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Determination of water requirement for sugarcane under different seasons

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Abstract
The study aimed to determine water requirement of sugarcane crop under three different seasons for Western Maharashtra. The nine meteorological stations *viz.*, Dhule, Jalgaon, Niphad, Pune, Rahuri, Solapur, K Digraj, Padegaon, and Kolhapur as each of one district over study area was selected for the analysis. Determination of crop water requirement is carried out for sugarcane crop under three different seasons over study area. The water requirement was calculated for all seasons at selected stations. The water requirement was estimated for 43 years during 1980-2022 for Jalgaon, Dhule, Niphad, Pune, Rahuri and Solapur stations, while 33 years during 1990 - 2022 for Padegaon and Kolhapur station and 28 years during 1995-2022 for Kasbe Digraj station as per the availability of data. The long term average weekly meteorological data was collected from the Indian Meteorological Department (IMD), Pune. Meteorological data were utilized to calculate crop evapotranspiration using Microsoft Excel. The FAO 56 Penman-Monteith method was employed to estimate crop water requirement in conjunction to crop coefficient (Kc) values. The spatial distribution in CWR were interpreted with the inverse distance weighted (IDW) method. The average crop water requirement of sugarcane crop under different seasons was calculated. The spatial variation of average crop water requirement (CWR) of *suru* sugarcane, pre seasonal sugarcane and *adsali* sugarcane varies from 1252 to 1856 mm, 1624 to 2305 mm and 1567 to 2883 mm, respectively. Jalgaon station showed higher values of CWR of sugarcane for all stations whereas, lowest values of CWR for *suru* and pre seasonal sugarcane are shown by Padegaon and Kolhapur stations, respectively, whereas *adsali* sugarcane it was showed by K. Digraj station.Spatial analysis of CWR is beneficial for planner and policy makers in all sectors of agriculture for planning of *suru* sugarcane, pre seasonal and *adsali* sugarcane to identify water requirement zones in Western Maharashtra for optimal resource management and utilization. The determination of regional water requirement for the sugarcane crop prior to the cropping season is helpful to the farmers in the study area for planning the effective utilization of water resources. It will lead to preserve and conserve the resources for the next cropping season.

Keywords: Crop water requirement (CWR); crop coefficient; spatial distribution; Western Maharashtra

Introduction
Water is a vital input in agricultural production systems, yet it is often a limited resource. In semi-arid regions of India and worldwide, irrigated agriculture relies heavily on the availability of dependable water sources, which are influenced by rainfall patterns and access to stored water, such as reservoirs (Mushtaq *et al.*, 2012) [9]. Among the many management decisions faced by farmers, the optimal allocation of available irrigation water is particularly complex and challenging. Farmers must balance the competing objectives of minimizing water use while maximizing crop yields and profitability, all under the uncertainty of future weather and seasonal climate. Such climatic uncertainty often drives conservative irrigation strategies, which prioritize risk reduction in unfavorable years, sometimes at the expense of overall productivity (Jones *et al.*, 2000) [7].
The crop water requirement refers to the total quantity of water needed by a crop from sowing to harvest, including the manner and rate at which the crop consumes water during its growth period. An effective method for estimating crop water needs is through evapotranspiration (ET), which plays a central role in irrigation water management (Allen *et al.*, 1998) [1]. Reference evapotranspiration (ET_0) represents the rate of ET from a

hypothetical reference surface—typically a uniformly grown, well-watered grass cover of fixed height that fully shades the ground.

Climatic parameters such as humidity, temperature, wind speed, and solar radiation significantly influence the estimation of ET_0. The actual water requirement of a crop is obtained by multiplying ET_0 with the crop coefficient (Kc), which varies according to the crop's growth stages and duration. Therefore, evapotranspiration-based approaches are widely regarded as reliable and efficient tools for optimizing agricultural water use. (Seenu *et al.*, 2019) [12].

Materials and methods

Study area: An investigation was carried out in the Western Maharashtra agro-climatic region of Maharashtra to evaluate the variability in crop water requirements for sugarcane, a major crop cultivated in this area. The region covers a geographical area of 11.55 M ha, of which 1.69 M ha is under irrigation, and supports a population of 34.09 million. The average annual rainfall ranges from 608 to 635 mm, and the climate is predominantly hot and dry.

Approximately 89% of the annual rainfall over the central part of the region occurs during the southwest monsoon season (June-September), with about 37 rainy days out of 122 days receiving daily rainfall of ≥ 2.5 mm (Guhathakurta, 2020) [5]. The region lies between latitudes 15°40' and 22°00' N and longitudes 73°11' and 76°24' E. The study area encompasses nine districts: Sangli, Satara, Kolhapur, Nashik, Solapur, Ahmednagar, Pune, Jalgaon, and Dhule.

Data Acquisition

In the present study, 43 years of recorded data from nine stations across the Western Maharashtra region were utilized to estimate the crop water requirement of sugarcane during different seasons. Average weekly meteorological parameters including maximum and minimum temperatures, maximum and minimum relative humidity, bright sunshine hours, and wind speed were obtained from the Indian Meteorological Department (IMD), Pune, and the State Agricultural University (SAU), Rahuri.

Determination of the water requirement (WR) of crops is a fundamental component of crop planning in any irrigation project. Water requirement is defined as the total quantity of water irrespective of its source needed by a crop or a cropping pattern over a specific period to ensure normal growth under field conditions at a given location (Michael, 2008) [8]. Water requirement consists of the water lost through crop evapotranspiration (ETc) or consumptive use (Cu), along with unavoidable losses incurred during water application, and the additional water needed for various special agricultural operations.

WR = ETc or Cu + application losses + special needs (1)

Water requirement is therefore considered a *demand*, while the *supply* is met through various sources of water, primarily irrigation water (IR), effective rainfall (ER), and contributions from the soil profile (S). (Michael, 2008) [8].

In this study, the water requirement was estimated by considering only the demand component, while excluding application losses and special operational needs, as these factors vary across locations. Crop evapotranspiration was calculated using the following relationship

$$ET_C = ET_0 \times K_C \tag{2}$$

Where, ETc = Crop evapotranspiration (mm day-1),
ET_0 = Reference evapotranspiration (mm day-1) and,
Kc = Crop coefficient (dimensionless)

The FAO-56 Penman-Monteith method is widely recommended as the standard approach for estimating reference evapotranspiration (ET_0) (Allen *et al.*, 1998) [1]. This combined method, proposed by the Expert Consultation on FAO Methodologies for Crop Water Requirements, integrates both aerodynamic resistance and surface resistance components. The formulation is presented as follows:

$$ET_0 = \frac{0.408 * \Delta * (R_n - G) + \gamma * \left(\frac{900}{T+273}\right) * U_2 * (e_s - e_a)}{\Delta + \gamma * (1 + 0.34 * U_2)} \tag{3}$$

Where,
ET_0 = Reference evapotranspiration (mm day^{-1}),
Δ = Slope of saturation vapour pressure temperature curve (kPa^0C^{-1}),
γ = Psychometric constant (kPa $^0C^{-1}$),
T = Mean air temperature (^0C),
e_s = Saturated vapour pressure (kPa),
e_a = Actual vapour pressure (kPa),
R_n = Net radiation (MJ $m^{2-1}day^{-1}$),
G = Soil heat flux density (MJ $m^{2-1}day^{-1}$),
U_2 = Wind speed at 2m height (ms^{-1}) and,
(e_s-e_a) = Saturated vapour pressure deficit (kPa)

Details of Sugarcane Crop

To assess crop water requirement and fulfilling the objectives, the crop grown majorly in three different seasons in the study area i.e., *suru* sugarcane, pre seasonal sugarcane, *adsali* sugarcane. The details of sugarcane crop for analysis along with its growth period, duration and seasons are presented in Table 1.

Table 1: Details of sugarcane crop considered for analysis

Crops	Sowing Date	Harvesting	Duration
Suru sugarcane	1 Jan	31 Dec	365 days (12 months)
Pre seasonal sugarcane	15 Oct	15 Jan	457 days (15 months)
Adsali sugarcane	16 July	15 Jan	549 days (18 months)

Crop Coefficient (K_C) Equations

Crop coefficient varies with crop growth stages. Here, Kc values for initial stage, development mid-season stage and late season stages are interpolated. The daily K_C values for different crops for Rahuri region during their entire growth were calculated by the polynomial equations generated by Department of Irrigation and Drainage Engineering and recommended by MPKV, Rahuri (Anonymous, 2017) [2]. These daily K_C was further converted into weekly basis depending on need. It was assumed that these equations are valid over entire study area and do not change with respect to place and time.

Initial stage (Init)

During this stage, leaf area is limited, and evapotranspiration occurs predominantly through soil evaporation. Consequently, the crop coefficient (Kc) is relatively high when the soil surface is moist following irrigation or rainfall, but decreases substantially when the soil becomes dry.

Development stage (Deve)

As the crop develops and increasingly shades the soil surface, soil evaporation becomes progressively restricted, and transpiration gradually emerges as the dominant component of evapotranspiration.

- Mid-season stage (Mid)
- At this stage the K_C reaches its maximum value.
- Late season stage (Late)

The Kc value at the end of the late-season stage is influenced by crop and water management practices. It tends to be higher when the crop is irrigated frequently up to the point of harvest, particularly for fresh-market production. In contrast, when the crop is allowed to senesce and dry in the field before harvest, the Kc value becomes lower due to reduced stomatal conductance and declining leaf activity.

***Suru* sugarcane**

The polynomial equation for estimating the crop coefficient (K_C) for *suru* sugarcane crop is given as;

$K_C = 0.484(t/T)^4 - 4.948(t/T)^3 + 3.988(t/T)^2 + 0.636(t/T) + 0.372$ …(4)

Where,

Kc = Crop coefficient of *suru* sugarcane on t^{th} day

T = Day since sowing

T = Total crop growth period in days

Pre seasonal sugarcane

Polynomial equation for estimating the crop coefficient (KC) for pre seasonal sugarcane crop as;

$K_C = 8.185(t/T)^4 - 18.66(t/T)^3 + 10.85(t/T)^2 - 0.161(t/T) + 0.415$ …. (5)

Where,

Kc = Crop coefficient of pre seasonal sugarcane on t^{th} day

T = Day since sowing

T = Total crop growth period in days

***Adsali* sugarcane**

The polynomial equation for estimating the crop coefficient (K_C) for *adsali* sugarcane crop is given as;

$K_C = 11.22(t/T)^4 - 22.67(t/T)^3 + 11.41(t/T)^2 + 0.326(t/T) + 0.405$ ……..(6)

Where,

Kc = Crop coefficient of *adsali* sugarcane on t^{th} day

t = Day since sowing

T = Total crop growth period in days

Result and Discussion

The crop water requirement for sugarcane was assessed across the study area for three growing seasons—*suru*, pre-seasonal, and *adsali*. The estimation was carried out at selected stations following the methodology described in Section 3.5.1. Water requirement was computed using long-term meteorological records: 43 years of data (1980-2022) for Jalgaon, Dhule, Niphad, Pune, Rahuri, and Solapur; 33 years of data (1990-2022) for Padegaon and Kolhapur; and 28 years of data (1995-2021) for Kasbe Digraj, based on data availability. The results indicated considerable spatial and temporal variation in the crop water requirement across the entire region.

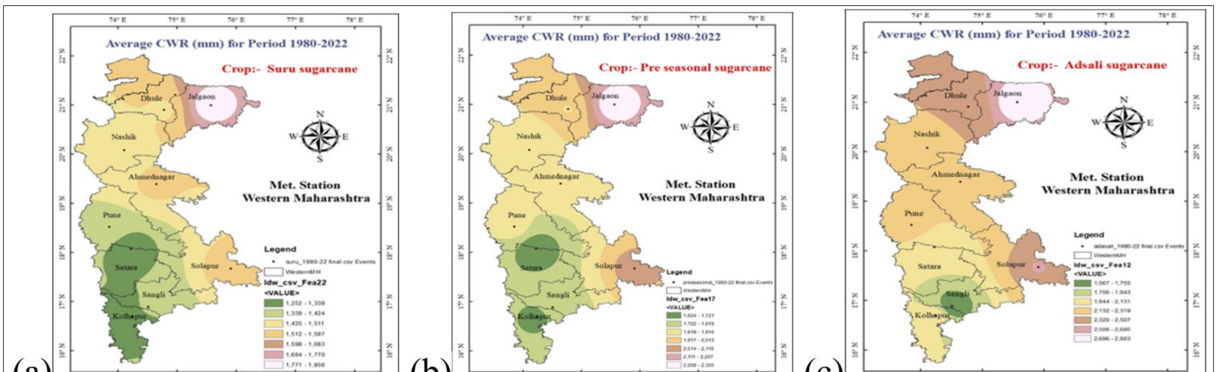

Fig 1: Spatial distribution in crop water requirement of four crops for decadal period 1980-2022

***Suru* sugarcane**

The average crop water requirement of *suru* sugarcane crop were obtained as 1487, 1841, 1406, 1433, 1587, 1434, 1259, 1246 and 1350 mm for Dhule, Jalgaon, Pune, Rahuri, Solapur, Niphad, Kolhapur, Padegaon and Kasbe Digraj station, respectively (Table 2). The spatial Distribution maps of the average annual crop water requirement were generated using the Inverse Distance Weighted (IDW) interpolation method. The results revealed that average annual crop water requirement across the study area ranged from 1252 to 1856 mm. The lowest values (1252-1338 mm) were recorded at Padegaon and Kolhapur, while the highest values (1771-1856 mm) were observed at Jalgaon. A clear spatial trend was evident: CWR values increased from the southern part of the region (Kolhapur) toward the southeast (Solapur), with a more pronounced rise toward the northeast (Jalgaon) within Western Maharashtra (Fig. 1a). This pattern also indicates that CWR values exhibit a notable relationship with longitude. The resulting graph (Fig. 2) illustrates the temporal variation in the crop water requirement (CWR) of *suru* sugarcane for the selected stations across the study area. Higher CWR values were recorded during the 1984-1994 period, whereas comparatively lower values were observed between 2010 and 2020 for most stations. Historical trends indicate that Jalgaon, followed by Solapur, consistently exhibited higher average CWR values, while Padegaon and Kolhapur showed comparatively lower values. Similar patterns were reported by Patil and Dhumal (2023) [10], who documented higher CWR values for Jalgaon during the 1980s (2032.2 mm), with a gradual decline in subsequent decades, whereas Kolhapur recorded the lowest values in recent years.

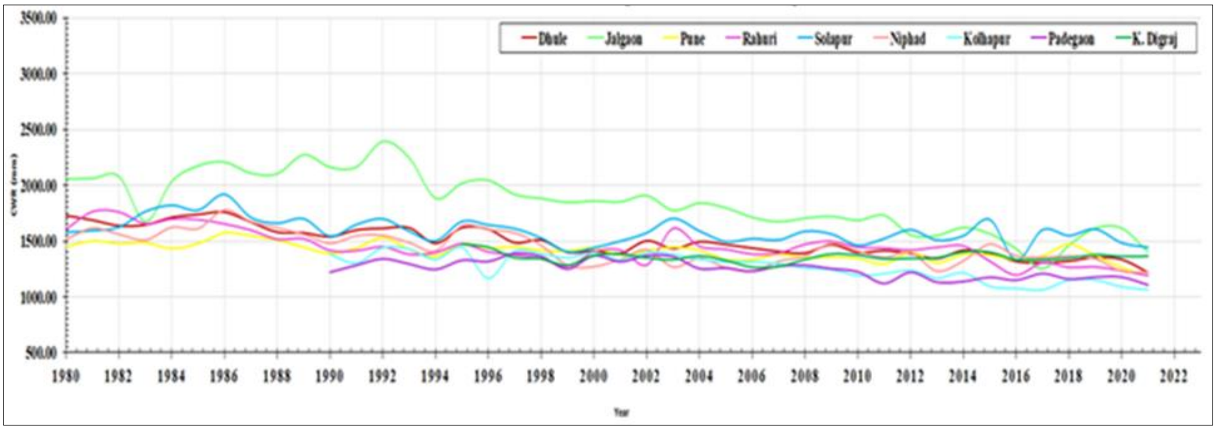

Fig 2: Time series data of water requirement of *suru* sugarcane

Pre seasonal sugarcane

The average crop water requirement of pre seasonal sugarcane crop were obtained 1910, 2394, 1839, 1845, 2079, 1867, 1691, 1624 and 1769 mm for Dhule, Jalgaon, Pune, Rahuri, The average annual crop water requirement (CWR) for the stations—Solapur, Niphad, Kolhapur, Padegaon, and Kasbe Digraj—is presented in Table 2. Spatial distribution maps were generated using the Inverse Distance Weighted (IDW) method. The analysis revealed that average annual CWR values across the study area ranged from 1624 to 2305 mm. The lowest values (1624-1721 mm) were recorded at Padegaon and Kolhapur, while the highest values (2208-2305 mm) were observed at Jalgaon. A clear spatial trend was noted, with CWR values increasing from the southern region (Kolhapur) toward the northeast (Jalgaon) of Western Maharashtra (Fig. 1b). This pattern also indicates a notable correspondence of CWR values with longitude.

The resulting graph (Fig. 3) depicts the temporal variations in the crop water requirement (CWR) of pre-seasonal sugarcane across the selected stations in the study area. Higher CWR values were observed during 1984-1994, while lower values were recorded during 2010-2020 for most stations. Historical data indicate that Jalgaon, followed by Solapur, consistently exhibited higher average CWR values, whereas Kolhapur and Padegaon recorded lower values. Sharma *et al.* (2018) reported similar trends for *rabi* season wheat, showing higher CWR values during 1990-2000 under warmer climatic conditions, and lower values during 2010-2020, likely due to reduced evapotranspiration demands and changes in cultivation practices at the selected stations.

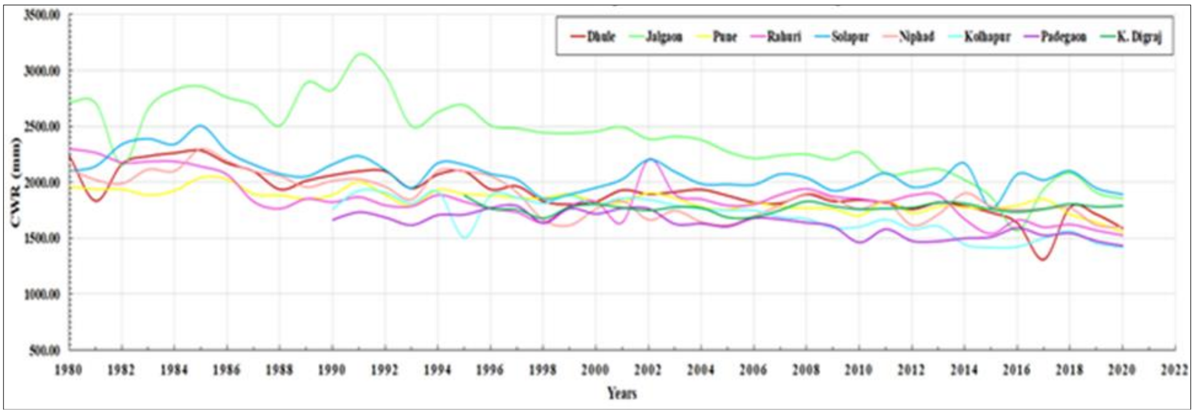

Fig 3: Time series of water requirement of pre seasonal sugarcane

***Adsali* sugarcane**

The average crop water requirement (CWR) of *adsali* sugarcane was recorded as 2322, 2883, 2227, 2236, 2521, 2248, 2060, 1970, and 1563 mm for Dhule, Jalgaon, Pune, Rahuri, Solapur, Niphad, Kolhapur, Padegaon, and Kasbe Digraj stations, respectively (Table 2). Spatial distribution maps of average annual CWR were prepared using the Inverse Distance Weighted (IDW) method. The results showed that average annual CWR across the study area ranged from 1567 to 2883 mm, with the lowest values (1567-1755 mm) observed at Padegaon and the highest values (2696-2883 mm) recorded at Jalgaon. A clear spatial pattern was observed, with CWR increasing from the southern part of the region (Kasbe Digraj) toward the northeast (Solapur), and further rising toward Jalgaon within Western Maharashtra (Fig. 1c). This pattern also suggests a notable correspondence between CWR values and longitude. The resulting graph (Fig. 4) illustrates the temporal variations in the crop water requirement (CWR) of *adsali* sugarcane across the selected stations in the study area. Higher CWR values were observed during 1984-1992, whereas lower values were recorded between 1995 and 2020 for most stations. Historical data indicate that Jalgaon, followed by Solapur, consistently exhibited higher average CWR values, while Kasbe Digraj and Padegaon recorded the lowest values.

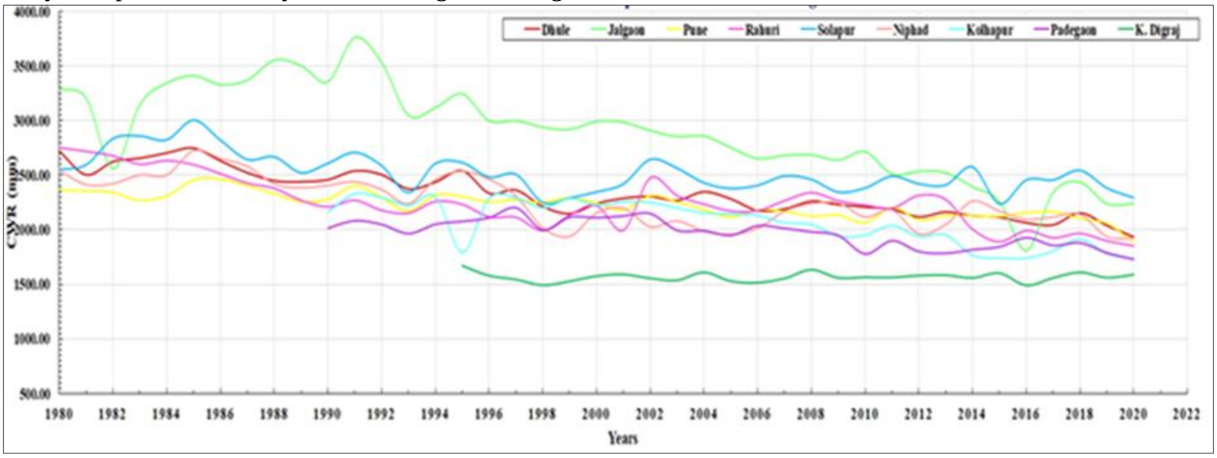

Fig 4: Time series of water requirement of *adsali* sugarcane

Conclusion

Different parameters such as temperature, humidity, rainfall, sunshine hours etc, plays vital role in crop growth which directly affect the productivity in agriculture. Different locations show different climatic conditions and different impact on crop growth is observed. The derived average weekly ET_0, along with the crop coefficient (Kc) values, were used to estimate crop evapotranspiration (ETc). The spatial variation of average crop water requirement (CWR) of *suru* sugarcane, pre seasonal sugarcane and *adsali* sugarcane varies from 1252 to 1856 mm, 1624 to 2305 mm and 1557 to 2883 mm, respectively over the study area i.e., Western Maharashtra. As per the existing scenario of CWR, there was variation in annual CWR for sugarcane crop for three seasons over a period for all stations. Jalgaon had the highest CWR for all seasons followed by Solapur and Dhule. The lowest CWR for *suru* sugarcane, pre seasonal sugarcane and *adsali* sugarcane was shown by Kolhapur, Padegaon and Kasbe Digraj station respectively.

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