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Unveiling the Thirst: Revealing the Water Requirements of Gujrat's Thriving Crops using CROPWAT 8.0

Muhammad Bilal Naeem[1], Summera Jahan[1,2]*
[1]*Department of Botany, Hafiz Hayat Campus, University of Gujrat, Gujrat, Pakistan.*
[2]*Institute of Botany, University of the Punjab, Lahore, Pakistan.*

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ABSTRACT

Water plays an essential role in agriculture, serving as a primary reserve that directly impacts crop production and food security. Water conservation is critical for sustainable agriculture and the well-being of communities and ecosystems, chiefly due to the increasing global demand and rising water dearth concerns. The water needs of crops and irrigation scheduling in the district Gujrat, Pakistan, are currently missing enough information. Therefore, this study was conducted to determine the crop water requirements and establish irrigation schedules for the major crops in district Gujrat, Pakistan. The crop water requirement (CWR) and irrigation schedules were determined by CROPWAT 8.0 by using the input climate data obtained from the POWER-NASA website from 1991-2020. Other than climatic data, crops (wheat, rice, sugarcane, and maize) and soil information were added from CROPWAT 8.0 pre-existing data. The crop planting dates were estimated by Ayub Agriculture Research Institute (AARI). The gross and net crop water requirements are 624.3 mm and 491.3 mm for wheat, 1805.2 mm and 1768.3 mm for rice, 4135.1 mm and 3537.2 mm for sugarcane, and 1203.5 mm and 1051.4 mm for maize. The deployment of CROPWAT 8.0 proves to be valuable in precisely assessing crop water requirements and computing irrigation scheduling. The study's outcomes show the potential to boost food production and aid in well-organized water reserve management.

Corresponding Author: Summera Jahan
Email: aremmus_jahan@yahoo.com

INTRODUCTION

All living organisms rely on soil, water, and plants as essential natural resources for their provision and well-being. Among these resources, water stands as an elementary key that considerably influences and ensures the production of crops because without an adequate and reliable water supply, achieving guaranteed crop production becomes a frightening challenge (Molden *et al.*, 2007). Water serves as the lifeblood of agriculture, nurturing plants and enabling them to grow, thereby playing a crucial role in sustaining food security and the well-being of ecosystems and communities (Young *et al.*, 2021). The prudent management and maintenance of these vital resources are crucial to protect a sustainable and thriving future for both humanity and the environment (Cosgrove and Loucks, 2015). Given the current curve of water usage and escalating global demand, it appears increasingly suspicious that the world water cycle will be able to effectively cope with the growing pressures (Tzanakakis *et al.*, 2020).

Gujrat is a district located in the northeastern part of Punjab province in Pakistan. It is situated between the Jhelum and Chenab rivers, at a latitude of approximately 32.6 °N and a longitude of around 74.1 °E. It has a subtropical climate characterized by hot and humid summers, moderate winters, and a monsoon season with heavy rainfall (G. o. Punjab, 2023). The region features mostly alluvial, loam, clay loam, sandy, and occasionally saline/alkaline soils, each with varying characteristics and aptness for agriculture (Pervaiz *et al*., 2002). The cultivation of four major crops – Wheat, Rice, Sugarcane, and Maize – in the region of Gujrat holds profound significance for the local economy (Punjab, 2021).

Gujrat heavily relies on irrigation for its agricultural activities, drawing water from diverse sources such as rivers, canals, and groundwater. The primary water source for the district is the Chenab River, which supplies water through canals to support irrigation needs. Additionally, Gujrat benefits from additional water resources through the presence of the Upper Jhelum Canal and Rasul-Qadir Abad Link Canal (G. o. Punjab, 2023).

The groundwater reserves also play a crucial role in meeting water demands in Gujrat. The extraction of groundwater for irrigation and domestic purposes is commonly facilitated through tube wells and traditional wells. However, it is important to note that extreme groundwater extraction and unrestrained water consumption for agricultural activities can lead to the reduction of water tables and aquifers, posing long-term sustainability challenges (Khorrami and Malekmohammadi, 2021). Consequently, balancing water usage is fundamental to ensure the maintenance of these valuable resources (Tzanakakis *et al*., 2020).

Scientists extensively utilize software modeling programs such as CROPWAT 8.0 to evaluate crop evapotranspiration, crop water requirements (CWR), and irrigation scheduling (Jabaar and Abed; Solangi *et al*., 2022; Soomro *et al*., 2023). These software tools, developed by the Food and Agriculture Organization (FAO), serve as precious aids for irrigation engineers and agronomists in conducting crucial calculations for water irrigation studies. They are mainly helpful in the management and planning of irrigation schemes. For this specific exploration, the CROPWAT model was employed to examine the irrigation water requirements and scheduling of major cultivated crops (including wheat, rice, sugarcane, and maize) in district Gujrat. Agriculture is one of the backbones of Gujrat's economy, playing a crucial role in the livelihoods of its inhabitants. As climate change continues to impact weather patterns, the sustainability and productivity of agriculture face unprecedented challenges. In this context, our study on the crop water requirements in Gujrat emerges as a critical endeavor, driven by the following reasons: i) Gujrat, like many other regions, struggles with the growing fear of water scarcity. Understanding the precise water requirements of crops is important for optimizing irrigation practices, ensuring efficient water utilization, and mitigating the impact of water shortages on agricultural yields. Ii) Enhancing agricultural productivity is not only pivotal for food security but also for boosting the economic prosperity of Gujrat. By unraveling the details of crop water requirements, we aim to provide actionable insights that can empower farmers with the knowledge needed to maximize yields while minimizing water usage. Iii) In an era of increasing environmental awareness, sustainable water management is imperative. Our study seeks to contribute to the development of environmentally responsible farming practices that strike a balance between agricultural productivity and the conservation of water resources. iv) As policymakers grapple with the complexities of water allocation and usage, our research endeavors to provide valuable inputs for evidence-based decision-making. By elucidating the crop water requirements specific to Gujrat, we aim to inform policies that promote sustainable agriculture and water resource management. So, in undertaking this study, we aspire to not only advance scientific knowledge but also to catalyze positive changes at the grassroots level. Our commitment to unraveling the intricate relationship between water and agriculture in Gujrat is underscored by the belief that informed practices lead to a resilient and prosperous agrarian community.

MATERIAL AND METHODS

Study area

The study area lies in the northeast of Punjab, Gujrat occupies a land area of 3,192 sq. km and is positioned between the coordinates of 32.6° N latitude and 74.1° E longitude, with a population estimate of approximately 2,048,008 individuals. Gujrat shares borders with the districts, Mandi Bahauddin and Sialkot to the north, Gujranwala to the east, and Jhelum to the west. Of the total area spanning 864,225 acres in Gujrat, approximately 66.29 % is dedicated to cultivation. Moreover, two-thirds of this cultivable land requires irrigation for its water supply (Government of Punjab, 2023). The study area is shown by constructing a map using ArcGIS Pro in Figure 1.

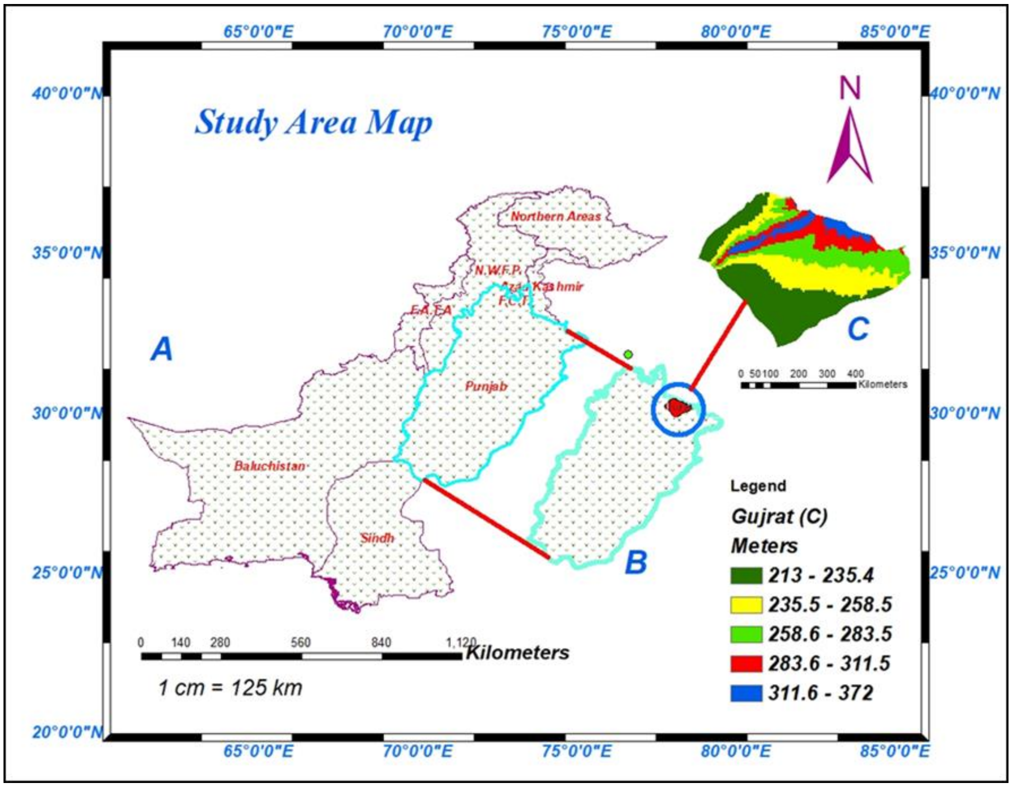

Figure 1. Study Area Map (Gujrat), map constructed in ArcGIS.

Crops Selected for Study

Wheat, rice, sugarcane, and maize, being the predominant crops cultivated in district Gujrat, were chosen as the focus of this study (G. o. Punjab, 2023). The crop information employed for this study is presented in Table 1.

Table 1. Information of crops under study. Sowing dates were estimated according to the Ayub Agriculture Research Institute guide, while other details were acquired from CROPWAT 8.0

Crop	Planting date	Harvesting date	Crop Coefficient (Kc)		
			Initial	Development/ Mid	Late
Wheat	15 Nov	24 March	0.30	1.15	0.30
Rice	10 June	07 Oct	0.50*	1.05*	0.70*
			1.10**	1.20**	1.05**
Maize	1 Sep	31 Aug	0.40	1.25	0.75
Sugarcane	15 Jan	19 May	0.30	1.20	0.35

For rice, * for dry Kc and ** for wet Kc

Abbreviation: Kc, Crop Coefficient

Crop Water Requirement Calculations

The crop water requirement has been calculated by using a computational tool, CROPWAT 8.0, according to FAO's equation (Allan *et al*., 1998).

$$IN = ETc - Pe$$

Where, IN is the net water requirement, ETc is evapotranspiration of crop, and Pe represents effective rainfall. Moreover, the evapotranspiration was calculated by using this expression (Allan *et al*., 1998),

$$ETc = ETo \times Kc$$

Where, ETo is Reference Evapotranspiration, and Kc is crop coefficient. Reference evapotranspiration was calculated by using the Penman Monteith Equation (Howell and Evett, 2004).

$$ETo = \frac{0.408\Delta(Rn - G) + \gamma[900/(T+273)]\,U_2\,(e_s - e_a)}{\Delta + \gamma(1 + 0.34\,U_2)}$$

Where; T is the average daily temperature at 2 m height (°C), Rn is net radiation, G is the soil heat flux in MJ m^2 d^{-1}, Δ is the slope of the saturation vapor pressure-temperature relationship in kPa (°C) $^{-1}$, γ is psychometric constant in kPa°C^{-1}, U_2 is daily wind speed at 2m height in ms^{-1}, e_s is the mean saturation vapor pressure and e_a is actual vapor pressure.

Whereas the effective rainfall was estimated by selecting the United States Department Agriculture's Soil Conservation Service method (U.S.D.A SCS) in CROPWAT 8.0, which is,

$$Pe = \left[\frac{P \times (125 - 0.2 \times P)}{125}\right]$$

If P ≤ 250mm

$$Pe = [125 + 0.1 \times P]$$

If P > 250mm

Pe is effective rainfall, while P is the total precipitation in mm.

Computational tool

CROPWAT version 8.0 is an innovative computer program developed by the Food and Agriculture Organization (FAO) that engages a range of equations to calculate crucial parameters such as reference evapotranspiration, crop water requirement (CWR), irrigation scheduling, and irrigation water requirement (IR). By utilizing inputs such as rainfall, soil characteristics, crop information, and climate data, this user-friendly program provides valuable support in enhancing irrigation schedules and accurately determining water supply for diverse crop patterns, whether under irrigated or rainfed conditions.

Data requirement and acquisition

CROPWAT 8.0 requires various input data to estimate reference evapotranspiration, including minimum temperature, maximum temperature, relative humidity, wind speed, and daylight hours. To obtain comprehensive crop water requirement estimations, this software further relies on precipitation data, crop coefficients, and soil type information.

Data about to minimum temperature, maximum temperature, relative humidity, wind speed, and precipitation for the study area from 1991 to 2020 was acquired from the National Aeronautics and Space Administration (NASA) Langley Research Center (LaRC) Prediction of Worldwide Energy Resource in 2023 (POWER, 2023). The sunlight hours were automatically estimated by CROPWAT 8.0 once the other input data was inputted.

The crop-related data for wheat, rice, sugarcane, and maize were added and processed into the CROPWAT 8.0 program. This information encompassed crucial parameters including rooting depth, crop coefficient, critical depletion yield response factor, and duration of plant growth stages. Planting dates were determined in accordance by the agricultural operations guide of the Ayub Agriculture Research Institute (AARI) department, as shown in Table 1 (G. o. t. Punjab, 2023).

Regarding soil parameters, the FAO CROPWAT 8.0 model provided comprehensive details on the soil properties. This encompassed information such as total available moisture content, initial moisture depletion, maximum rain infiltration rate, and maximum rooting depth. The study employed the soil conservation (S.C.) method from the United States Department of Agriculture (USDA). The soil in the Gujrat area was classified as a medium type based on FAO standards (NATIONS, 2023).

RESULTS AND DISCUSSION

Upon inputting climatic data from 1991-2020 specific to the study area, along with essential information about crops and soil into CROPWAT 8.0, the software generated several significant output variables. These variables include reference evapotranspiration, effective rainfall, crop evapotranspiration, crop water requirement, and an irrigation schedule.

Reference evapotranspiration

Table 2. displays the reference evapotranspiration values obtained using CROPWAT 8.0. The peak summer months (May, June, and July) recorded the highest reference evapotranspiration, likely attributed to the prevailing extreme climatic conditions during this period. During the dry seasons, the combination of low relative humidity, high temperatures, and sunlight contributed to an increase in evapotranspiration (Valipour, 2015). Conversely, the ETo values were lowest during the winter months, primarily due to the cold weather conditions prevailing at that time. The variations in ETo values are indicative of the diverse weather parameters experienced in the study area.

Table 2. Reference Evapotranspiration of district Gujrat from average climatic data (1991-2020) obtained by POWER-NASA website.

Month	Min. Temp (°C)	Max. Temp (°C)	Humidity (%)	Wind Speed (m/s)	Sunlight (hours)	Radiation (MJ/m²/day)	ETo (mm/day)
January	3.1	25.2	47	4.3	10.9	15.6	4.56
February	4.9	28.6	49	5.2	12.1	19.7	5.94
March	8.8	35.3	44	5.3	14.1	25.9	8.58
April	13.3	41.9	36	6.1	16.3	32.2	12.52
May	20.5	46.7	25	6.2	16.5	34.1	15.39
June	25.2	47.7	29	5.6	15.6	33.2	14.90
July	25.9	45.1	51	4.6	14.0	30.6	11.37
August	24.4	40.5	61	4.0	11.7	26.1	8.52
September	20.4	38.9	56	3.8	12.2	24.3	7.89
October	14.4	36.7	41	4.0	12.9	21.6	7.63
November	9.2	31.6	35	4.5	11.8	17.0	6.57
December	4.7	27.6	38	4.4	11.3	15.0	5.34
Average	14.6	37.1	43	4.8	13.3	24.6	9.10

ETo, Reference Evapotranspiration

Effective rainfall

Effective rainfall refers to the portion of rainfall that a crop can utilize effectively after accounting for losses caused by surface runoff and deep filtration. It plays a crucial role in evaluating the Crop Water Requirement (CWR). The average annual rainfall of 30 years (1991–2020) and the CROPWAT effective rainfall method USDA S.C.S are used here to estimate the effective rainfall and to calculate the water requirements and irrigation schedules for the four crops. Table 3. presents the effective rainfall data for both the entire study area and the major crops under investigation.

Table 3. Annual average rainfall and effective rainfall for district Gujrat from 1991-2020.

Month	Precipitation (mm)	Effective rainfall (mm)				
		Overall	Wheat	Rice	Sugarcane	Maize
January	30.7	29.2	29.2	-	29.2	17.4
February	50.9	46.8	46.6	-	46.6	46.6
March	49.0	45.2	36.3	-	45.1	45.1
April	32.1	30.5	-	-	30.6	30.6
May	24.9	23.9	-	16.5	23.9	12.8
June	65.7	58.8	-	59.0	59	-
July	196.7	134.8	-	134.8	134.8	-
August	159.9	119.0	-	118.9	118.9	-
September	80.2	69.9	-	69.9	69.9	-

October	16.9	16.4	-	7.0	16.5	-
November	9.0	8.9	04.6	-	9	-
December	14.8	14.4	14.5	-	14.5	-
Total	730.8	597.7	131.2	405.9	597.7	152.2

Crop Water Requirement and Irrigation Schedule of Wheat, Rice, Sugarcane, and Maize

Wheat: For wheat cultivation in district Gujrat, the gross crop water requirement for the entire growth period is quantified at 624.3 mm. After factoring in the effective rainfall of 131.3 mm, the net crop water requirement or irrigation necessity for wheat is determined to be 491.3 mm. Table 4 presents comprehensive data on crop evapotranspiration (both daily and with 10-day intervals), effective rainfall, and irrigation requirements for wheat at various stages throughout each decade of its growth cycle. This detailed information enables a thorough understanding of the water needs of wheat during different phases of its development in the study area.

The irrigation schedule of wheat, generated using CROPWAT 8.0 and visualized in Figure 2, prescribes two essential irrigation events based on the critical depletion of radially available moisture (RAM) in the soil. The first irrigation is recommended on the 71st day when the soil's moisture depletion reaches 55 %, while the second irrigation is advised on the 110th day when the soil's moisture depletion again reaches 65 %. RAM refers to the portion of water accessible for crop use, whereas TAM represents the total available moisture in the soil.

Table 4. Crop Water Requirement for Wheat calculated in CROPWAT 8.0.

Month	Decade	Stage	Kc	ETc (mm/day)	ETc (mm/dec)	Eff rain (mm/dec)	Irr Req (mm/dec)
Nov	2	Ini	0.30	1.97	11.8	1.4	10.6
Nov	3	Ini	0.30	1.85	18.5	3.2	15.3
Dec	1	Ini	0.30	1.72	17.2	3.9	13.3
Dec	2	Dev	0.37	1.97	19.7	4.4	15.3
Dec	3	Dev	0.70	3.54	39.0	6.2	32.8
Jan	1	Dev	1.05	4.90	49.0	8.0	41.0
Jan	2	Mid	1.28	5.60	56.0	9.6	46.3
Jan	3	Mid	1.29	6.32	69.5	11.6	57.9
Feb	1	Mid	1.29	7.01	70.1	14.2	55.9
Feb	2	Mid	1.29	7.56	75.6	16.4	59.2
Feb	3	Late	1.21	8.15	65.2	16.0	49.2
Mar	1	Late	0.91	6.97	69.7	15.6	54.0
Mar	2	Late	0.58	4.93	49.3	15.7	33.6
Mar	3	Late	0.35	3.44	13.7	5.0	6.8
					624.3	131.3	491.3

Ini, Initial stage of the crop; Dev, Developmental stage of the crop; Mid, Mid-stage of the crop; Late, late stage of the crop; ETc, Evapotranspiration of the crop; Eff, Effective; Irr Req, Irrigation requirement.

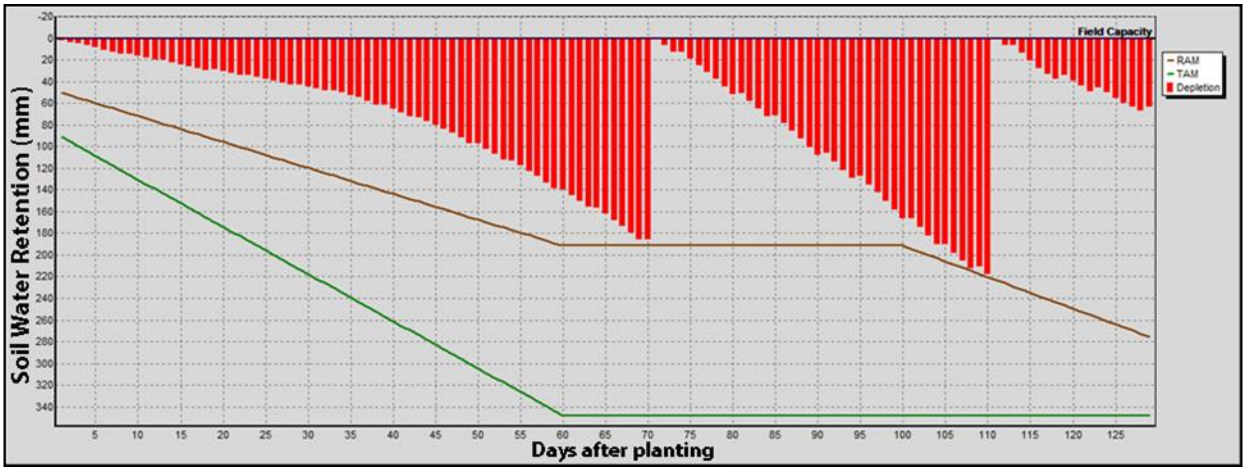

Figure 2. Irrigation schedule of Wheat generated by CROPWAT 8.0.

Rice: The gross crop water requirement for rice is reported to be 1805.2 mm, while the effective rainfall received during the crop season amounts to 405.9 mm. Consequently, the net water requirement for rice is calculated to be 1768.3 mm per season (Table 5). As rice belongs to the paddy crop category, it exhibits a growth pattern distinct from other crops. Notably, the field is initially flooded with water before the actual planting, and a nursery is carefully prepared approximately 10 days before planting (Nawaz *et al*., 2022). Given its water-loving characteristics, rice necessitates a substantial water supply throughout various stages of its life cycle.

Figure 3. illustrates the irrigation schedule of rice generated by CROPWAT 8.0. The software recommends a total of 18 irrigation practices at critical moisture depletion levels, starting from the pre-puddling stage and continuing until the end of the crop's growth cycle. To prepare the field for planting, four irrigations are scheduled for pre-puddling and puddling stages, almost a month before the actual planting date. The puddling stage concludes with the fifth irrigation, which takes place one day before the planting date. The cumulative value of these five irrigations amounts to 338.5 mm.

During the initial stage of rice, three irrigations are advised on the 3rd, 9th, and 15th day after planting, totaling 312.8 mm of water. The developmental stage of rice requires four irrigations, scheduled on the 21st, 30th, 40th, and 50th day after planting, totaling 395.4 mm of water. For the mid-stage of rice, three irrigations are recommended on the 58th, 71st, and 82nd day after planting, with a cumulative value of 305.5 mm. Finally, for the end stage of rice, three irrigations are suggested on the 92nd, 102nd, and 111th day after planting, accounting for 305.5 mm of water.

These irrigation schedules are essential to meet the water demands of rice, a water-loving crop that requires adequate moisture throughout various stages of its life cycle. By following these guidelines, farmers can optimize water use and enhance rice productivity.

Table 5. Crop Water Requirement for Rice calculated in CROPWAT 8.0.

Month	Decade	Stage	Kc	ETc (mm/day)	ETc (mm/dec)	Eff rain (mm/dec)	Irr Req (mm/dec)
May	2	Nur	1.20	1.89	18.9	6.0	12.9
May	3	Nur/LPr	1.06	16.50	181.4	10.5	273.5
June	1	Ini	1.07	16.37	163.7	14.5	418.7
June	2	Ini	1.10	16.82	168.2	17.7	150.5
June	3	Dev	1.10	15.39	153.9	26.8	127.2
July	1	Dev	1.14	14.28	142.8	39.4	103.4
July	2	Dev	1.20	13.60	136.0	49.3	86.8

July	3	Mid	1.26	13.09	130.9	46.1	97.9
Aug	1	Mid	1.28	11.91	119.1	42.5	76.7
Aug	2	Mid	1.28	10.62	106.2	41.2	65.0
Aug	3	Mid	1.28	10.43	104.3	35.2	79.5
Sep	1	Late	1.27	10.31	103.1	28.9	74.3
Sep	2	Late	1.24	9.76	97.6	23.5	74.1
Sep	3	Late	1.19	9.30	93.0	17.5	75.6
Oct	1	Late	1.15	8.90	62.3	7.0	52.3
					1805.2	405.9	1768.3

Nur, Nursery; LPr, leaf to panicle ratio, Ini, Initial stage of the crop; Dev, Developmental stage of the crop; Mid, Mid-stage of the crop; Late, late stage of the crop; Kc, Crop coefficient; ETc, Crop Evapotranspiration; Eff, Effective; Irr Req, Irrigation requirement.

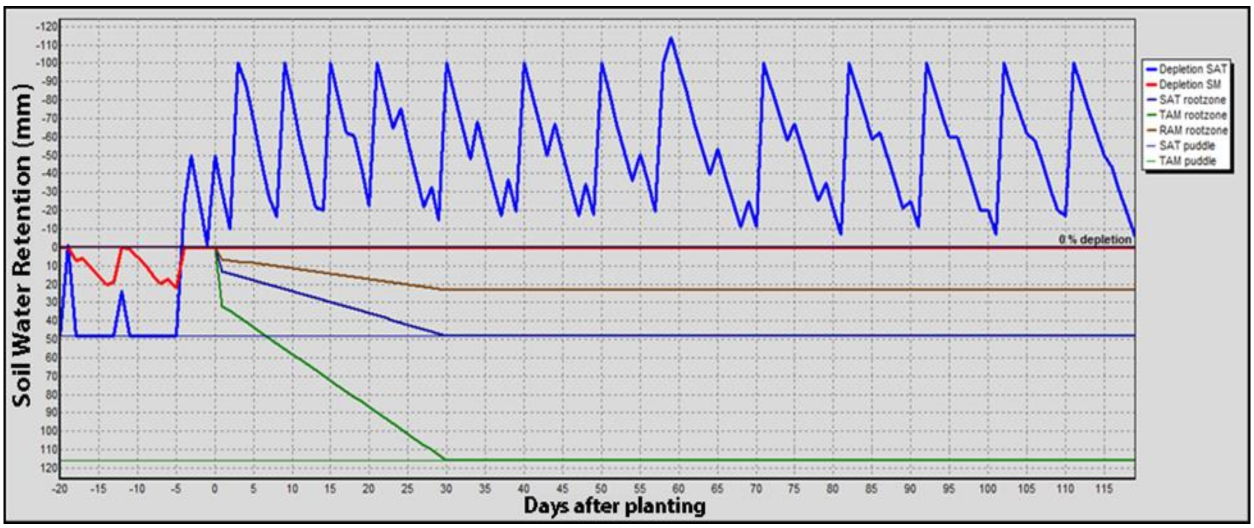

Figure 3. Irrigation schedule of Rice generated by CROPWAT 8.0.

Sugarcane*:* The total crop water requirement for sugarcane throughout its complete growth period within the study area is estimated to be 4135.1 mm. Taking into account the effective rainfall of 597.8 mm, the net crop water requirement or irrigation necessity for sugarcane is calculated to be 3537.2 mm. Table 6 provides a comprehensive breakdown of sugarcane's crop evapotranspiration, including both daily and per 10-day intervals, as well as the effective rainfall, and irrigation requirement at each decade stage of the crop's development. This detailed data offers valuable insights into the water demands of sugarcane at various growth phases in district Gujrat.

Figure 3. displays the irrigation schedule of sugarcane generated by CROPWAT 8.0. Throughout the entire year-long duration of the crop, a total of eleven irrigations are recommended based on critical depletion of radially available moisture in the soil.

The first irrigation is advised after the 75th day during the developmental stage of the crop when the soil's moisture depletion reaches 67 %. Subsequently, seven irrigations are suggested during the mid-stage of the crop after the 111th, 157th, 192nd, 214th, 231st, 246th, and 259th day at the critical depletion levels ranging from 66% to 69 %.

The last three irrigations are scheduled during the late stage of the crop after the 272nd, 287th, and 307th day. This irrigation schedule is designed to efficiently meet the water requirements of sugarcane at various growth stages throughout the entire year.

Table 6. Crop Water Requirement for Sugarcane calculated in CROPWAT 8.0.

Month	Decade	Stage	Kc	ETc (mm/day)	ETc (mm/dec)	Eff rain (mm/dec)	Irr Req (mm/dec)
Sep	1	Ini	0.40	3.24	32.4	28.9	3.5
Sep	2	Ini	0.40	3.16	31.6	23.5	8.1
Sep	3	Ini	0.40	3.12	31.2	17.5	13.8
Oct	1	Dev	0.50	3.85	38.5	10.0	28.5
Oct	2	Dev	0.68	5.17	51.7	3.3	48.3
Oct	3	Dev	0.86	6.29	69.2	3.2	66.0
Nov	1	Dev	1.05	7.28	72.8	3.4	69.4
Nov	2	Dev	1.23	8.08	80.8	2.4	78.4
Nov	3	Mid	1.41	8.66	86.6	3.2	83.5
Dec	1	Mid	1.47	8.46	84.6	3.9	80.7
Dec	2	Mid	1.47	7.86	78.6	4.4	74.2
Dec	3	Mid	1.47	7.48	82.2	6.2	76.0
Jan	1	Mid	1.47	6.90	69.0	8.0	60.9
Jan	2	Mid	1.47	6.42	64.2	9.6	54.5
Jan	3	Mid	1.47	7.19	79.1	11.6	67.5
Feb	1	Mid	1.47	7.97	79.7	14.2	65.5
Feb	2	Mid	1.47	8.60	86.0	16.4	69.6
Feb	3	Mid	1.47	9.94	79.5	16.0	63.5
Mar	1	Mid	1.47	11.23	112.3	15.6	96.7
Mar	2	Mid	1.47	12.48	124.8	15.7	109.1
Mar	3	Mid	1.47	14.46	159.1	13.8	145.2
Apr	1	Mid	1.47	16.59	165.9	11.6	154.4
Apr	2	Mid	1.47	18.58	185.8	9.8	176.0
Apr	3	Mid	1.47	19.93	199.3	9.2	190.1
May	1	Mid	1.47	21.63	216.3	7.4	208.9
May	2	Mid	1.47	23.23	232.3	6.0	226.3
May	3	Late	1.47	22.74	250.2	10.5	239.6
June	1	Late	1.42	21.77	217.7	14.5	203.3
June	2	Late	1.36	20.82	208.2	17.7	190.5
June	3	Late	1.30	18.20	182.0	26.8	155.2
July	1	Late	1.24	15.57	155.7	39.4	116.3
July	2	Late	1.18	13.43	134.3	49.3	85.0
July	3	Late	1.12	11.66	128.2	46.1	82.1
Aug	1	Late	1.06	9.86	98.6	42.5	56.1
Aug	2	Late	1.00	8.29	82.9	41.2	41.7
Aug	3	Late	0.93	7.63	83.9	35.2	48.7
					4135.1	597.8	3537.2

Ini, Initial stage of the crop; Dev, Developmental stage of the crop; Mid, Mid-stage of the crop; Late, late stage of the crop; Kc, Crop coefficient; ETc, Crop Evapotranspiration; Eff, Effective; Irr Req, Irrigation requirement.

Maize*:* The gross crop water requirement for maize in the study area is calculated to be 1203.5 mm for the entire duration of the crop. However, with an effective rainfall of 152.5 mm, the net crop water requirement or irrigation necessity for maize is determined to be 1051.4 mm. Table 7. provides a detailed breakdown of maize's crop evapotranspiration, including both daily and per 10-day intervals, as well as the effective rainfall and irrigation requirement at each decade stage of the crop's development. This comprehensive data offers valuable insights into the water demands of maize during various growth phases within the specific study location. Figure 4. illustrates the irrigation schedule of maize generated by CROPWAT 8.0. The schedule suggests five crucial irrigations based on the critical depletion of radially available moisture during the crop season.

Table 7. Crop Water Requirement for Maize calculated in CROPWAT 8.0.

Month	Decade	Stage	Kc	ETc (mm/day)	ETc (mm/dec)	Eff rain (mm/dec)	Irr Req (mm/dec)
Jan	2	Ini	0.30	1.31	7.8	5.8	3.0
Jan	3	Ini	0.30	1.47	16.1	11.6	4.5
Feb	1	Dev	0.39	2.11	21.1	14.2	6.9
Feb	2	Dev	0.70	4.09	40.9	16.4	24.5
Feb	3	Dev	0.99	6.68	53.4	16.0	37.5
Mar	1	Dev	1.28	9.75	97.5	15.6	81.8
Mar	2	Mid	1.42	12.05	120.5	15.7	104.8
Mar	3	Mid	1.42	13.96	153.6	13.8	139.8
Apr	1	Mid	1.42	16.02	160.2	11.6	148.7
Apr	2	Late	1.42	17.89	178.9	9.8	169.1
Apr	3	Late	1.19	16.10	161.0	9.2	151.8
May	1	Late	0.83	12.23	122.3	7.4	114.9
May	2	Late	0.49	7.78	70.0	5.4	64.0
					1203.5	152.5	1051.4

Ini, Initial stage of the crop; Dev, Developmental stage of the crop; Mid, Mid-stage of the crop; Late, late stage of the crop; Kc, Crop coefficient; ETc, Crop Evapotranspiration; Eff, Effective; Irr Req, Irrigation requirement.

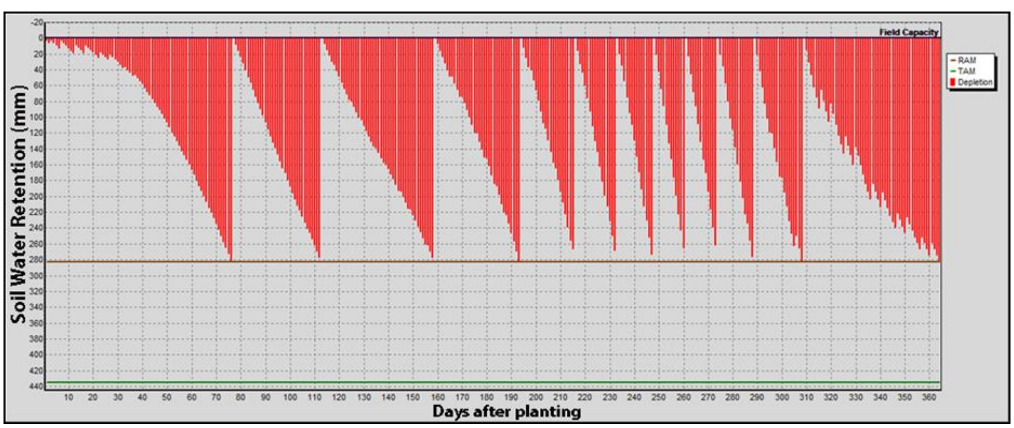

Figure 4. Irrigation schedule of Sugarcane generated by CROPWAT 8.0.

The first irrigation is recommended after 55 days when the soil's moisture depletion reaches 57 % initially. The second irrigation is advised after 70 days when the soil's moisture depletion advances to the next 58 % level. Following that, the third irrigation is scheduled after 81 days at a successive 55 % depletion rate. Subsequently, the fourth irrigation is proposed after 91 days at a successive 57 % depletion level, and the fifth irrigation is recommended after 103 days when the soil's moisture depletion reaches 66 %. This irrigation schedule is made to meet the specific water requirements of maize during its growth stages throughout the crop season, as determined by CROPWAT 8.0.

The crop water requirements (Tables 3-8) and irrigation schedules (Figures 2-5) are shown. The summary of irrigation amount and frequency of wheat, rice, sugarcane, and maize is summarized in Table 8. According to CROPWAT 8.0 irrigation scheduling, 417 mm out of 491.3 mm water is needed for wheat, 1602.8 mm out of 1768.3 mm water need of rice, 3182.2 mm out of 3537.2 mm water need of sugarcane, 850.9 mm out of 1051.4 mm water need of maize, is to be fulfilled by irrigation.

Table 8. Summary of irrigation frequency and irrigation need of crops generated by CROPWAT 8.0.

Irrigation Number	Crop irrigation amount according to irrigation frequency (mm)			
	Wheat	Rice	Sugarcane	Maize
1	192.5	53.8	289.5	166.2
2	224.5	48.0	285.4	167.8
3	-	98.0	285.6	159.8
4	-	67.8	286.3	166.3
5	-	70.9	283.2	190.8
6	-	110.1	288.8	-
7	-	103.8	295.7	-
8	-	98.9	289.5	-
9	-	96.1	283.8	-
10	-	103.0	297.5	-
11	-	97.4	296.9	-
12	-	98.9	-	-
13	-	95.7	-	-
14	-	103.0	-	-
15	-	106.8	-	-
16	-	102.3	-	-
17	-	106.4	-	-
18	-	95.7	-	-
Total	417.0	1602.8	3182.2	850.9

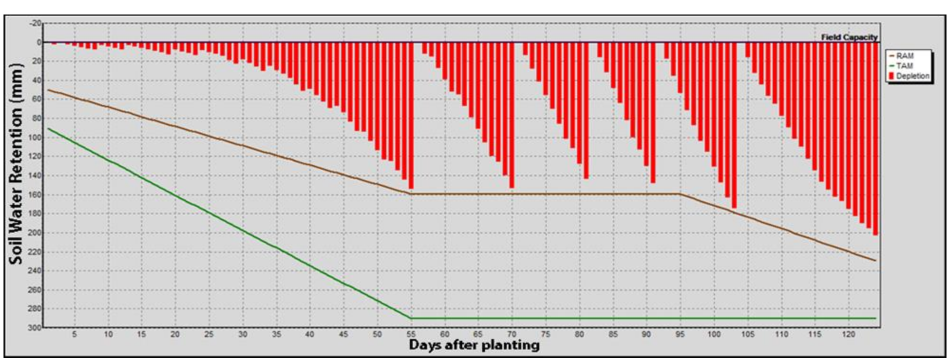

Figure 5. Irrigation schedule of Maize generated by CROPWAT 8.0.

CONCLUSION

The results have revealed that crop water requirement for wheat, rice, sugarcane, and maize is 491.3 mm, 1768.3 mm, 3537.2 mm, and 1051.4 mm per growing season. Additionally, the study indicates that rainfall significantly reduces the irrigation water requirement for crops. The crop with lengthy growing seasons such as sugarcane demonstrated increased crop water requirement, while shorter season crops have less crop water requirement, but it also depends on crop coefficient as well as climatic conditions. The calculated CWR and irrigation scheduling, combined with weather behavior understanding, can serve as a guide for future researchers and assist farmers in making informed decisions about the frequency and amount of irrigation for these crops in the study area. Nonetheless, similar studies can be conducted by utilizing the climatic variables from different regions within any country.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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