Estimation of Crop Water Requirement and Irrigation Scheduling of Rice in Southeastern Region of Bangladesh Using FAO-CROPWAT 8.0

R. A. Amin, M. B. Hossain, and A. Yunus

1 Introduction

With the rapid population growth, cereal food demand will also be increasing and providing freshwater for the world population has also become a major challenge. So water management and irrigation have to be optimized fully to gain maximum yield without water loss. Improvement in water use efficiency will also help in achieving the full benefit of other production inputs, like fertilizers, high-quality seeds, tillage, labor, energy, and machinery [1]. Water management can be done efficiently by CROPWAT [2]-aided irrigation scheduling which ensures the application of the desired amount of water at the right time to conserve water resources. For design and management of irrigation schemes, CROPWAT is a Food and Agricultural Organization (FAO) recommended model, designed by Smith [2] which assesses reference evapotranspiration (ET_o), crop evapotranspiration (ET_c) and irrigation water requirements by integrating climate, crop and soil data [3]. This model was developed by Land and Water Development Division of (FAO). Evaluation of irrigation practices of farmers and estimating the performance of crops under irrigated and non-irrigated conditions can also be done with this program in addition to irrigation scheduling [4]. Presently, the largest amount of water is consumed by agriculture and most of it is lost through evapotranspiration [5]. Rice is a staple food in the tropical region of the world. In Asia, more than 90% of the world's rice (*Oryza sativa L.*) is produced and consumed [6]. For a water-loving crop like rice, standing water is essential in

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the initial stages for supple plant growth and yield maximization. Evapotranspiration loss in this process is very high, and the cost of over irrigation results in higher production prices. Standing water also creates a salinity problem causing the land to become unsuitable for cultivation. Proper scheduling can minimize water logging problems by reducing the drainage requirements and lower fertilization costs by holding surface runoff and deep percolation (leaching) to a minimum.

Constructing dam and reservoirs upstream of transboundary rivers have been causing a shortage of flow in the dry season in Bangladesh, resulting in freshwater scarcity and salinity intrusion in the southern region of Bangladesh. The construction and maintenance of irrigation canal system are not cost-effective. Percolation during the canal flow raises the groundwater level creating marshlands and salinity in the soil along canals. The productivity of the irrigated rice ecosystem is threatened by decreasing water availability since 50% of freshwater is used for rice production in Asia [7] and irrigated rice culture fulfills 75% of the global demand of rice [8]. Water use efficiency may be improved through genetic engineering and biotechnology. But being a complex trait, scientists are skeptical about it [9].

Bangladesh is a riverine country with an average rainfall of 2000 mm. But the temporal and spatial distribution of rainfall is highly uneven and resulting in a dry spell of 5–6 months. Boro season varieties are mainly cultivated during the dry season for its higher yield and better rice quality. Irrigation is mandatory in this season, and water management must be done to minimize the cost. Production of Aus and Aman season can also be increased through irrigation if scheduling is done effectively. Hence, in this paper, an attempt has been made to estimate the irrigation requirement and time of irrigation for rice in the southeastern region of Bangladesh for all three seasons using CROPWAT 8.0.

2 Materials and Methods

2.1 Site Selection

The study area was in the southeastern region of Bangladesh (23.96–23.01°N and 90.66–91.39°E, altitude 5–15 m above mean sea level). Four districts, namely Cumilla, Feni, Chandpur, Brahmanbaria, were selected for the study. The total area of the selected study area is almost 7705.81 sq. km, and the total irrigated area is 3619.253 sq. km [10]. Therefore, almost 46.92% of the total area is irrigated in dry (Boro) season. The study area mainly belongs to agroecological zone (AEZ)-19 (Old Meghna Estuarine Floodplain), AEZ-16 (Middle Meghna River floodplain), AEZ-17(Lower Meghna River floodplain), and AEZ-23 (Chittagong Coastal Plains) [10]. Among these zones, AEZ-19 covers most of the land area [10] and the soil type of study area is mostly silt loam [11].

2.2 Data Collection

The CROPWAT model simulates crop water requirement and scheduling under various types of climatic, crop, and soil conditions. It calculates ET_o by using minimum and maximum temperature (°C), relative humidity (in %), wind speed (km/h), and sunshine hours (hours). The monthly values of these parameters were collected from the Bangladesh Meteorological Department (BMD) from 1981 to 2010 timespan.

From these, the model calculated radiation (MJ m^{-2} day^{-1}) and used it to calculate ET_o for every 10 days (defined as "decade" by FAO) and then accumulated it to generate monthly data.

Climatic data were not available for the Brahmanbaria District. So, climatic data of the Cumilla District were also used for calculating radiation and reference evapotranspiration (ET_o) for the Brahmanbaria District.

Rainfall data of Cumilla, Chandpur and Feni districts were collected from Bangladesh Meteorological Department (BMD) and the same from Bangladesh Water Development Board (BWDB) for Brahmanbaria District.

Rice is cultivated in three seasons (Aus, Aman, and Boro) in Bangladesh. For this research work, all three seasons were considered. BRRI dhan48 (110 days duration), BRRI dhan71 (114 days duration), and BRRI dhan89 (158 days duration) were taken for Aus, T. Aman, and Boro varieties, respectively. 10th May, 30th July, and 10th January were taken as the transplanting date for the selected varieties, respectively. Rice growing period was divided as:

I. Nursery/land preparation (seedling stage 20 days in Aus, 25 days in T. Aman, and 40 days in Boro season).
II. Initial stage (transplanting to seedling establishment, usually 10 days in all season).
III. Crop development stage (tillering to panicle initiation, 20 days in Aus, 19 days in T. Aman, and 48 days in Boro season).
IV. Mid-stage (panicle initiation to 100% flowering, 30 days for all three varieties]).
V. Late stage (flowering to maturity, 30 days for all three varieties).

Maximum rooting depth and puddling depth were considered 40 cm and 15 cm, respectively. The default values were taken from the model for crop coefficient ($K_{c_{\text{dry}}}$ and $K_{c_{\text{wet}}}$), critical depletion fraction, yield response factor (Ky). 1.05 m, 1.08 m, and 1.06 m were taken as the crop height for the varieties, respectively [12].

Hossain [13] reported the moisture content of silt loam soil at field capacity and wilting point were 26.8% and 12.9%, respectively, whereas drainable porosity was approximately 18% [12]. The bulk density of silt loam soil was 1.5 g cm-3 [13]. The maximum infiltration rate of the soil was considered 40 mm day^{-1}.

2.3 *Calculation of Reference Evapotranspiration* (ETo)

CROPWAT model calculated reference evapotranspiration using the FAO Penman–Monteith method [14]. The Penman–Monteith equation can be written as

$$\mathrm{ET_o} = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{\mathrm{T}+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)} \tag{1}$$

where $\mathrm{ET_o}$ = reference evapotranspiration [mm day^{-1}], R_n = net radiation at the crop surface [MJ m^{-2} day^{-1}], G = soil heat flux density [MJ m^{-2} day^{-1}], T = mean daily air temperature at 2 m height [°C], u_2 = wind speed at 2 m height [m s^{-1}], e_s = saturation vapor pressure [kPa], e_a = actual vapor pressure [kPa], $e_s - e_a$ = saturation vapor pressure deficit [kPa], Δ = slope vapor pressure curve [kPa °C], γ = psychrometric constant [kPa °C^{-1}], and 900 is a conversion factor.

2.4 *Calculation of Effective Rainfall*

CROPWAT model considers four methods for effective rainfall calculation. These are fixed percentage, FAO/AGLW formula, empirical formula, and USDA soil conservation service method. In this study, the USDA soil conservation service method [15] was used.

$$P_{\mathrm{eff(dec)}} = P_{\mathrm{dec}} * \frac{(125 - 0.6 * P_{\mathrm{dec}})}{125} \text{ for } P_{\mathrm{dec}} \le \frac{250}{3} \text{ mm} \tag{2}$$

$$P_{\mathrm{eff(dec)}} = \frac{125}{3} + (0.1 * P_{\mathrm{dec}}) \text{for } P_{\mathrm{dec}} > \frac{250}{3} \text{ mm} \tag{3}$$

where $P_{\mathrm{effective}}$ = effective monthly rainfall (mm), P_{dec} = total decade rainfall (mm).

2.5 *Estimation of irrigation water requirement and time of application*

The amount of water that is supplied to meet the water requirement of the crop is called crop water requirement. It is determined by subtracting efficient rainfall from crop evapotranspiration (ET_c). ET_c denotes the amount of water that is lost through evapotranspiration and is found by multiplying crop coefficient (K_c) with reference evapotranspiration. Since default values were taken for K_c, the model estimated Kc dry value was 0.70, 1.05, and 0.7 in nursery, development, and late stages, respectively. Whereas K_c wet value was 1.20, 1.20, and 1.05 in the nursery, development, and late stages, respectively. The crop water requirement was estimated by using [16].

$$\mathrm{CWR}_i = \sum_{t=0}^{T}\left(k_{c_i} \cdot \mathrm{ET_o} - P_{\mathrm{eff}}\right) \quad (4)$$

where Kc_i = crop coefficient of the given crop during the growth stage t and T is the final growth stage. The crop evapotranspiration $\mathrm{ET_c} = K_c \times \mathrm{ET_o}$ where K_c is crop coefficient and $\mathrm{ET_o}$ = reference crop evapotranspiration (mm day -1).

For irrigation scheduling, it was considered that irrigation will be done at 0 mm standing water depth and water will be refilled up to 50 mm water depth. Irrigation efficiency was considered 80%. Irrigation scheduling was done for all three seasons (Aus, T. Aman, and Boro) in all four districts in the study area.

3 Results and Discussions

3.1 Reference Evapotranspiration

Reference evapotranspiration ($\mathrm{ET_o}$) for three districts was estimated and shown in Fig. 1. The mean annual $\mathrm{ET_o}$ of rice crop was 1398 mm year^{-1} for four selected districts in the southeastern region of Bangladesh. For Chandpur and Feni, observed $\mathrm{ET_o}$ values were higher (more than average value of 118 mm and 114 mm, respectively) from March to June and lower from July to February. For Cumilla District, observed $\mathrm{ET_o}$ values were higher (more than average value of 116 mm) from March to September and lower from October to February. In all three districts, the highest (155–168 mm) $\mathrm{ET_o}$ was observed in May and the lowest (77–85 mm) in January. In March to May, low relative humidity and high temperatures resulted in increased

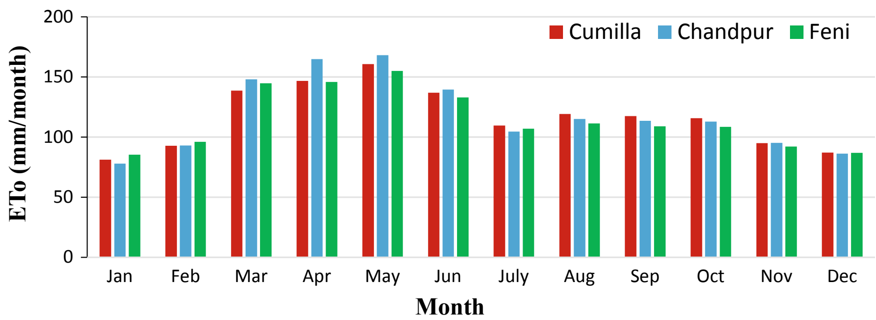

Fig. 1 Spatiotemporal distribution of monthly normal evapotranspiration in Cumilla, Chandpur, and Feni districts

ET_o. In March to May, low relative humidity and high temperatures resulted in increased ET_o. On the other hand, high humidity along with low temperature and sunshine hours reduced ET_o in the rainy season. Lower ET_o observed in the winter (November–February) was caused by lower values of temperature, sunshine, and wind speed.

3.2 Rainfall vs Crop Evapotranspiration

Rainfall, effective rainfall, evapotranspiration, and crop evapotranspiration requirement are shown in Fig. 2. Rainfall data analysis provides an approximate average of 2100 mm rainfall in Cumilla, Chandpur, Brahmanbaria districts with an average effective rainfall of 1085 mm year^{-1}. For the Feni District, the observed rainfall is approximately 3100 mm with an effective rainfall of 1203 mm year^{-1}. Maximum rainfall was observed in July, and almost 80% of the total rainfall occurs between April and September. From May to October, rainfall is almost enough to meet the evapotranspiration requirement. However, imbalanced spatial and temporal distribution may account for supplemental irrigation in some areas. For the other six months of the year, irrigation is necessary to avoid yield reduction.

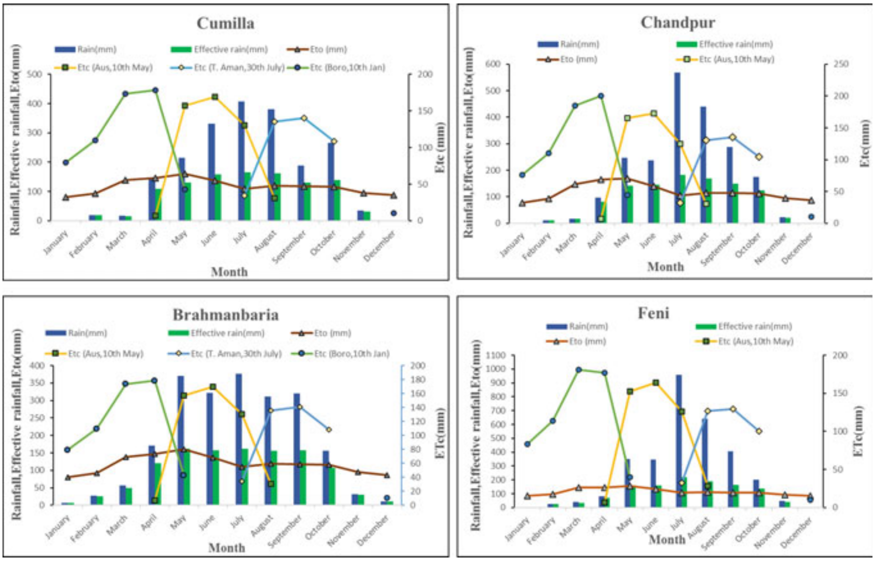

Fig. 2 District-wise distribution of average rainfall, effective rainfall, reference evapotranspiration over the months and rice crop evapotranspiration in three seasons (Aus, T. Aman & Boro)

3.3 Rice evapotranspiration and Irrigation requirement

Tables 1, 2, and 3 show the crop water requirements for all three seasons in four districts inside the study area. For all four districts of the study region, the CROPWAT model estimated crop water requirement and irrigation requirement during its growing period. BRRI dhan48, BRRI dhan71, and BRRI dhan89 were selected for Aus, Aman, and Boro season. For T.Aus rice transplanted on 10th May accounted crop evapotranspiration (ET_c) of a range of 478–500 mm. For seedling and initial stages, effective rainfall was enough to fulfill the water requirement. But for development and mid-stages, supplemental irrigation is necessary. In late stages, monsoon season rainfall was enough to satiate the water requirement as shown in Table 1. Transplanting date for Aman is assumed 30th July with a lifespan of 114 days. Almost no irrigation is required for this season and crops are considered rainfed in this season as shown in Table 2. But uneven spatial distribution may require a little irrigation to gain maximum yield. For Boro season, 10th January is taken as the transplanting date. Since it is dry season, heavy irrigation requirement is observed as shown in Table 3. Boro season rice yields the highest amount of rice, and so irrigation requirements must be met. The crop coefficient (K_c) values are shown for Cumilla District only.

3.4 Irrigation Scheduling

Irrigation scheduling for Cumilla and Chandpur districts for all three seasons is shown in Tables 4 and 5, respectively. In Cumilla District, 7 split applications of irrigation were required during T. Aus season with a gross irrigation of 503 mm. Though T. Aman is considered as rainfed crop, the model showed that it requires 340 mm water to avoid yield reduction. Boro season crop is highly irrigation-dependent, and 969 mm irrigation with 14 split application was necessary to fulfill the need. In Chandpur District, the gross irrigation in T. Aus and T. Aman season is 513 mm and 271 mm with 7 and 4 split applications, respectively. But in Boro season, 16 split applications of total 1109 mm water were required to avoid water stress as shown in Table 5.

Irrigation scheduling for Brahmanbaria and Feni districts for all three seasons is shown in Tables 6 and 7, respectively. In Brahmanbaria District, irrigation requirement remains more or less consistent with Cumilla and Chandpur districts with 505 mm (7 split applications) in T. Aus season. In Aman season, 268 mm (with 4 split applications) irrigation is required which is more or less consistent with Chandpur district. In Boro season, 980 mm irrigation (with 14 split applications) was necessary which is more or less consistent with Cumilla District. Feni District has higher rainfall than the rest of the study area. So lesser irrigation requirement was observed in the district with gross irrigation of 436 mm (6 split application) in T. Aus, 269 mm (4 split application) in Aman, and 1037 mm (15 split application) in Boro season.

Table 1 Normal crop water requirement for T. Aus rice at different locations of southeastern region

			Cumilla			Chandpur			B. Baria			Feni		
Stage	Duration	K_c	ΣEt_c (mm)	Eff. rainfall (mm)	IR (mm)	ΣEt_c(mm)	Eff. rainfall (mm)	IR (mm)	ΣEt_c (mm)	Eff. rainfall (mm)	IR (mm)	ΣEt_c (mm)	Eff. rainfall (mm)	IR (mm)
Seedling/land prep	0–20	1.2	6.6	29.9	0	7.2	25.1	0	6.6	52.6	0	6.5	18.6	0
Initial	21–30	1.12	37.1	38.7	0	38.2	39.4	0	37.1	52.1	0	34.8	50.8	0
Development	31–50	1.13 ± 0.02	120.2	92.2	28	126.9	102.8	24.1	120.3	110	10.3	117.6	109.4	8.2
Mid	51–80	1.25	169.6	158.1	11.5	172.8	144.8	28	169.6	157.1	12.5	163.8	159.2	4.6
Late	81–110	1.16 ± 0.09	161.3	202.2	0	155.1	217.6	0	161.3	199.5	0	154.6	258.9	0
Total			494.8	521.1	39.5	500.2	529.7	52.1	494.9	571.3	22.8	477.3	596.9	12.8

Table 2 Normal crop water requirement for T. Aman rice at different locations of southeastern region

			Cumilla			Chandpur			B. Baria			Feni		
Stage	Duration	K_c	ΣEt_c (mm)	Eff. rainfall (mm)	IR (mm)	ΣEt_c (mm)	Eff. rainfall (mm)	IR (mm)	ΣEt_c (mm)	Eff. rainfall (mm)	IR (mm)	ΣEt_c (mm)	Eff. rainfall (mm)	IR (mm)
Seedling/land prep	0–25	1.2	6.8	89.8	0	6.7	96.3	0	6.8	85.7	0	6.8	117.2	0
Initial	26–35	1.12	27.4	53.1	0	25.3	59.3	0	27.4	54.5	0	25.6	73.5	0
Development	36–54	1.12 ± 0.02	89	101.5	0	86.9	104.7	0	89	103.2	0	82.1	123.9	0
Mid	55–84	1.2	145.7	145.1	0.6	137.2	157.9	0	145.7	158.4	0	135.7	170.9	0
Late	84–114	1.125 ± 0.075	150	162.3	0	146.1	158.4	0	150	149.2	0.8	138.3	171.9	0
Total			418.9	551.8	0.6	402.2	576.6	0	418.9	551	0.8	388.5	657.4	0

Table 3 Normal crop water requirements for Boro rice at different locations of southeastern region

BORO			Cumilla			Chandpur			B. Baria			Feni		
Stage	Duration	K_c	ΣEt_c (mm)	Eff. rainfall (mm)	IR (mm)	ΣEt_c (mm)	Eff. rainfall (mm)	IR (mm)	ΣEt_c (mm)	Eff. rainfall (mm)	IR (mm)	ΣEt_c (mm)	Eff. rainfall (mm)	IR (mm)
Seedling/land prep	0–40	1.2	10.3	0.3	10	10.4	0	10.4	10.3	10.4	0	10.4	0.3	10.1
Initial	41–50	1.12	17.9	0	17.9	17.3	0	17.3	17.9	2.3	15.6	18.5	0	18.5
Development	51–98	1.16 ± 0.06	171.2	20.8	150.4	168.7	11.8	156.9	171.2	30.2	141	178.8	27.8	151
Mid	59–128	1.26	173.6	16.2	157.4	185.1	16.9	168.2	173.6	50	123.6	180.9	34.5	146.4
Late	129–158	1.195 ± 0.055	221.5	135.9	85.6	244.7	108.7	136	221.5	156.2	65.3	217	104.9	112.1
Total			594.5	173.2	421.3	626.2	137.4	488.8	594.5	249.1	345.4	605.6	167.5	438.1

Table 4 Irrigation scheduling of rice (Cumilla District)

Date of Irrigation	Days to irrigate	Stage	Net irrigation (mm)	Gross irrigation (mm)
10th May transplanting (Aus)				
5 May	-4	Puddling	77	96
9 May	0	Puddling	53	66
22 May	13	Dev	54	68
31 May	22	Dev	55	69
12 June	34	Mid	54	68
22 June	44	Mid	54	68
2 July	54	Mid	51	64
Total			402	502
30 July transplanting (T. Aman)				
31 July	2	Init	54	68
2 September	35	Mid	55	69
12 September	45	Mid	56	70
22 September	55	Mid	50	63
16 October	79	End	54	68
Total			272	340
10 January transplanting (Boro)				
5 January	-4	Puddling	77	96
8 January	-1	Puddling	57	72
16 January	7	Init	51	64
24 January	15	Dev	50	62
1 February	23	Dev	51	64
10 February	32	Dev	54	68
17 February	39	Dev	50	63
25 February	47	Dev	55	69
4 March	54	Dev	50	63
11 March	61	Mid	58	73
18 March	68	Mid	54	67
24 March	74	Mid	54	67
30 March	80	Mid	54	68
11 April	92	End	54	67
Total			775	968

Table 5 Irrigation scheduling of rice (Chandpur District)

Date of Irrigation	Days to irrigate	Stage	Net irrigation (mm)	Gross Irrigation (mm)
10th May transplanting (Aus)				
5 May	-4	Puddling	77	96
9 May	0	Puddling	53	66
22 May	13	Dev	56	70
1 June	23	Dev	57	71
12 June	34	Mid	57	71
22 June	44	Mid	57	71
2 July	54	Mid	51	64
Total			410	513
30 July transplanting (T. Aman)				
31 July	2	Init	53	66
2 September	35	Mid	53	66
21 September	54	Mid	57	71
6 October	69	End	52	65
Total			217	271
10 January transplanting (Boro)				
5 January	-4	Puddling	77	96
8 January	-1	Puddling	57	71
16 January	7	Init	51	63
25 January	16	Dev	55	69
2 February	24	Dev	52	65
10 February	32	Dev	55	69
17 February	39	Dev	50	63
25 February	47	Dev	56	71
4 March	54	Dev	55	68
10 March	60	Mid	54	67
16 March	66	Mid	50	63
22 March	72	Mid	56	70
28 March	78	Mid	55	69
4 April	85	Mid	51	64
11 April	92	End	54	67
19 April	100	End	53	66
Total			887	1109

Table 6 Irrigation scheduling of rice (Brahmanbaria District)

Date of Irrigation	Days to irrigate	Stage	Net irrigation (mm)	Gross Irrigation (mm)
10th May transplanting (Aus)				
5 May	-4	Puddling	77	96
10 May	1	Init	55	69
22 May	13	Dev	54	68
1 June	23	Dev	54	68
12 June	34	Mid	54	68
22 June	44	Mid	54	68
2 July	54	Mid	51	64
Total			404	505
30 July transplanting (T.Aman)				
31 July	2	Init	54	68
2 September	35	Mid	55	69
12 September	45	Mid	50	63
16 October	79	End	53	67
Total			215	268
10 January transplanting (Boro)				
5 January	-4	Puddling	77	96
8 January	-1	Puddling	56	70
16 January	7	Init	51	64
25 January	16	Dev	55	69
2 February	24	Dev	51	64
10 February	32	Dev	53	66
18 February	40	Dev	50	63
26 February	48	Dev	54	67
5 March	55	Dev	56	71
11 March	61	Mid	50	63
19 March	69	Mid	54	67
29 March	79	Mid	57	71
6 April	87	Mid	57	72
12 April	93	End	56	70
Total			784	980

Since Boro season is the dry season (December–March) of Bangladesh, irrigation requirement for this season is maximum among all seasons.

Table 7 Irrigation scheduling of rice (Feni District)

Date of Irrigation	Days to irrigate	Stage	Net irrigation (mm)	Gross Irrigation (mm)
10th May transplanting (Aus)				
5 May	-4	Puddling	77	96
10 May	1	Init	54	68
22 May	13	Dev	53	67
1 June	23	Dev	55	68
12 June	34	Mid	54	68
22 June	44	Mid	53	66
Total			348	436
30 July transplanting (T. Aman)				
31 July	2	Init	53	67
2 September	35	Mid	53	66
22 September	55	Mid	53	66
11 October	74	End	54	67
Total			215	269
10 January transplanting (Boro)				
5 January	-4	Puddling	77	96
8 January	-1	Puddling	58	72
16 January	7	Init	52	65
24 January	15	Dev	51	64
1 February	23	Dev	53	66
11 February	33	Dev	56	71
19 February	41	Dev	57	71
26 February	48	Dev	50	63
4 March	54	Dev	52	65
10 March	60	Mid	55	69
17 March	67	Mid	54	67
24 March	74	Mid	50	63
31 March	81	Mid	51	63
10 April	91	End	52	65
18 April	99	End	56	71
Total			829	1037

4 Conclusion

The CROPWAT model estimates evapotranspiration, effective rainfall, and crop water requirement and does irrigation scheduling in the study with precision and assurance. Boro season rice requires maximum 1109 mm supplementary irrigation in Chandpur and overall more irrigation than other seasons. T. Aman requires a minimum of 268 mm irrigation in Brahmanbaria which denotes that without irrigation yield reduction might occur. T. Aus requires 489 mm supplementary irrigation an average. These results can be used for further research in the study area. Proper scheduling of irrigation can alleviate yield stress in crop and increase yield to maximum. Lessening cultivation costs will help to ensure food safety for the rapidly growing population of Bangladesh.

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