability has dropped by 40–60% between 1955 and 1990 (Gleick *et al*., 1993).

The declining trends of annual rainfall with more frequent hazardous events affecting catastrophe in terms of production destruction, extreme droughts, flooding, death and other calamities have been reported by many researchers (FAO ,1995). Therefore, appropriate strategies are needed for crop growth improvement through effective irrigation along with proper cultivation practices. Hence, water-efficient agricultural practices have massive importance to enable increasing cultivated area. Therefore, appropriate strategies are needed for crop growth improvement; create irrigation more effective and sustainable along with preserve farmland by proper cultivation practices. In this context, it is essential to improve irrigation management as well as water productivity (WP) or water use efficiency (WUE) in irrigation systems. Hamdy *et al*., (2003) realize great promises for improving irrigation namely supplemental irrigation, deficit irrigation (DI), rainwater harvesting, sprinkler irrigation, precision irrigation techniques and soil-water conservation practices. The desired irrigation management practices in irrigated or rainfed conditions are necessary for improving crop yields. However, limiting factor of water, effective use of land and water resources has great benefits of higher WP.

In Bangladesh, about 90% of the total rainfall occurs from April to October(Roy *et al*., 2010). T. Aman rice experienced terminal drought during the late monsoon. Rainfall is not sufficient for the potential yield of rice and most of the T. Aman rice remains at the flowering and grain filling stages after October (Sattar *et al*., 2009). The supplemental irrigation is highly essential in October-November for T. Aman rice cultivation. Rice yield is drastically reduced if supplemental irrigation is not applied timely. If the total amount of rainfall through the T. Aman crop growing period exceeds the crop water requirement then there is a need for supplemental irrigation due to the erratic distribution of rainfall (Saleh, 1991).

Nevertheless, irrigation for crop production, which is the largest water demanding sector in Bangladesh, needs extraordinary attention to manage upcoming water demand management. Improved irrigation management and agricultural practices can play a vital role to deal with the threat of water shortage (Acharjee *et al*., 2019). Suitable date of transplanting might be a modest and effective way to cope with changes in climatic factors with seasonal variability in rice production (Yesmin *et al*., 2019).

CROPWAT model can play a beneficial role in developing hands-on recommendations for optimization of crop production beneath of limited water supply conditions. CROPWAT is a customary model for agronomists, agro meteorologists and irrigation engineers to carry out appropriate calculations for crop water use studies and evapotranspiration and give precisely design of irrigation schedule (Smith, 1992). It permits the development of recommendations for the planning of irrigation schedule under erratic water supply situations, enriched irrigation practices and the assessment of production under rainfed environments or deficit irrigation (Shreedhar *et al*., 2015).

The present study targeted to find the prospect of utilizing maximum rainfall coverage during the T. Aman by figuring out the appropriate transplanting window based on rainfall distribution pattern. One of the key approaches is that application of exact amount of water to the crops at the exact time. For these motives, this study was carried out to estimate the irrigation requirement, total number of irrigation and appropriate time of irrigation to T. Aman rice in the Northwest and Southeast region of Bangladesh (Hossain *et al*. 2017).

METHODOLOGY

Study area

Figure 1 shows Daily rainfall and reference evapotranspiration data collected from seven districts namely Jashore, Pabna, Rangpur, Dinajpur, Mymensingh, Rajshahi and Bogura in Northwest and Southeast regions of Bangladesh for the period of 1981-2015. The sites and their coordinates are as follows: Jashore (23.16° N and 89.213°E), Pabna (24.15°N and 89.0667°E) and Bogura (24.85°N and 89.37°E). These regions belong to the agro-ecological zone (AEZ)-11 (High Ganges River floodplain) and AEZ-12 (Low Ganges River floodplain). These two AEZs cover 13,21,062 hectare (ha) with 32% loamy, 43% silt loam, and 12% clayey soil and 7,97,139 ha with 13% silt loam, 29% silty clay, and 31% clayey soil respectively (FAO, 1988).

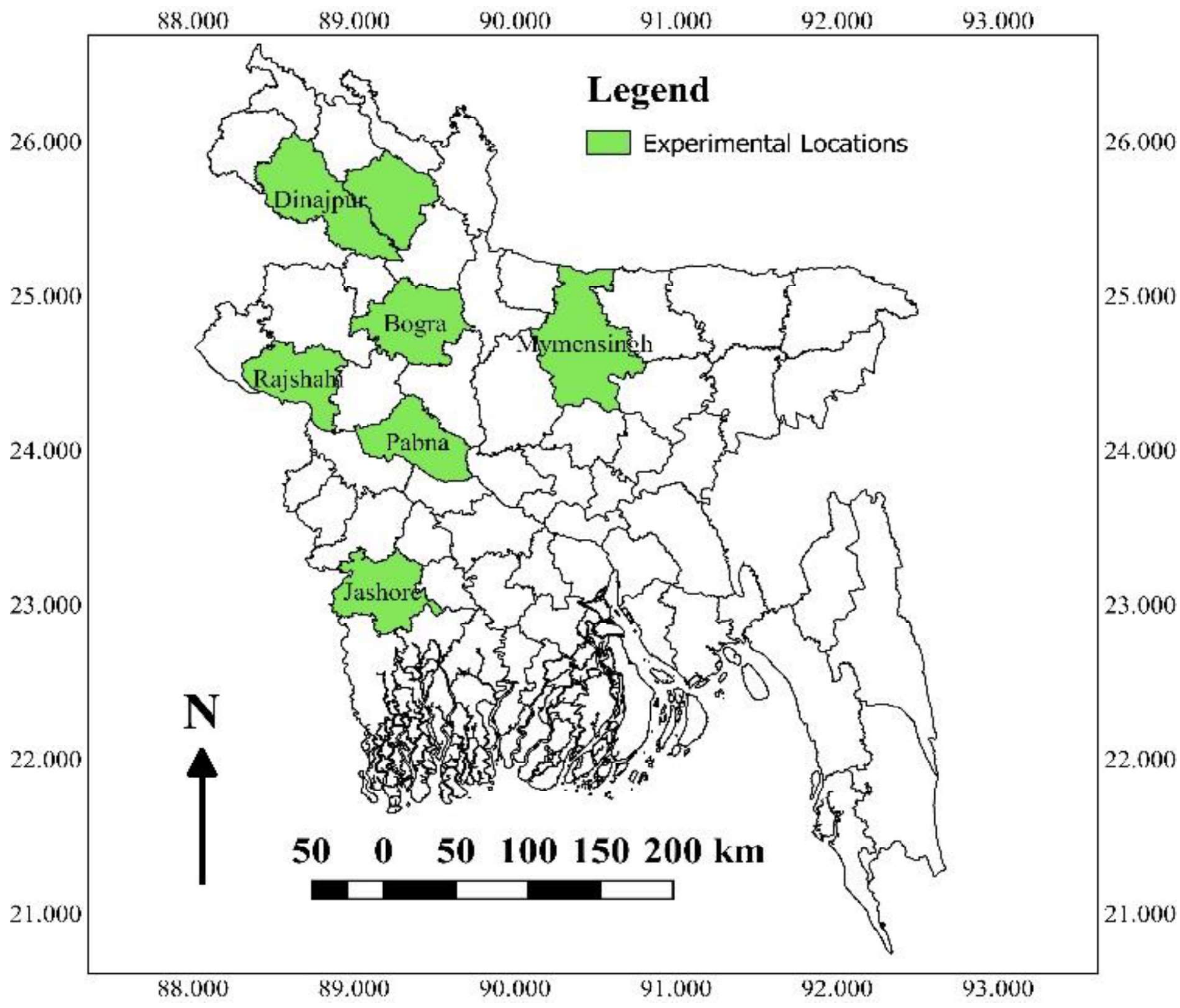


Fig 1: Experimental locations of the study area.

Input data requirement of the CROPWAT model

Land and Water Division of the FAO developed a practical decision support system called CROPWAT, is familiar to farmers for its easy calculation of crop water demands under diverse irrigation practices (Smith, 1992). The CROPWAT model uses climatic, crop and soil data for calculating the crop water requirement. The meteorological data contain: (1) maximum and minimum temperature (°C), (2) wind speed (ms^{-1}), (3) sunshine hours (h), (4) relative humidity (%) and (5) rainfall (mm).

All data of the study area are taken from Bangladesh Meteorological Department (BMD) from 1981-2015 for Jashore, Pabna (Ishwardi), and Bogura. In this study, T. Aman rice is considered for estimating crop water requirement. The CROPWAT model contains default data for T. Aman rice variety. The cropping pattern consists of date of planting, planted area (0–100% of the total area) and crop parameters (together with Kc value, root depth, depletion fraction, stage days).

In this study, irrigation scheduling was done for popular T. Aman variety BRRI dhan49 (135 days duration) and four transplanting dates (15 July, 30 July, 15 August, and 30th August). Growing period of rice was divided as follows:

(i) 30 days in seedling stage (nursery/land preparation)
(ii) Usually 10 days in initial stage (transplanting to seedling establishment)
(iii) Usually, 35 days in crop development stage (tillering to panicle initiation)
(iv) 30 days in mid stage (panicle initiation to 100%flowering) and
(v) 30 days in late stage (flowering to maturity).

The model considered Kc dry value as 0.7 for nursery, 1.05 for development and 0.7 for late stage. On the other hand, Kc wet value as 1.2 fornursery, 1.2 for development and 1.05 for late stage.

The CROPWAT model necessitates soil water status such as: initial available moisture, readily available moisture, and total available moisture. In this study the CROPWAT model comprehends default data for loamy soil. Default maximum percolation rate was 3.4 mm day^{-1} for silt loam soil in the model. The rice rooting depth was considered up to 40 cm.

Calculation of reference or potential Evapotranspiration (ET_o)

The CROPWAT software was used to determine ETo in mm $day^{-1}$and the radiation in $MJm^{-2}d^{-1}$ using relative humidity (%), wind speed ($m\ s^{-1}$), sunshine hours (h) and the average maximum and minimum temperatures (°C). All data were collected from Bangladesh Meteorological Department.

ET_o was calculated according to Penman-Monteith method using CROPWAT 8.0 model. The Penman–Monteith equation (FAO, 1998) incorporated in the CROPWAT model. Potential: CROPWAT model, crop water requirement, effective rainfall, crop water requirement, irrigation scheduling, T. Aman, transplanting date

Evapotranspiration is expressed by using following equation:

$$ET_0 = \frac{0.0408\,\Delta\,(R_n - G) + \gamma \frac{900}{T+273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34\,u_2)} \tag{1}$$

Where, ET_0 is reference or potential crop evapotranspiration (mm d^{-1}); G is soil heat flux (MJ $m^{-2}d^{-1}$); T is average air temperature (°C); Rn is net radiation at the crop surface (MJ $m^{-2}d^{-1}$); γ is psychrometric constant (kPa $°C^{-1}$); U2 is wind speed measured at 2 m height (ms^{-1}); ($e_s - e_a$) is vapor pressure deficit (kPa); Δ is slope of the vapor pressure curve (kPa$°C^{-1}$); and 900 is a conversion factor.

Calculation of effective rainfall

Effective rainfall was calculated by giving decadal rainfall in CROPWAT and the average rainfall was calculated for a 34-year period. The amount of precipitation which effectively

USDA Soil Conservation method was used to calculate effective rainfall (Smith, 1991). In USDA Soil Conservation method assumes crops can use usually 60–80% of precipitation up to 250 mm per month. The crops will be benefited only 10% if the total precipitation exceed 250 mm per month. In other words, if precipitation increased, its efficiency decreased. The effective rainfall is calculated by empirical equation:

$$P_{effective} = P * \frac{(125-0.2\,P)}{125} \text{ For P<250 mm} \quad (2)$$

$$P_{effective} = 125 + 0.1\,P \text{ For P>250 mm} \quad (3)$$

Where, $P_{effective}$ is effective rainfall (mm), and P is monthly rainfall (mm)

Estimation of crop water requirement and time of application

The amount of water, plant uptake by the help of its rooting system is called crop water requirement (CWR) which is essential for plant growth and development (Michael, 1974). According to (FAO, 2005) CWR equals crop evapotranspiration under standard conditions, and it is expressed as:

$$CWR = \sum(ET_0 \times k_c) \quad (4)$$

Where Kc is the crop coefficient of the given crop during the growth stage and T is the final growth stage.

RESULTS AND DISCUSSION

Distribution of potential crop evapotranspiration and rainfall

Figure 2 illustrates the annual potential evapotranspiration (ET_0) and annual rainfall in the study locations. It showed that the highest annual rainfall 2,243 mm in Rangpur followed by 2,220 mm, 1,812 mm, 1,759 mm in Mymensingh, Dinajpur and Bogura, respectively.

The lowest rainfall was 1,372 mm in Rajshahi. Among the study locations, the highest ET_0 was 1,450 mm in Jashore, whereas the lowest 1,228 mm accounted in Mymensingh. Annual rainfall exceeded the ET_0 in Jashore, Bogura, Rangpur, Dinajpur and Mymensingh locations. In the other locations, rainfall and ET_0 were similar.

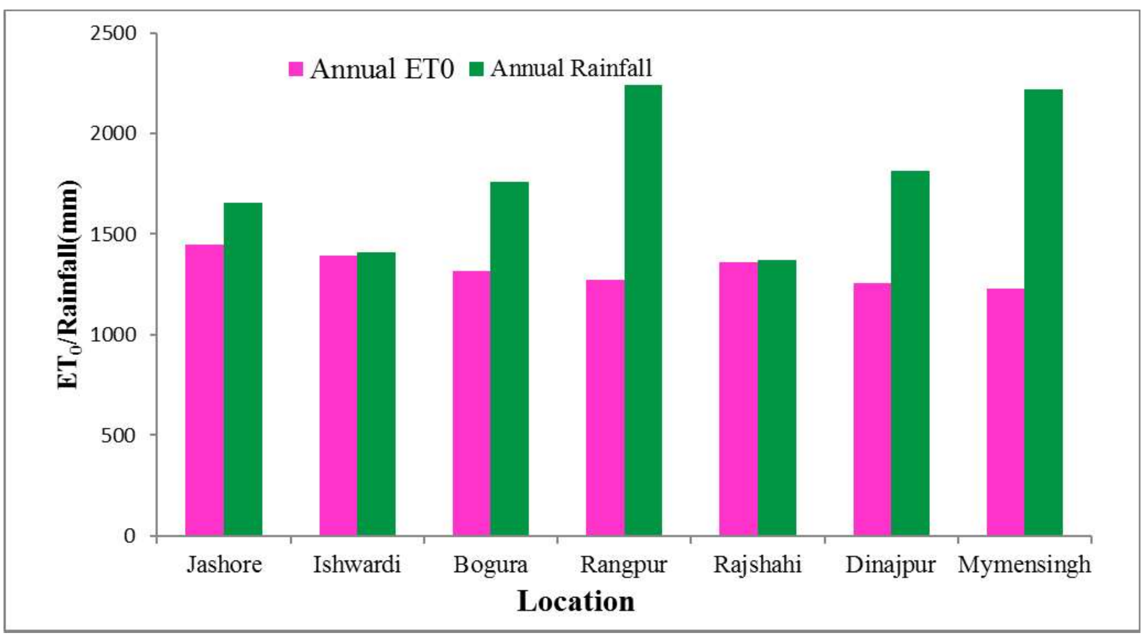
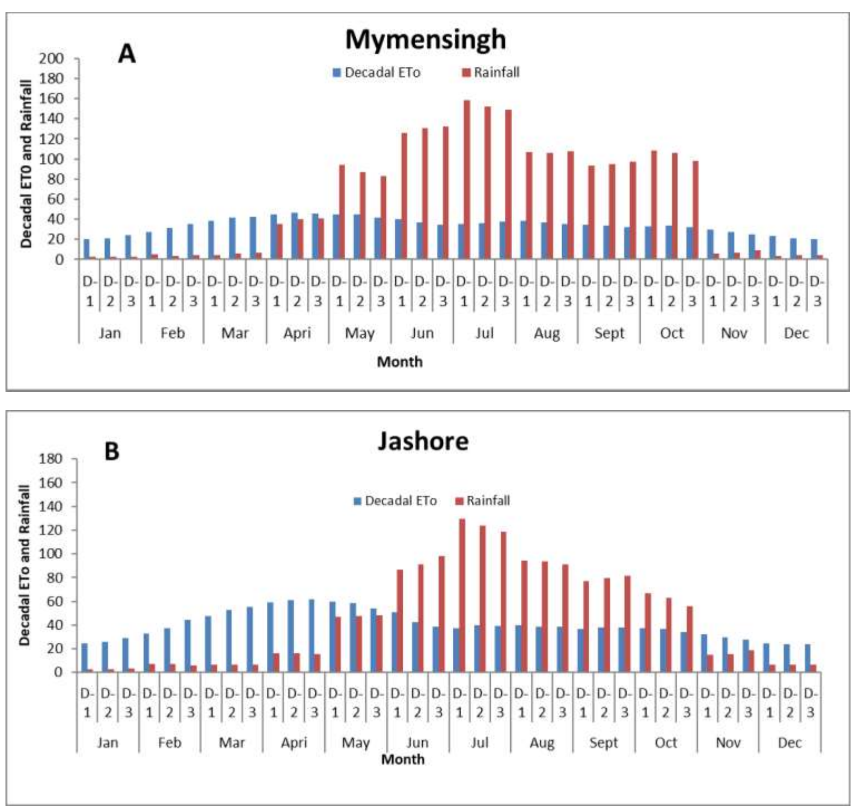


Fig 2. Spatial distribution of annual normal rainfall and potential evapotranspiration.

Spatiotemporal variation of crop water requirement and rainfall

Spatiotemporal distribution of decadal normal crop water requirement (ET_0) and rainfall in the study region were analyzed (Fig. 3). In Rangpur, from the first decade of May to last decade of October rainfall was found higher than ETo. It indicated that no irrigation was required to meet the consumptive use of crop due to enough rainfall. In the other period of the year, rainfall was deficit than ET_o and thus needed irrigation. In Jashore, between the first decade of June to the last decade of October rainfall was higher than ETo but between November to May ETo was higher than rainfall. The observed decadal ETo values compared to rainfall were higher from May to October and lower from November to April in Mymensingh. The highest decadal ETo was found in the second decade of April and the lowest in the first decade of January in Rajshahi. For the location of Bogura, the first decade of June to the last decade of October rainfall was higher than ETo and November to May ETo was higher than rainfall. In Dinajpur, it was observed that rainfall was higher than ETo from June to October, whereas from November to May, ETo was higher than rainfall. In another study, Hossain *et al*., (2017) found that during June to October rainfall was sufficient to meet the ETo in Western region of Bangladesh. Other than these months, ETo exceeded effective rainfall.

The temporal variation of ETo showed that the lowest ETo was found in January in almost all locations. It showed the rising trend after January and reached its peak in April. From March to June evapotranspiration increased due to low relative humidity and high temperatures. In contrast, in winter (November to February) evapotranspiration reduced due to high humidity along with low sunshine hours and temperature. Similarly, Hossain *et al*., (2017) found that potential ET value reduced with the lower values of wind speed, sunshine hours and temperature.



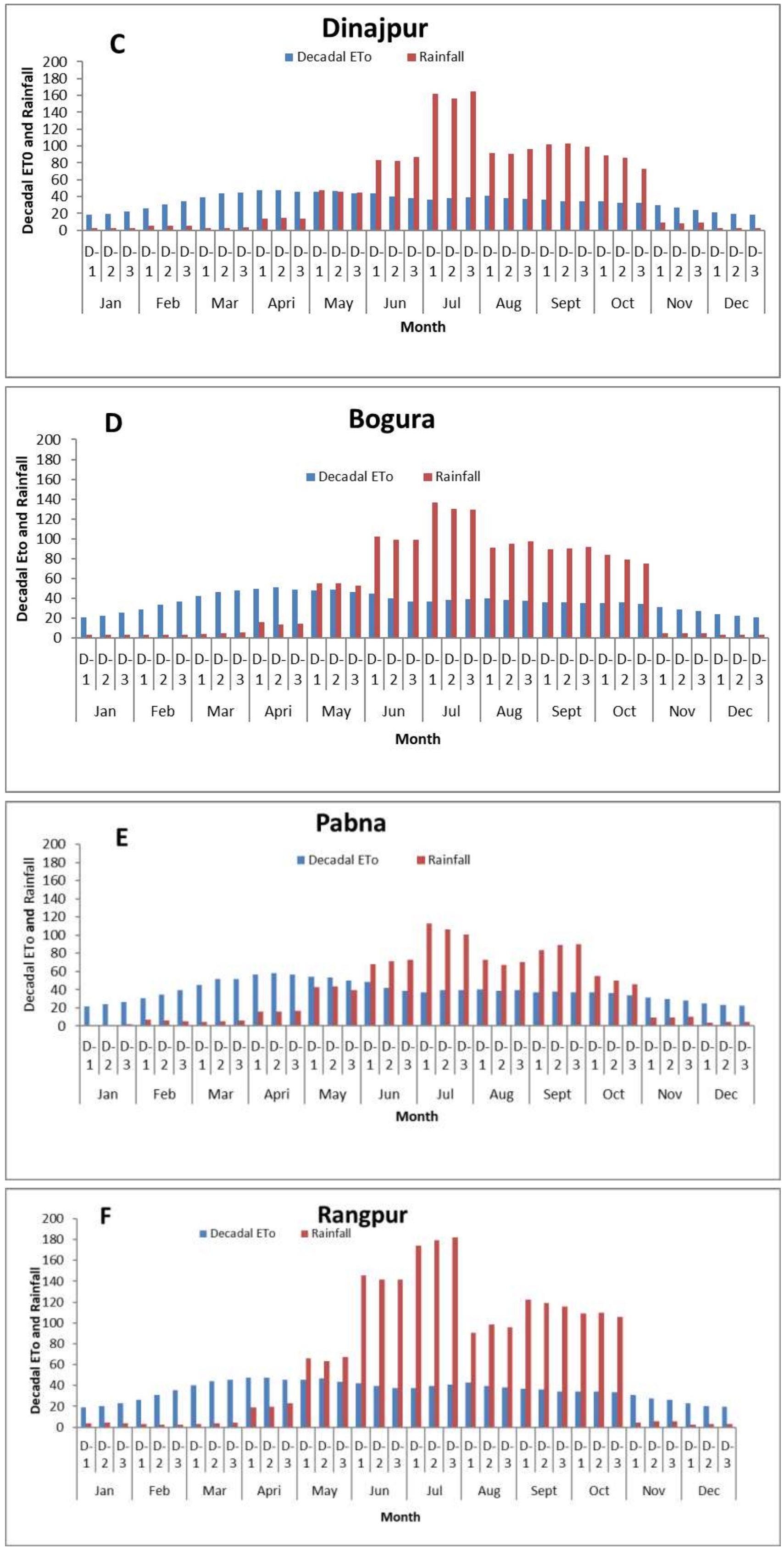


Fig 3. Spatiotemporal distribution of decadal normal ETo and rainfall in selected locations in Bangladesh (A-Mymensingh; B-Jashore; C-Dinajpur; D-Bogura; E-Pabna and F- Rangpur).

Crop water requirement, Effective Rainfall (ER) and net Irrigation Requirement (NIR) considering different transplanting dates:

Figure 4 shows rice crop water requirement (ETc) and effective rainfall for different transplanting dates which were analyzed. It depicts that the total effective rainfall was higher than ETc in transplanting dates for all locations. Among the tested transplanting dates, transplanting on 15 July showed rice would receive the highest rainfall amount during its growing span and produce highest ETc in all locations. Both rainfall and ETc followed a decreasing trend for delay transplanting. The maximum rainfall coverage was observed in Rangpur (720 mm), followed by Mymensingh (705 mm), Dinajpur (693 mm), Bogura (682 mm) for 15 July transplanting. However, the minimum rainfall was found in Pabna (416 mm) and Rajshahi (423 mm) for 30 August transplanting. Although, seasonal effective rainfall was higher than ETc, its uneven distribution caused drought in the crop growing period.

Table 1 shows the irrigation requirement and net irrigation requirement of T. Aman rice which were analyzed. It depicts that no supplemental irrigation was needed for transplanting on 15 July in all locations except Pabna. CROPWAT model estimated one supplemental irrigation (65 mm) for Pabna rice is transplanted on 15 July. Both the number of irrigation and NIR showed increasing trend for the delay transplanting. T. Aman rice transplanted on 30 July demanded one supplemental irrigation for Jashore (63 mm) and Rajshahi (65 mm) and two supplemental irrigations for Pabna (130 mm). However, no supplemental irrigation was predicted for Rangpur, Bogura, Dinajpur and Mymensingh.

The analysis suggests that transplanting on 15 August required supplemental irrigation of varying number for all locations. The highest three irrigations of 200 mm were estimated for Pabna region. Two irrigations were required for Jashore (133 mm) and Rajshahi (130 mm). Only one irrigation was estimated for Bogura, Rangpur, Dinajpur and Mymensingh regions. The effective rainfall after 15 August decreased steeply and crop growing period went to mid-November to December which is the dry month of the year. Thus, crop transplanted after 15 August faced terminal drought and accounted for supplemental irrigation. The highest five supplemental irrigations of 337 mm in total were estimated for Pabna, whereas the lowest three supplemental irrigations were accounted for Rangpur, Dinajpur and Rajshahi locations.

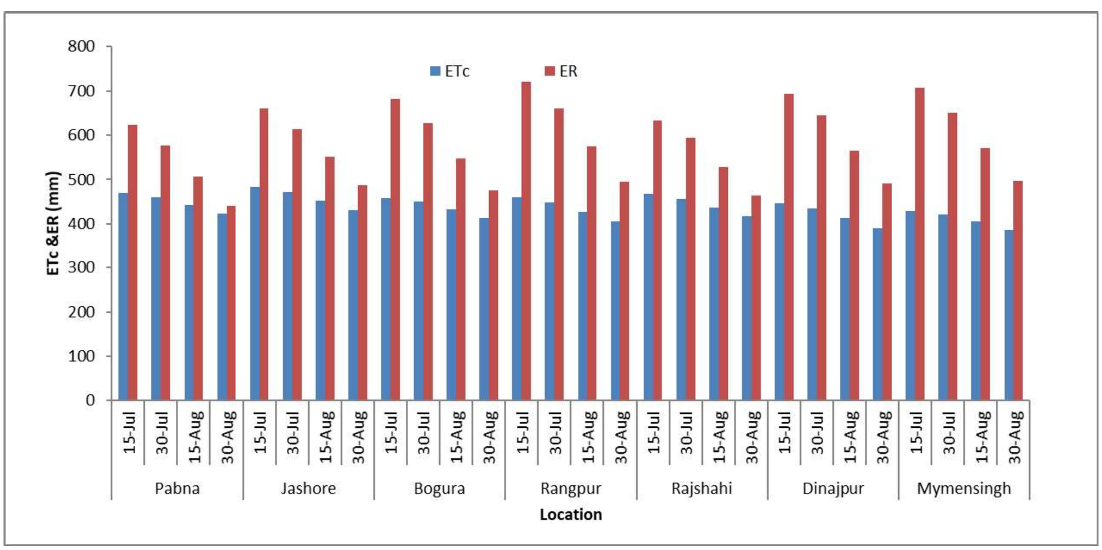


Fig 4. Spatial variation of rice crop water requirement (ETc) and effective rainfall

Table 1. Seasonal net irrigation requirement of T. Aman rice for different transplanting time in the study location.

Location	D/T	IR	NIR	No. of Irrigation
Pabna	15 July	1.9	65.3	1
	30 July	35.6	130	2
	15 August	69.8	199.7	3
	30 August	112.7	336.7	5
Jashore	15 July	0	0	0
	30 July	19.6	63	1
	15 August	45.3	132.6	2
	30 August	84.9	265.9	4
Bogura	15 July	0	0	0
	30 July	0	0	0
	15 August	70.7	61	1
	30 August	110.8	246	4
Rangpur	15 July	0	0	0
	30 July	0	0	0
	15 August	67.1	60.1	1
	30 August	106.5	185.3	3
Rajshahi	15 July	0	0	0
	30 July	25.4	65	1
	15 August	55	129.7	2
	30 August	94.8	260.2	3
Dinajpur	15 July	0	0	0
	30 July	0	0	0
	15 August	52.4	62	1
	30 August	89	186.4	3
Mymensingh	15 July	0	0	0
	30 July	0	0	0
	15 August	58.2	62	1
	30 August	95.4	222	4

CONCLUSION

Irrigation scheduling of T. Aman rice based on normal rainfall distribution was analyzed for Northwest and Southeast regions of Bangladesh using CROPWAT model. The estimated crop water requirement of T. Aman rice found lower when it was transplanted on 15 July in all locations due to higher effective rainfall. Both irrigation requirement and its split application gradually increased with delay transplanting over 15 July. No supplemental irrigation was required for T. Aman rice for 30 July transplanting in Rangpur, Dinajpur, Bogura and Mymensingh regions. Transplanting on 30 July in Jashore and Rajshahi, required one supplemental irrigation to meet the crop water demand. Supplemental irrigation must be applied in Pabna for T. Aman rice cultivation transplanting on 15 July to 30 August. Early transplanting demanded less irrigation than late transplanting. Transplanting of T. Aman rice within 30 July found the most appropriate time for utilizing maximum rainfall irrespective of all locations. Delay transplanting of T. Aman rice experienced terminal drought which may encounter yield reduction. Timely transplanting of rice could be saved ground water for irrigation as well as cost of production.

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