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Estimation of Crop Water Requirement of Kharif Rice Over Ribhoi District of Meghalaya

Evakordor Jyrwa[1*], A.S. Nain[1] and Jonali Goswami[2]
[1]Department of Agrometeorology,
G.B. Pant University of Agriculture and Technology, Pantnagar (Uttarakhand), India.
[2]Northeastern Space Application Centre, Umiam (Meghalaya), India.

(Corresponding author: Evakordor Jyrwa)*
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ABSTRACT: In response to increasing global demands on our water resources, our study addresses the need to develop effective strategies for managing and planning irrigated farmland. We focus on accurately estimating crop water requirements using modeling. The distinctive rice-growing region of Meghalaya offers a diverse range of climates, from the heights of hilly terrain to the depths of flooded fields and this diversity creates challenges, especially when the rain is unpredictable. The purpose of this study is to calculate crop water requirements and irrigation requirements for rice crops in the Ri-bhoi district of Meghalaya. Employing the CROPWAT 8.0 model, the study calculated the crop water and irrigation requirements for Kharif rice in Ri-bhoi district. The results show that the total crop water requirement for rice throughout the growing season amounted to 504.4 mm/dec, while the irrigation requirement was 650.2 mm/dec. Because of the low effective rainfall in this region in 2022, irrigation needs for rice crops are high. The reference crop evapotranspiration in the district ranged from 2.29 mm/day to 4.53 mm/day. As predicted by the model, yields will not decrease at any growth stage with maximum rainfall efficiency. In which, the rainfall efficiency was 100% with an effective rainfall of 51mm during the growing season. This research thus offers valuable insights for enhancing water management strategies in agriculture.

Keywords: CROPWAT model, Rice, Crop water requirements, reference evapotranspiration, net irrigation requirements.

INTRODUCTION

The demand for efficient irrigation water usage in agriculture is intensifying due to climate change, making water the most vital and crucial resource for crop cultivation (Roja, 2020). One of the key aspects of agricultural planning is the assessment of water requirements for crops. These requirements can vary significantly not only between different types of crops but also throughout the various growth stages of each individual crop. As a result, the estimation of crop water needs, while considering the specific crop types, has become an area of interest for water resource planners and engineers (Nayak *et al*., 2016). Meghalaya's main food crop is rice, which accounts for approximately 82.40% of the area and 86.42% of grain production. The rice productivity in Meghalaya (1.91 t/ha) is considerably lower than the national average (2.06 t/ha). Growing rice in the region involves a range of climates from deep water to high altitudes (www.megagriculture.gov.in). Rice is grown in three different topographical zones: rainfed lowlands, rainfed uplands, and jhum land. Depending on agro-climatic conditions, variety, period, and soil conditions, rice crop water requirements range from 6 to 10 mm per day (Krishnaprabu, 2020). An assured supply of irrigation water is crucial to crop yield since rice requires more water than other crops of comparable duration. It is essential to have a scientific understanding of crop water requirements in order to be able to schedule irrigation efficiently, to balance water in canals, to plan regional drainage, to plan water resources, to operate reservoirs and to evaluate crop potential (Alshrouf *et al*., 2022). Typically, crop water requirements are expressed in millimetres per day (mm/day) or millimetres per period (mm/period) (FAO, 2002).

Researches often use modeling to determine the water requirements of crops. Crop evapotranspiration and yield responses to water are determined using the CROPWAT model, which was developed by FAO Land and Water Development Division. FAO Penman-Monteith method (Allen *et al.*, 1998) is used in the present study for determining reference crop evapotranspiration (ET0) since it is reported to provide values that are very consistent with actual crop water use data worldwide (Allen *et al*., 2006; Cai *et al*., 2007; López-Urrea *et al*., 2009). Several researchers to analyze crop water requirements in various parts of the world have used the CROPWAT model. Amin *et al*. (2022) conducted an estimation of irrigation needs and developed an irrigation scheduling approach specifically for rice cultivation using CROPWAT model.

A satellite remote sensing system can monitor land surface conditions and water resources at a variety of spatial and temporal resolutions (Muthuwatta *et al*., 2010). It becomes necessary to use remote sensing in irrigation commands to estimate crop water requirements. The use of remote sensing-based vegetation indices has allowed scientists to predict the water requirement of crops on a large scale (Ray and Dadhwal 2001; Reginato *et al*., 1985; Roerink *et al*., 1997).

MATERIALS AND METHODS

Study area. The area selected for studies is located in the Ri-Bhoi district of Meghalaya (Fig. 1). Ri-Bhoi district has an area of 2448 sq. km and lies between E 91°20'30" and E 92°17'00" Longitude and N 25°40' to N 26°20' Latitude and has a population of 258,840 (as of 2011). The land surface in this District is rugged and irregular. It consists of a series of hill ranges that gradually slope northward and eventually join the Brahmaputra Valley. Ri Bhoi District has a variety of climates, ranging from tropical in areas bordering Assam to temperate in areas bordering the East Khasi Hills District During the summer months, the areas bordering Assam experience hot and humid weather with an average temperature of 30°C, especially from May to July of the year. The average annual rainfall in the district was 2935mm. The temperature ranges from 10°C to 30°C in December and January respectively. The soil types in the Ri Bhoi District can be broadly classified as hill and plain soils. Patches of black loamy soil and lime silt make up the majority of the soil. This soil is generally medium loam and can support both local and improved crop varieties.

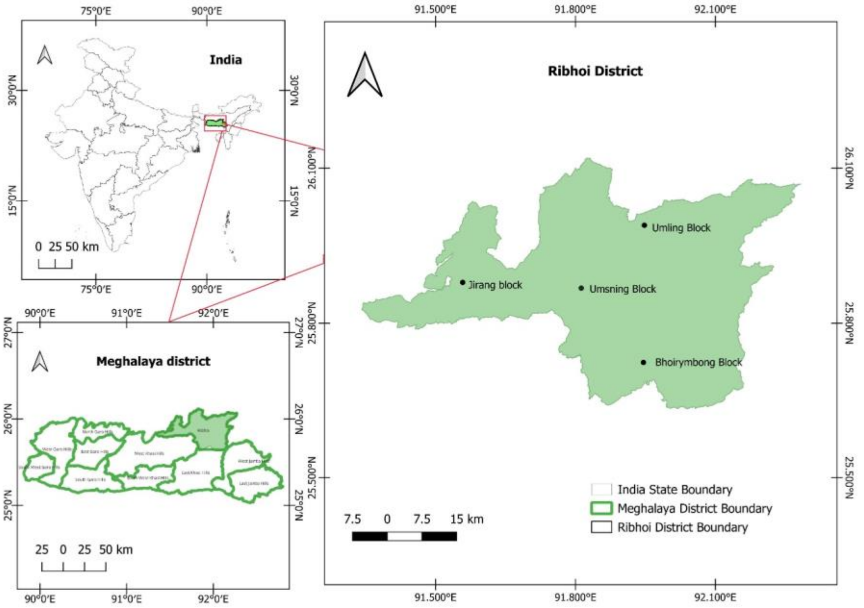

Fig. 1. Map of the study area (Ribhoi district).

Land use/land cover: The land use land cover of the study area has been aimed to identify and map the various types of land use/land cover classes in the area by graphical interpretation (Fig. 2). The following are the different classes of Land use/Land cover of the study area agriculture, built-up, forest, wasteland, waterbodies, and others. Forest is the most dominant land cover which covers an area of 86.9ha followed by wasteland with an area of 57 ha. The area under agriculture is 25.118ha (Table 1).

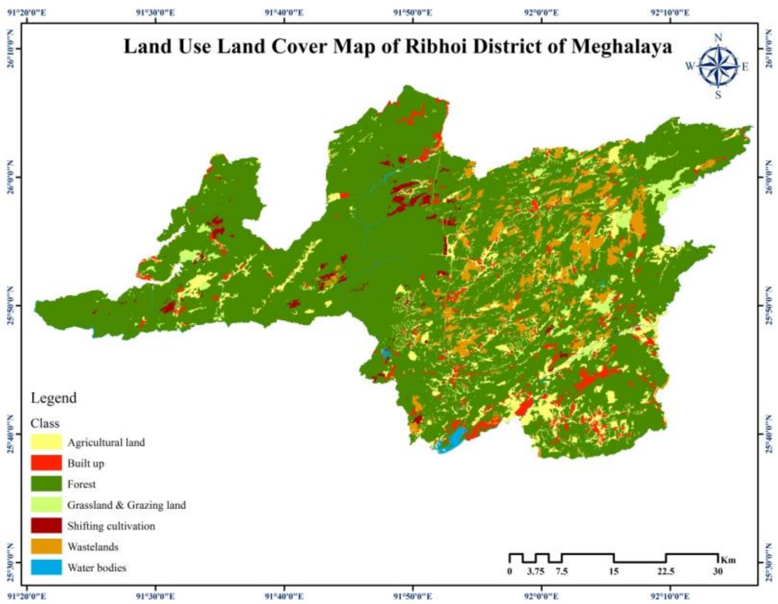

Fig. 2. Land use/ Land cover of Ribhoi district (Source: NESAC, Umiam).

Meteorological data: Meteorological parameters employed in the ETo calculation encompass the station's latitude, longitude, and altitude, in addition to maximum and minimum temperature (°C), maximum and minimum relative humidity (%), wind speed (km/day), and sunshine hours. These data were sourced from the Regional Meteorological Center in Shillong.

Crop data: Crop data, including sowing date, harvesting time, growing days, growth stages, rooting depth, yield response factor, and crop coefficient values (kc), are essential inputs for the model to calculate water requirements. In this region, the planting date varies annually, influenced by prevailing weather conditions. For this study, a common planting date of July 15thwas adopted, which aligned with the practice of most farmers.

Crop water requirements: Crop water requirements were assessed using the CROPWAT model, a decision-support system developed by FAO's Land and Water Development Division in collaboration with the Institute of Irrigation and Development Studies, University of Southampton, UK, and the National Water Research Centre of Egypt. In the determination of reference crop evapotranspiration (ETo), CROPWAT employs the FAO Penman-Monteith method (Allen *et al.,* 1998), which is described as follows:

$$ET_0 = 0.408\Delta\,(Rn - G)\ + y\frac{900}{T+273}\,U_2\,\frac{e_a - e_d}{\Delta + y(1+0.34\,U_2)}$$

Where,

ET_0 = reference crop evapotranspiration (mm/day)

Rn = net radiation at the crop surface (MJ m^{-2} day^{-1})

G = soil heat flux density (MJ m^{-2} day^{-1})

T = average air temperature (ºC)

U_2 = wind speed measured at 2 m height (m/s)

$(e_a – e_d)$ = vapor pressure deficit (kPa)

Δ = slope of the vapor pressure curve (kPa/ºC)

y= psychrometric constant (kPa/ºC).

Crop evapotranspiration (ETo): There are several reports on the estimation of crop coefficients Kc for many crops (Doorenbos and Pruitt 1977)*;* Doorenbos *et al*., 1980*;* Allen *et al*., 1998*).* According to well-established procedures (Allen *et al*., 1998) crop water requirements are determined by ETo and evaporation rates, expressed as crop coefficients (Kc) over the growing season.

$ET_{crop} = K_c \times ET_0$

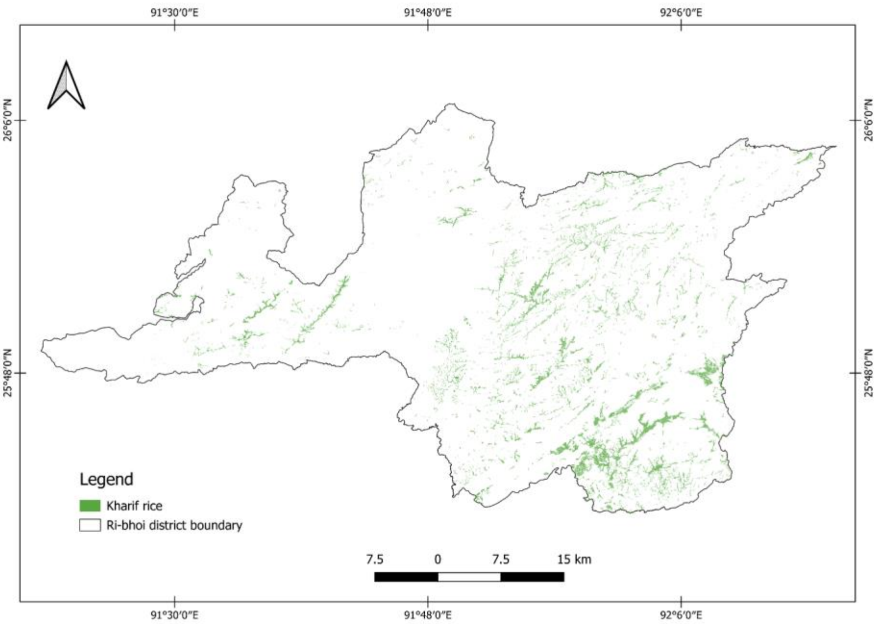

Fig. 3. Kharif rice crop area map of Ribhoi district (Source: NESAC, Umiam).

RESULTS AND DISCUSSION

The crop water requirement for rice in the Ri-bhoi district was determined using meteorological data from the period 2021-2022, calculated through the CROPWAT model using FAO Penman-Monteith method. The estimated crop water requirement for rice in the Ri-bhoi district is presented in Table 2. During the growing season, spanning from July to November, the total crop water requirement for rice was found to be 504.4 mm/decade with an irrigation requirement of 650.2 mm/decade, while the effective rainfall received during the season was amounted to 55.4 mm/decade. The higher net irrigation requirement suggests a lower availability of effective rainfall, whereas a reduction in irrigation requirement indicates an increase in effective rainfall. Adequate soil moisture due to effective rainfall efficiently fulfills the crop water requirements, resulting in water savings (Brouwer and Heibloem 1986). The water requirement for rice varied across its growth stages, which shows higher water requirement during the developmental stage about 49.7 mm/decade and declining in the later stages around 34.4 mm/decade. Based on the findings, the month of August had the highest water requirement for rice, closely followed by July, as indicated in Table 2. This higher demand can be attributed to the elevated reference evapotranspiration levels during those months. Furthermore, crops require a significant amount of water during the growth and development phases for a variety of physiological activities (Kumar *et al*., 2019). The irrigation plan for the kharif rice crop in the Ri-bhoi district was created using the CROPWAT model, taking meteorological information, rainfall patterns, crop and soil data into account. The timing of irrigation was determined by the stage of growth of the rice crop with a total of 11 split applications (650.2 mm/decade) required for kharif rice from pre-nursery, pudding, initial, development, mid, and late stages, as detailed in Table 6. The lower rainfall received in the district during 2022 is a key factor contributing to the increased irrigation requirement for this season. This illustrates that irrigation requirements increase as effective rainfall decreases during the rice growing season. Effective rainfall, however, varies with factors such as soil type, rainfall patterns, topography, groundwater conditions, and management practices (Brouwer and Heibloem 1986). As expected, yields remained unaffected at all growth stages with maximum rainfall efficiency of 100%. Detailed information on irrigation nets, gross, and actual water use by crop is presented in Table 5. The reference evapotranspiration (ETo), calculated using the CROPWAT model, reached its peak in March at 4.53 mm/day, while the lowest monthly average of ETo was recorded in January at 2.29 mm/day, as shown in Table 3. The results of ETo are in accordance with the findings by Gabr (2022) which showed that ET0 was lowest during the winters. Reduced air temperature, solar radiation hours, wind speed, and rising relative humidity all have an impact on the minimum ETo values whereas the reverse applies for the maximum ETo values (Yang *et al*., 2016). The increase in ETo is attributed to reduced precipitation and rising temperatures (Amin *et al*., 2022). ETo and temperature are directly related; as temperature increases, so does ETo, and vice versa, as depicted in Fig. 4.

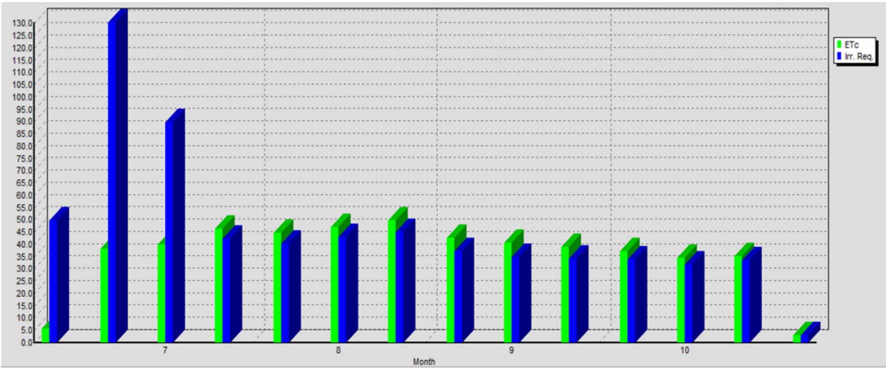

Fig. 4. Crop water requirement of rice during kharif season of 2022.

Table 1: Land use pattern of the Ri-bhoi district.

	Area in hectares
Geographical area	244.8
Forest area	86.9
Cultivable area	222.2
Land under non-agriculture use	14.0
Wasteland	57.0
Barren land	19.4
Current fallows land	6.2
Other fallows land	8.9

Source: Land Use Statistics of Meghalaya (2009-10)

Table 2: Crop water requirement and Irrigation requirement of rice in the Ri-bhoi district.

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Jun	3	Nurs/LPr	1.18	0.98	5.9	5.4	49.9
Jul	1	Nurs/LPr	1.06	3.84	38.4	6	130.5
Jul	2	Init	1.09	3.99	39.9	3.9	89.7
Jul	3	Init	1.1	4.22	46.4	4	42.3
Aug	1	Deve	1.1	4.47	44.7	4.3	40.4
Aug	2	Deve	1.11	4.72	47.2	4.1	43
Aug	3	Deve	1.12	4.52	49.7	4.5	45.2
Sep	1	Mid	1.13	4.27	42.7	5.2	37.4
Sep	2	Mid	1.14	4.06	40.6	5.7	34.8
Sep	3	Mid	1.14	3.9	39	4.6	34.4
Oct	1	Late	1.13	3.74	37.4	3.4	34
Oct	2	Late	1.09	3.44	34.4	2.5	32
Oct	3	Late	1.03	3.2	35.2	1.7	33.5
Nov	1	Late	1	3.04	3	0	3
					504.4	**55.4**	**650.2**

Table 3: Effect of meteorological parameters on reference evapotranspiration.

Month	Min Temp °C	Max Temp °C	Humidity %	Wind m/s	Sun hours	Rad MJ/m²/day	ETo mm/day
January	8.1	20.5	84	1.3	7.5	15.6	2.29
February	7.2	19.7	79	1.4	7.8	17.7	2.53
March	15.8	29.4	54	1.7	8.7	21.2	4.53
April	23.5	27.7	81	1.2	2.4	13.1	3.02
May	18.7	28	89	1.2	6.9	20.3	3.99
June	20.1	27.4	98	0.8	5.5	18.2	3.48
July	22.7	29.9	95	1.2	5.5	18.1	3.67
August	21.4	30.9	93	1.3	7.1	20.2	4.15
September	20.7	29.4	95	1.1	6.2	17.9	3.57
October	18.6	27.9	91	1.3	6.3	16.3	3.16
November	12	26.2	87	1.4	8.7	17.4	2.99
December	9	23.3	86	1.3	8.5	16.1	2.47
Average	**16.5**	**26.7**	**86**	**1.3**	**6.8**	**17.7**	**3.32**

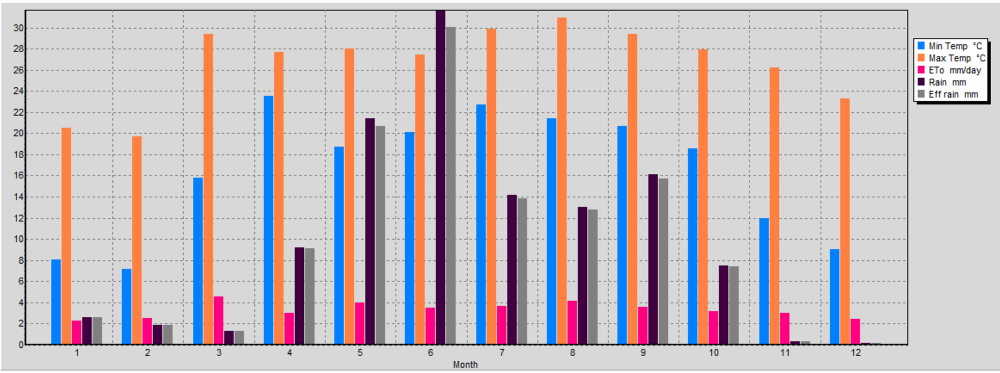

Fig. 5. Climatological parameters of Ri-bhoi district during 2022.

Table 4: Total gross and net irrigation of Rice during kharif season.

Total gross irrigation	1405 mm
Total net irrigation	983.5 mm
Actual water uses by crop	440.9 mm
Potential water uses by crop	440.9 mm
Total rainfall	50.9 mm
Effective rainfall	50.9 mm
Efficiency rain	100 %
Field efficiency	70%

Table 5: Irrigation scheduling of kharif rice over Ri-bhoi district

Date	Day	Stage	Rain mm	Ks fract	Eta %	Puddl state	Percol. mm	Depl.SM mm	Net Gift mm	Loss mm	Depl.SAT mm
30-Jun	-14	PrePu	0	1	100	Prep	0	1	49.3	0	48
10-Jul	-4	Puddl	0	1	100	Prep	0	5	98	0	48
12-Jul	-2	Puddl	0	1	100	OK	15	0	52.5	0	2.5
18-Jul	4	Init	0	1	100	OK	3.4	0	98.2	0	-1.8
01-Aug	18	Init	0	1	100	OK	3.4	0	102.5	0	2.5
14-Aug	31	Dev	0	1	100	OK	3.4	0	97	0	-3
27-Aug	44	Dev	2.3	1	100	OK	3.4	0	97.7	0	-2.3
09-Sep	57	Mid	0	1	100	OK	3.4	0	95.6	0	-4.4
23-Sep	71	Mid	2.4	1	100	OK	3.4	0	96.2	0	-3.8
07-Oct	85	Mid	1.7	1	100	OK	3.4	0	95.6	0	-4.4
22-Oct	100	End	0	1	100	OK	3.4	0	100.9	0	0.9
01-Nov	End	End	0	1	0	OK	0	0			

CONCLUSIONS

This study reveals significant variations in the monthly crop water requirement and irrigation needs of rice in the Ri-bhoi district. During the growing season, rice was found to require 504.4 mm/dec of water, while the irrigation demand stood at 650.2 mm/dec. Because of the low effective rainfall in this region in 2022, irrigation needs for rice crops are high. If the effective rainfall is high, there will be adequate moisture in the soil to meet the crop's water needs through efficient water use, which enables irrigation water savings. This district has the main disadvantage of being predominantly dependent on rainfall for irrigation. The possibility of moisture stress on the plant will increase in a district with low effective rainfall and no irrigation system. Understanding the spatiotemporal distribution and dynamics of rice cultivation in the state is crucial for addressing issues related to food demand and water scarcity. Using this model, we can apply the irrigation demands of a specific crop, thereby saving irrigation water, and we can identify the rice crop distribution over a district using GIS.

FUTURE SCOPE

The findings of the study about the crop water and irrigation needs for rice growing in Meghalaya's Ri-bhoi area provide new opportunities for agricultural research and development. Present studies can focus on creating rice varieties that are climate resilient and improving crop management practices for various climatic conditions. Future research can enhance water management practices and precision agricultural techniques by utilizing GIS and remote sensing technology. Future research must also focus on examining sustainable agricultural practices, performing economic analyses, forming policies, interacting with local communities, and maintaining long-term data collection efforts in order to improve rice farming sustainability and ensure food security in the region.

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Conflict of Interest. None.

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