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Research Article

Estimation of crop water requirement and irrigation scheduling of rice in Shivamogga district of Karnataka using FAO CROPWAT

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Abstract

Climate change is expected to have a significant impact on the water needs of rice crop worldwide in the upcoming decades. Proper water management is essential to enhance the crop yield as well as maximising the region's water use efficiency. The objective of this study was to estimate the crop water requirement (CWR) and irrigation scheduling of rice in Shivamogga district of Karnataka using CROPWAT model for a time span of 20 years (2001 to 2020). It was estimated that the crop water requirement of rice was 565.50 mm with the highest and lowest CWR 606.1 and 527.9 mm in 2011 and 2001, respectively. Crop water requirement value showed a slight increasing trend ($R^2 = 0.0544$) throughout the years from 2001 to 2020. Total gross irrigation (TGI) and total net irrigation (TNI) for rice was 491.61 and 344.12 mm, respectively during the study period. The present study is useful for effective planning and management of irrigation water needs of rice in Shivamogga district of Karnataka.

Keywords: Climate change, Crop water requirement, CROPWAT model, Gross irrigation, Irrigation scheduling, Rice

1. Introduction

Despite having 18% of the world's population, India only has 4% of the world's water resources (Dhawan, 2017). Out of total available freshwater in India, 78 per cent of water is consumed by the agricultural sector (Sharma *et al*., 2018; Biswas *et al*., 2022). It is widely acknowledged that the world is experiencing an unprecedented water shortage, and that one of the main factors escalating the situation is poor water management in agriculture (Madani *et al*., 2016). Climate change has shifted India's climate to extremes (Mall *et al*., 2006), changing rainfall patterns and intensity (Wassmann *et al*., 2009), which has a significant impact on crop production, primarily in rainfed areas (Kumar, 2022).

Two basic factors are critical- firstly, agriculture is by far the largest user of freshwater and secondly, water use in agriculture tends to have lower net returns as compared to other competing users of fresh water (Moe and Rheingans, 2006; Taheripour *et al*., 2015). As per estimates, in the future, the world's food systems will need 40–50% more freshwater than they do now to produce the same amount of food (Foley, 2011). Municipal, domestic as well as industrial demand for fresh water will increase by 50-70 per cent during this period. India has one of the world's most vulnerable and unreliable water supplies and experiences considerable water stress (Srinivasan *et al*., 2013). One of the main approaches to these emerging challenges is to focus on improving water productivity in agriculture, as even small improvements could have large implications for local and national water budgets and allocation policies (Hamdy *et al*., 2003).Managing irrigation water starting from the source to its application to the crop holds a crucial place in improving water use efficiency (Evans and Sadler, 2008) at crop level as well as water productivity at field level ultimately increasing more crops per unit drop of water.

Knowledge of crop water requirement (CWR) is one of the crucial factors for improvement of irrigation water management (Laxmi *et al.*, 2022; Sharma and Tare, 2022). Modeling of CWR helps in effective irrigation scheduling, water resource planning, and drainage requirement if any and ultimately determines crop production potential (Kambale *et al.*, 2022).

In terms of area and food production, rice (*Oryza sativa* L.) is one of the most major cereal crops in the world (Niamatullah *et al.*, 2010) followed by wheat (Kumar *et al., 2019*). South East Asia grows and consumes more than 90% of the world's rice. With a yearly per capita consumption of 80 kg of rice, it is a staple grain that provides a richness of nutrients for more than half of the world's population (Godfray *et al.*, 2010). In the human diet, rice serves as the primary source of energy (21%), providing 35–60% of all the calories consumed (Depar *et al.*, 2011). By 2050, there will be 9.15 billion people on the planet, which will result in a rise in the demand for food, notably rice, as well as an increase in the area under production for this crop to about 29.9 million ha (Crossette, 2010). Irrigated rice is a key component of Asian countries' food security and way of life (Saha *et al.*, 2014). On 79 million hectares worldwide, rice is harvested, and transplanted technology accounts for around 75% of that production. To produce one kilo of unmilled rice, rice plants use an average of 2500 litres of water, ranging from 800 to 5000 litres (Bouman, 2009). Rice cultivation consumes between 24 to 30 percent of the world's developed fresh water resources, making it the leading consumer of fresh water worldwide (*Bouman et al.,* 2007; Singh, 2013). The sustainability of the ecosystem supporting irrigated rice is jeopardized by the shrinking water supply for cultivation (Sun *et al.,* 2012).

As CWR depends upon environmental conditions and specific to crop requirements, its estimation at regional level becomes necessary for better management aspect (Doorenbos and Pruitt, 1977). Recently there has been a paradigm shift in calculation of CWR by using computer based simulation models and CROPWAT is such a model. Considering above mentioned points, an experiment on crop water requirement and irrigation scheduling of *kharif* rice by using CROPWAT 8.0 model in Shivamogga district, Karnataka was carried out for 20 years from 2001 to 2020.

2. Material and methods

2.1 Study area

The study area considered here is Shivamogga district of Karnataka, India. Geographical location of Shivamogga is 13.55° N (Latitude) and 75.34°E (Longitude) at an elevation of 631 metres. The area comes under agroclimatic zone XII *i.e.*west coast plains and ghat region (XII).

2.2 Model description and input data

CROPWAT 8.0 for Windows is a computer based program developed by FAO that uses data of soil, climate and crop to calculate crop water and irrigation water requirements. Further, this program helps to create irrigation scheduling approach for several crop management practices as well as the calculation of scheme water supply for various crop patterns. CROPWAT for Windows uses the FAO (1992) Penman-Monteith method for calculation reference crop evapotranspiration.

2.2.1 Climate data

Daily data of maximum temperature, minimum temperature and rainfall were collected from All India Coordinated Research Project on Agro- meteorology, Bengaluru for the year 2001 to 2020. Daily data was converted to monthly data for each year and these monthly data were considered for the modelling of CWR and irrigation scheduling of *kharif* rice from 2001 to 2020 by the use of CROPWAT 8.0 model. CROPWAT calculates ET_0 taking into provided climate data. A sample of computation of ET_0 by CROPWAT is shown in Fig. 1.

2.2.2 Reference evapotranspiration (ET_0)

In CROPWAT, the reference evapotranspiration (ET_0) is calculated directly from meteorological data or estimated by utilizing the Penman-Monteith equation (Allen *et al.*, 1998) with monthly climatic data.

$$ET_0 = 0.408\Delta\ (Rn-G) + \gamma\ (900T+273)\ u^2\ (es-ea)\ /\Delta + \gamma(1+0.34u^2)$$

Where,

ET_0: Reference evapo-transpiration (mm day^{-1})

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

G: Soil heat flux density (MJ m^{-2} day^{-1})

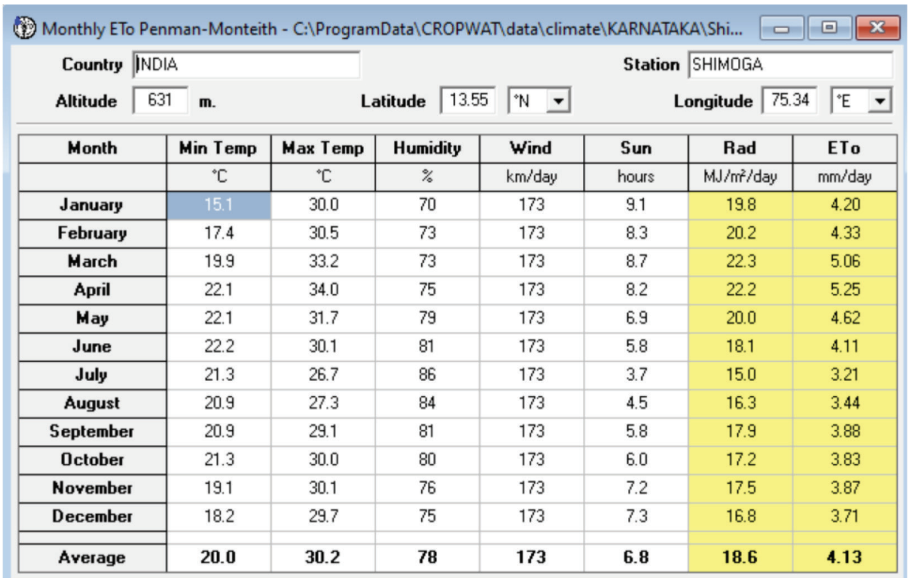
T: Mean daily air temperature at 2 m height (°C) es: Saturation vapor pressure (kPa)

ea: Actual vapor pressure (kPa)

es - ea: Saturation vapor pressure deficit (kPa)

Δ: Slope vapour pressure curve (kPa/°C)

γ: Psychrometric constant (kPa/°C)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Country INDIA — Station SHIMOGA

Altitude 631 m. — Latitude 13.55 °N — Longitude 75.34 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	15.1	30.0	70	173	9.1	19.8	4.20
February	17.4	30.5	73	173	8.3	20.2	4.33
March	19.9	33.2	73	173	8.7	22.3	5.06
April	22.1	34.0	75	173	8.2	22.2	5.25
May	22.1	31.7	79	173	6.9	20.0	4.62
June	22.2	30.1	81	173	5.8	18.1	4.11
July	21.3	26.7	86	173	3.7	15.0	3.21
August	20.9	27.3	84	173	4.5	16.3	3.44
September	20.9	29.1	81	173	5.8	17.9	3.88
October	21.3	30.0	80	173	6.0	17.2	3.83
November	19.1	30.1	76	173	7.2	17.5	3.87
December	18.2	29.7	75	173	7.3	16.8	3.71
Average	20.0	30.2	78	173	6.8	18.6	4.13

Fig. 1: Calculation of ET_0 by CROPWAT model

2.2.3 Crop data

The software needs some information about rice crop. By feeding name of the crop and planting date of the particular crop, other informations related to the crop such as harvesting date, crop coefficient value (Kc), rooting depth, length of plant growth stages and yield response factor will be obtained from software itself. Fig. 2 shows crop data related to rice applied in this software.

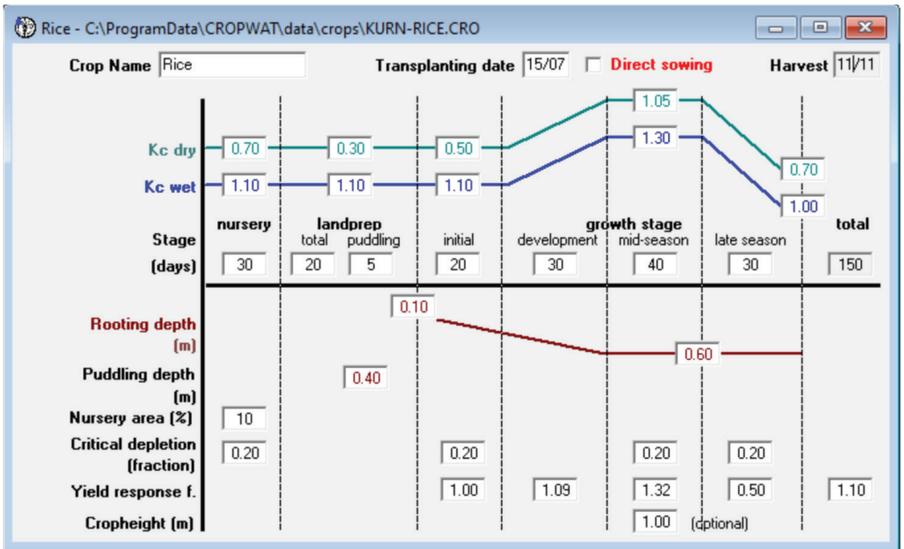

Fig. 2: Various crop data obtained by CROPWAT model

2.2.4 Soil data

Soil type of the study area is red loamy. The software needs other informations related to soil such as total available soil moisture, maximum rain infiltration rate, maximum rooting depth, initial soil moisture depletion and initial available soil moisture. These informations were obtained from FAO manual 56. Fig. 3 shows application of these information in the software.

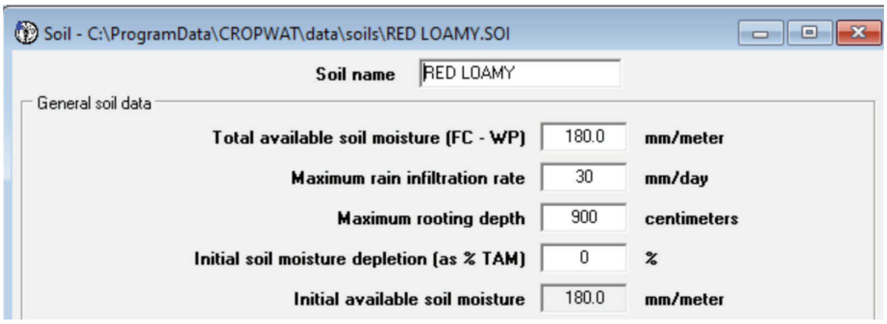

Fig. 3: Soil related data

3. Results and Discussion

Table 1: Crop water requirement (CWR), effective rainfall (ER) and irrigation requirement (IR) of rice (2001 – 2020) obtained from CROPWAT model

Year	CWR (mm)	ER (mm)	IR (mm)
2001	570.7	650	283.4
2002	535.8	642.5	298.3
2003	543.1	702.2	263.9
2004	527.9	760.1	229.6
2005	594.3	760.1	259
2006	568.8	745.9	201.9
2007	542.4	744.1	235.2
2008	576	684.9	262.2
2009	574	725.5	282
2010	579.8	731.6	278.6
2011	606.1	729.9	306.1
2012	567.9	759.4	256.7
2013	560.7	719.1	248.1
2014	564.3	663.8	280
2015	568.3	649.8	306.9
2016	577.2	707.3	231.6
2017	564.7	681.4	307.2
2018	564.8	661.2	294.8
2019	559.5	759.6	230.8
2020	563.7	653.3	317.1
	565.50	706.59	268.67

3.1 Crop water requirement (CWR)

In Shivamogga district of Karnataka, crop water requirement (CWR) of *kharif* paddy was estimated as 565.50 mm (20 years average from 2001 to 2020). The highest CWR (606.1 mm) was observed in 2011 where as the lowest (527.9 mm) was reported in the year 2001 (Table 1). Crop water requirement value ranges between 527.9 mm to 606.1 mm with slight increasing trend (R^2= 0.0544) throughout the years from 2001 to 2020 (Fig.4).

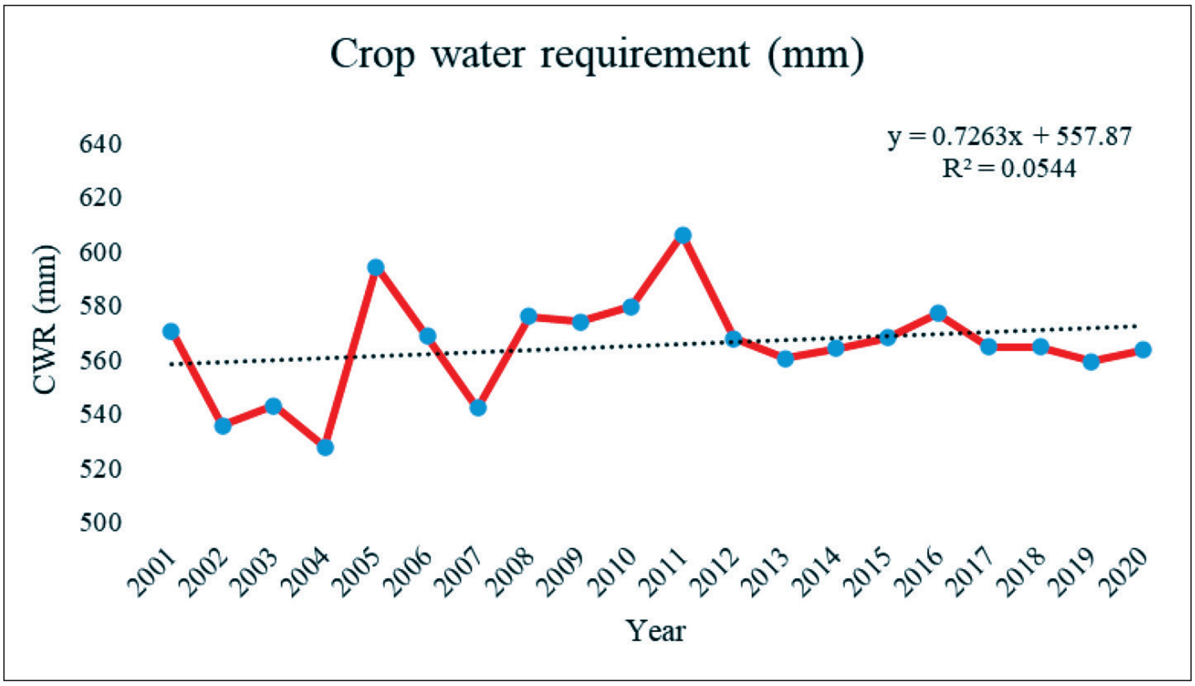

Fig. 4: Crop water requirement of rice (2001 – 2020) obtained from CROPWAT model

3.2 Effective rainfall (mm)

An average of 706.59 mm effective rainfall was recorded during the growing season of *kharif* paddy from 2001 to 2020. Both the years 2004 and 2005 received the highest ER (760.1 mm) while 2002 received the lowest ER of 642.5 mm (Table 1). The value of effective rainfall ranges between 642.5 mm to 760.1 mm with slight decreasing trend ($R^2 = 0.0191$) throughout the years from 2001 to 2020 (Fig.5).

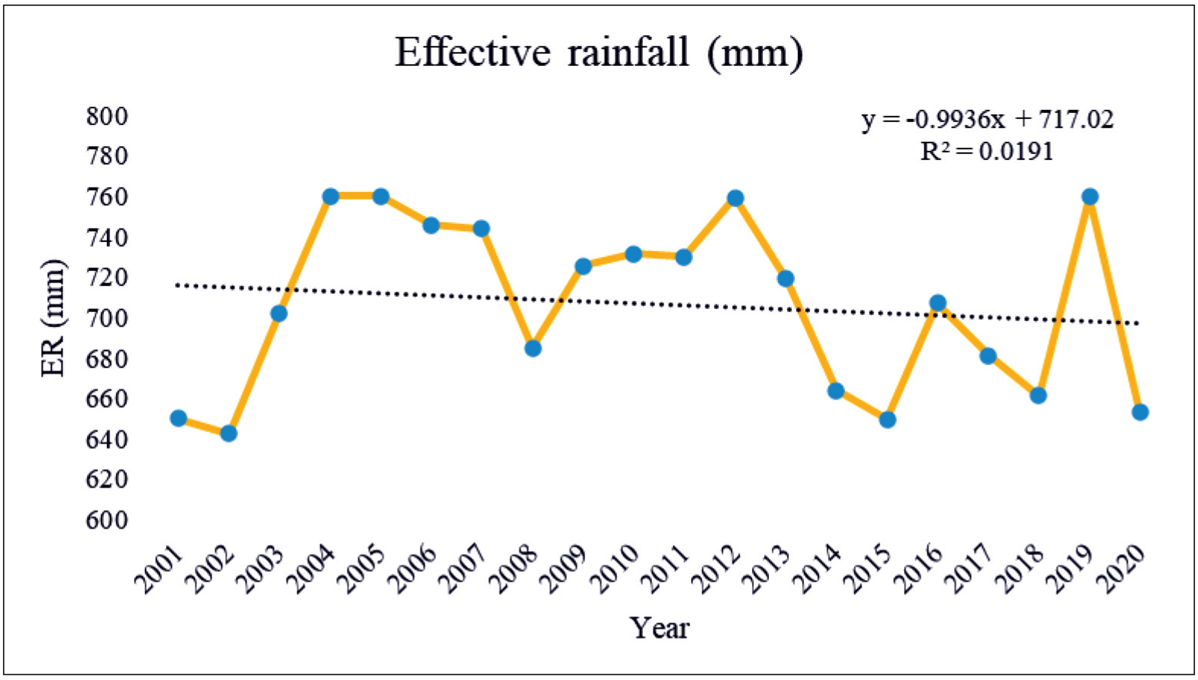

Fig. 5: Effective rainfall for rice (2001 – 2020) obtained from CROPWAT model

3.3 Irrigation requirement (IR)

An average of 268.67 mm of irrigation requirement was needed for *Kharif* paddy from 2001 to 2020 (Table 1). The highest irrigation requirement (317.1 mm) was reported in 2020 as this year experienced lesser amount of effective rainfall. In 2006, the lowest irrigation requirement was 201.9 mm as this year received higher volume of effective rainfall and this fulfilled the crop water need. The value of irrigation requirement showed a slight increasing trend (R^2 = 0.0627) throughout years starting from 2001 to 2020 (Fig. 6).

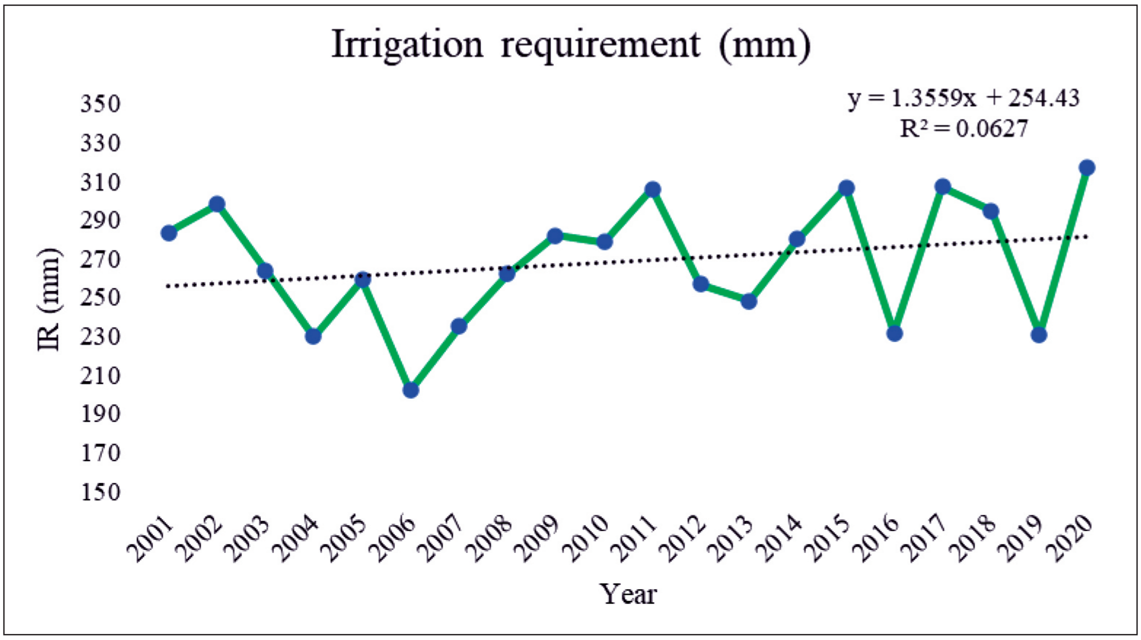

Fig. 6: Irrigation requirement of rice (2001 – 2020) obtained from CROPWAT model

3.4 Scheduling of irrigation by CROPWAT model

On an average, total gross irrigation (TGI) and total net irrigation (TNI) requirement was 491.61 and 344.12 mm, respectively. The highest value of TGI and TNI (693.9 and 485.7 mm, respectively) was recorded in 2011 followed by 2020 (679.9 and 475.9 mm, respectively). As both in 2011 and 2020, effective rainfall was less (50.1 and 65.6 per cent, respectively), gross irrigation and total net irrigation requirement was more. The lowest value of TGI and TNI (275.3 and 192.7 mm, respectively) was reported in 2006 and this was due to the higher per cent effective rainfall (83.4) received in the same year compared to other years (Table 2). There were no irrigation losses throughout the years starting from 2001 to 2020 and hence the average of total irrigation losses (TIL) came to 0 mm (Table 2). 730.04 mm (average of 20 years) of total percolation losses (TPL) was observed with the highest TPL (800 mm) in 2020 which was because of higher gross as well as net irrigation requirement. Average actual water use by crop (AWUC) was found to be 481.52 mm ranging from 446.4 mm in 2004 to 514.5 mm in 2011. Potential water use by the crop (PWUC) was same as that of AWUC as there was no limitation in availability of water required by the crop. Efficiency in irrigation schedule and deficiency irrigation schedule was 100 and 0 per cent, respectively as there was no TIL observed. Total rain water loss was found to be 509.06 mm (20 year average value) ranging from 182.1 mm in 2016 to 1014.7 mm in 2011. Inverse trend of TRL was found for efficient rainfall per cent indicating that years with higher efficient rainfall percent reported to have lower total rain losses. There was no deficit in moisture at harvest throughout the years and that's why value came as 0. Actual irrigation requirement in all the 20 years came negative as rainfall alone was sufficient to raise *kharif* paddy crop in Shivamogga district.

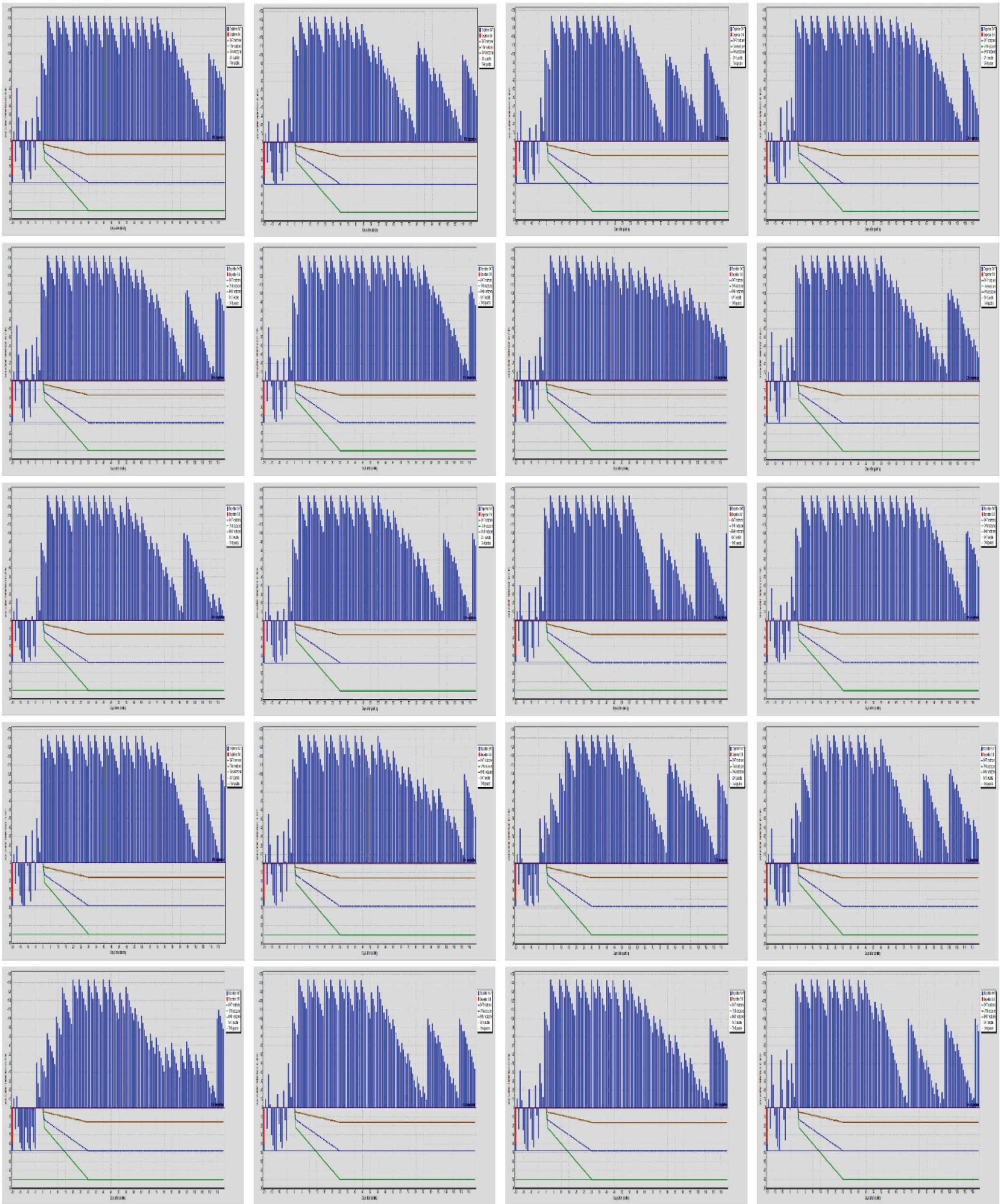

Fig. 4: Daily Soil moisture balance cum irrigation scheduling graphs during *kharif* rice (2001 – 2020) obtained from FAO CROPWAT model.

Table 2: Different parameters related to irrigation scheduling (2001 – 2020) obtained from CROPWAT model

Year	TGI (mm)	TNI (mm)	TIL (mm)	TPL (mm)	AWUC (mm)	PWUC (mm)	EIS(%)	DIS(%)	TRL (mm)	MDH (mm)	AIR (mm)	EfR (%)
2001	557.3	390.1	0	721.8	487.2	487.2	100	0	235.7	0	-513.7	80.9
2002	553.8	387.6	0	719.3	452.7	452.7	100	0	460.5	0	-488.4	67.1
2003	405.4	283.8	0	733.5	460.8	460.8	100	0	608.1	0	-614.6	63.9
2004	411.5	288.1	0	756.7	446.4	446.4	100	0	619.1	0	-687.4	64.7
2005	415.7	291	0	754.7	507.4	507.4	100	0	589.2	0	-656.2	66.4
2006	275.3	192.7	0	729	484.7	484.7	100	0	236.2	0	-706.1	83.4
2007	407.3	285.1	0	779.2	463.5	463.5	100	0	638.5	0	-656.2	63.7
2008	421.1	294.8	0	688.3	487.2	487.2	100	0	287.6	0	-531.9	78
2009	552.9	387	0	778	492.9	492.9	100	0	582.5	0	-607.3	65.4
2010	555.3	388.7	0	715	492.7	492.7	100	0	739.7	0	-546.9	58.4
2011	693.9	485.7	0	749.8	514.5	514.5	100	0	1014.7	0	-504.4	50.1
2012	418.7	293.1	0	723.8	478.3	478.3	100	0	794.7	0	-628.5	58.2
2013	412	288.4	0	764.5	478.5	478.5	100	0	358.3	0	-662.2	76.1
2014	555.6	388.9	0	673.1	482.6	482.6	100	0	267.8	0	-476.5	78.2
2015	561.9	393.3	0	689.1	484.9	484.9	100	0	333.3	0	-449.9	73.7
2016	418.8	293.2	0	634.3	492.2	492.2	100	0	182.1	0	-554.8	85.2
2017	564.3	395	0	731.8	481.6	481.6	100	0	636.5	0	-554.3	61.9
2018	555.7	389	0	722.4	482.4	482.4	100	0	376.6	0	-508.7	72.5
2019	415.8	291	0	736.4	478.2	478.2	100	0	680.5	0	-630.2	62
2020	679.9	475.9	0	800	481.6	481.6	100	0	539.5	0	-546.5	65.6
Mean	**491.61**	**344.12**	**0**	**730.04**	**481.52**	**481.52**	**100**	0	509.06	0	-576.24	68.77

(TGI=Total gross irrigation, TNI=Total net irrigation, TIL=Total irrigation losses, TPL=Total percolation losses, AWUC=Actual water use by crop, PWUC=Potential water use by crop, EIS=Efficiency irrigation schedule, DIS=Deficiency irrigation schedule, TRL=Total rain loss, MDH=Moist deficit at harvest, AIR=Actual irrigation requirement, EfR=Efficiency rain)

Conclusion

Crop water requirement (CWR) of *kharif* rice for Shivamogga district was computed using FAO CROPWAT 8.0 Model based on Penman Monteith equation from 2001 to 2020 and CWR was 565.50 mm (average of 20 years). Irrigation requirement for rice to raise the crop in *kharif* season was 268.67 while effective rainfall was 706.59 mm. On an average, total gross irrigation (TGI), total net irrigation (TNI), total percolation losses (TPL), actual water use by the crop (AWUC), Potential water use by the crop (PWUC), total rain losses (TRL), actual irrigation requirement (AIR) was 491.61, 344.12, 730.04, 481.52, 481.52, 509.06 and -576.24 mm, respectively was observed for irrigation scheduling in rice crop. These findings can be used to improve water productivity, irrigation efficiency which will enable to get more rice productivity in the Shivamogga district of Karnataka.

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Compliance with ethical standards: No

Conflict of Interest: No

Author contributions: Designing of experiment, data collection, analysis and preparation of manuscript by all of four authors

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