J. Agric. Res. Technol., 50 (1) : 009-014 (2025) https://doi.org/10.56228/JART.2025.50102

Regional Estimation for Water Requirement of *Rabi* Season Crops

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(Received : 03.08.2024 Accepted : 24.11.2024)

Abstract

Water is a crucial natural resource for crop production, and variations in weather patterns and climatic conditions necessitate the study of water requirements for different crops under diverse environmental settings. This investigation was conducted in the Western Maharashtra agro-climatic region, which comprises nine districts: Dhule, Jalgaon, Niphad, Pune, Ahmednagar, Solapur, Sangli, Satara, and Kolhapur. The study aimed to estimate the crop water requirements (CWR) using the FAO 56 Penman-Monteith method. Long-term weekly average meteorological data (1980–2021) were sourced from the Indian Meteorological Department in Pune. The reference evapotranspiration (ET0) was calculated using Microsoft Excel, and the crop coefficient (Kc) equation developed for the Rahuri region was applied in conjunction with ET_0 to compute the CWR. The CWR values were derived based on the assumption that the crop coefficient remains constant over time and location. The study focused on commonly cultivated *rabi* crops, including wheat, *rabi* maize, tomato, and potato. The spatial variation in average CWR for these crops ranged from 341 to 481 mm for wheat, 239 to 338 mm for *rabi* maize, 425 to 603 mm for tomato, and 219 to 309 mm for potato. Temporal variation in annual CWR was observed, with Jalgaon station recording the highest CWR values for all crops, while the lowest CWR values were noted at Padegaon station for wheat, tomato, and potato, and at Rahuri station for *rabi* maize.

Key words : Crop Evapotranspiration (ET_0); Crop coefficient (kc); Spatial variation.

The climate change issue has gained worldwide attention and is becoming a significant problem.It is perceived that climate change mainly entails higher temperatures. However, the temperature rise is merely the beginning of the narrative. It is observed to cause changes in the hydrological cycle by affecting precipitation and evaporation (Bates *et al*., 2008; Huntington 2006). This effect leads to variation on crop production and need of crop water requirement. The geographical location of Western Maharashtra is such that it has variation in climatic conditions due to varied topo-graphical and climatological features.

The term crop water requirement means the "total amount of water required by the crop and the way in which it requires water from the time of sowing up to the time of harvesting".water requirement of crops can be determined effectively using an approach called evapotranspiration. Evapotranspiration (ET) plays a major role in irrigation water management (Allen et al., 1998). Reference evapotranspiration is a concept of estimating ET from the reference surface which resembles an in-depth surface of green grass of stable height, actively growing, fully shading the surface with sufficient water. Humidity, temperature, wind speed, and solar radiation are the factors that have a major impact on estimating ET0. The amount of water required for a crop is thus determined by multiplying ET0 with the crop coefficient (Kc) which depends on the growth stages and duration of a crop. So, evapotranspiration is considered to be one of the successful approaches to optimize the usage of water for crops (Seenu et al., 2019). Potential evapotranspiration is the essential term in the hydrological cycle, as well as very vital for suitable water management and effective irrigation scheduling hence, highly affect the crop water requirement and water allocation (Dong et al., 2020). Generally, PET is the maximum evapotranspiration that could occur at a site under normal meteorological conditions.

Materials and Methods

Study area : An investigation was conducted for the Western Maharashtra, Maharashtra's agro-climatic region, to assess the variability of crop water requirement of selected rabi crops grown in the region. Western Maharashtra region which is bounded by latitude 15^0 40' to 22^0 00' N and longitude 73^0 11' to 76^0 24' E. The geographical area is 11.55 M-ha while total area under irrigation is 1.69 M-ha and population is 34.09 million. The average annual rainfall in the region ranges 608-635 mm. Climate of Western Maharashtra is hot and dry.The 89% of annual rainfall in the central part is received during southwest monsoon rainfall (June to September) with 37 rainy days out of 122 days having daily rainfall (r >= 2.5) (Guhathakurta et al. 2020). Western Maharashtra are slightly alkaline and colour varies from black to deep black or reddish. Due to variation in topography and soils, the vegetation of Western Maharashtra varies in its composition. The study area comprises nine districts, viz.Sangali, Satara, Kolhapur, Nashik, Solapur, Ahmednagar, Pune, Jalgaon and Dhule.

Data Acquisition : In present study, 42 years of recorded data at nine stations in Western Maharashtra regions were used to estimate crop water requirement of four crops viz, wheat, rabi maize, tomato and potato. The details of average weekly meteorological data *viz*., maximum temperature, minimum temperature, maximum relative humidity, minimum relative humidity, bright sunshine hour and wind speed data was acquired from Indian Meteorological Department (IMD), Pune and SAU, Rahuri.

Estimation of crop water requirement: The estimation of the water requirement (WR) of crops is one of the basic needs for crop planning of any irrigation project. Water requirement may be defined as the quantity of water regardless of its source, required by a crop or diversified pattern of crops in a given period of time for its normal growth under field conditions at a place (Michael, 2008).

Water requirement includes the losses due to crop evapotranspiration (ET_c) or consumptive use (Cu) plus the losses during the application of water (unavoidable losses) and the quantity of water required for special operation.

$$WR = ET_c \text{ or } C_u + \text{application losses} + \text{special needs} \quad \ldots (1)$$

Water requirement is therefore a 'demand' and the 'supply' would consist of contribution from any of the source of water, the major source being the irrigation water (IR), effective rainfall (ER) and soil profile contribution (S) (Michael, 2008).

Here, water requirement was estimated considering demand side and nullifying the losses due to application and special needs as these parameters varies from place to place. The crop evapotranspiration is calculated by following relationship,

$$ET_C = ET_0 \times K_C \quad \ldots (2)$$

Were, ET_c = Crop evapotranspiration (mm day^{-1}), ET_0 = Reference evapotranspiration (mm day^{-1}) and, Kc = Crop coefficient (dimensionless)

The FAO 56 Penman-Monteith method is recommended as the sole method for determining ET_0 (Allen et al. 1998). The combination formula recommended by the Expert Consultation on FAO Methodologies for Crop Water requirement derived by combining the equation of aerodynamic resistance and surface resistance is stated below:

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

Were, 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 (MJm$^{2-1}$day^{-1}), G = Soil heat flux density (MJm$^{2-1}$day^{-1}), U_2 = Wind speed at 2m height (ms^{-1}) and, (es - ea) = Saturated vapour pressure deficit (kPa)

Details of Selected Crops : To estimate crop water requirement and fulfilling the objectives, the crops grown majorly in rabi season in the study area were selected i.e., wheat, *rabi* imaize, tomato and potato. The details of selected crops for analysis along with their growth period, duration and seasons are presented in Table 1.

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). These daily Kc 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.

Table 1. Details of selected crop with growth period

Crops	Sowing date	Harves-ting date	Duration	Season
Wheat	5 Nov	04 March	120 Days	*rabi*
Rabi maize	15 Oct	30 Jan	110 Days	*rabi*
Tomato	10 Nov	30 March	140 Days	*rabi*
Potato	20 Oct	10 Jan	90 Days	*rabi*

Initial stage (Init) : During this period, the leaf area is small, and evapotranspiration is predominately in the form of soil evaporation. Therefore, the K_c during the initial period is large when the soil is wet from irrigation or rainfall and is low when the soil surface is dry.

Development stage (Deve) : As the crop develops and shades more and more on the ground, the evaporation becomes more restricted and transpiration gradually becomes the major process.

Mid-season stage (Mid) : At this stage the K_c reaches its maximum value.

Late season stage (Late) : The K_c value at the end of the late season stage reflects crop and water management practices. This value is high if the crop is frequently irrigated until harvested fresh. If the crop is allowed to senescence and to dry out in the field before harvest the Kc value will be small, due to less efficient stomata conductance of leaf surfaces.

The details of K_c equation for selected crops i.e., wheat, rabimaize, potato, tomato are well-illustrated through Fig. 1 to 4 as below;

1) **Wheat :** The wheat crop is grown in Rabi season. The crop coefficient (Kc) curve and polynomial equation of wheat crop used for the analysis is presented below.

The polynomial equation for estimating the crop coefficient (K_c) for wheat crop is given as;

$$K_{ct} = 10.092 * \left(\frac{t}{T}\right)^5 - 20.039 * \left(\frac{t}{T}\right)^4 + 12.871 * \left(\frac{t}{T}\right)^3 - 7.0936 * \left(\frac{t}{T}\right)^2 + 3.7412 * \left(\frac{t}{T}\right) + 0.5942 \quad \text{.... (4)}$$

Where, K_{ct} = Crop coefficient of wheat on tth day, t = Day since sowing, T = Total crop growth period in days

2) ***Rabi* maize :** The maize crop is grown in rabi season. The crop coefficient (K_c) curve and polynomial equation ofrabi maize crop used for the analysis are presented below.

Polynomial equation for estimating the crop coefficient (K_c) for *rabi* maize crop as;

$$K_{ct} = 77.475 * \left(\frac{t}{T}\right)^5 - 193.14 * \left(\frac{t}{T}\right)^4 + 165.98 * \left(\frac{t}{T}\right)^3 - 60.13 * \left(\frac{t}{T}\right)^2 + 10.175 * \left(\frac{t}{T}\right) - 0.0431 \quad \text{.... (5)}$$

Where, K_{ct} = Crop coefficient of *rabi* maize on t^{th} day, t = Day since sowing and T = Total crop growth period in days

3) **Tomato :** The tomato selected for analysis is rabi tomato. The crop coefficient (K_c) curve and polynomial equation of *rabi* tomato crop used for the analysis are presented below.

The polynomial equation for estimating the crop coefficient (K_c) for tomato crop is given as;

$$K_{ct} = 3.350 * \left(\frac{t}{T}\right)^4 - 9.666 * \left(\frac{t}{T}\right)^3 + 6.793 * \left(\frac{t}{T}\right)^2 - 0.375 * \left(\frac{t}{T}\right) + 0.597 \quad \text{....(6)}$$

Where, K_{ct} = Crop coefficient of tomato on t^{th} day, t = Day since sowing and T = Total crop growth period in days

4) **Potato :** The potato crop is grown in Rabi season. The crop coefficient (K_c) curve and polynomial equation of potato crop used for the analysis are presented below.

Polynomial equation for estimating the crop coefficient (Kc) for potato crop as;

$$K_{ct} = 5.291 * \left(\frac{t}{T}\right)^4 - 13.80 * \left(\frac{t}{T}\right)^3 + 9.582 * \left(\frac{t}{T}\right)^2 - 0.961 * \left(\frac{t}{T}\right) + 0.523 \quad \text{....(7)}$$

Result and Discussion

The estimation of crop water requirement is carried out for four crops viz., wheat, rabi maize, tomato and potato over study area. The water requirement was calculated for all crops at selected stations as per methodology explained in section 3.5.1.The water requirement was estimated for 42 years during 1980-2021 for Jalgaon, Dhule, Niphad, Pune, Rahuri and Solapur stations, while 32 year during 1990 - 2021 for Padegaon and Kolhapur station and 27 years during 1995-2021 for Kasbe Digraj station as per the availability of data. Throughout the study area the result showed that there was variation in crop water requirement.

1. **Wheat :** The average crop water requirement of wheat crop were obtained as 364, 481, 385, 367, 448, 371, 412, 341 and 397 mm for Dhule, Jalgaon, Pune, Rahuri, Solapur, Niphad, Kolhapur, Padegaon and KasbeDigraj station, respectively (Table 3).The spatial distribution maps of average annual crop water requirement were prepared separately using inverse distance weighted (IDW) method . It was observed that the average annual crop water requirement values varies from 340 to 490 mm over study area. The minimum values of crop water requirement (340 to 380 mm) were observed at Padegaon, Rahuri, Niphad and Dhule station, while maximum value (441 to 490 mm) obtained at Jalgaon and Solapur station. It was also observed that the values of CWR increases from central part (Pune region) to south-east (Solapur region) and relatively more increase towards north-east (Jalgaon region) of study area i.e., Western Maharashtra (Fig 5).

2. ***Rabi* maize :** The average crop water requirement of rabi maize crop were obtained 254, 338, 268, 257, 308, 265, 285, 239 and 276 mm for Dhule, Jalgaon, Pune, Rahuri, Solapur, Niphad, Kolhapur, Padegaon and KasbeDigraj station, respectively (Table 3). The

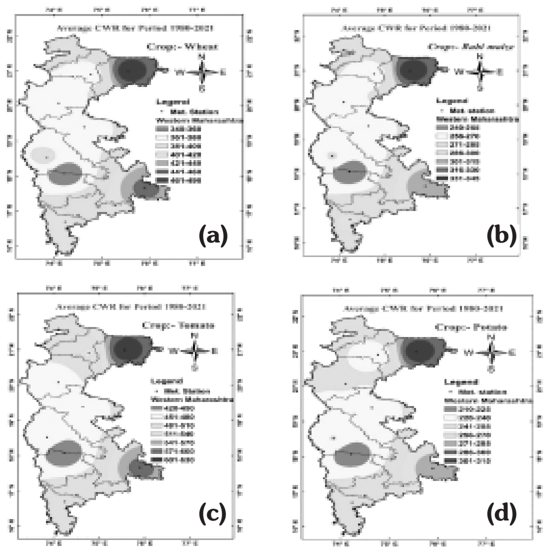

Fig. 5 Spatial distribution in crop water requirement of four crops for decadal period 1980-2021

spatial distribution maps of average annual crop water requirement were prepared separately using inverse distance weighted (IDW) method . It was observed that the average annual crop water requirement values varies from 240 to 345 mm over study area. The minimum values of crop water requirement (240 to 270 mm) were observed at Padegaon, Rahuri ,Niphad and Dhule station, while maximum value (316 to 345 mm) obtained at Jalgaon station. It was also observed that the values of CWR increases from central part (Pune region) towards north-east (Jalgaon region) of study area i.e., Western Maharashtra (Fig 5).

3. **Tomato :** The average crop water requirement of wheat crop were obtained 475, 603, 465, 459, 562, 463, 501, 425 and 488 mm for Dhule, Jalgaon, Pune, Rahuri, Solapur, Niphad, Kolhapur, Padegaon and KasbeDigraj station, respectively (Table 3). The spatial distribution maps of average annual crop water requirement were prepared separately using inverse distance weighted (IDW) method . It was observed that the average annual crop water requirement values varies from 420 to 630 mm over study area. The minimum values of crop water requirement (420 to 480 mm) were observed at Padegaon, Rahuri, Niphad and Dhule station, while maximum value (571 to 630 mm) obtained at Solapur and Jalgaon station. It was also observed that the values of CWR increases from central part (Pune region) to south-east (Solapur region) and relatively more increase towards north-east (Jalgaon region) of study area i.e., Western Maharashtra (Fig 5).

4. **Potato :** The average crop water requirement of potato crop were obtained 233, 309, 245, 236, 279, 245, 257, 219 and 250 mm for Dhule, Jalgaon, Pune, Rahuri, Solapur, Niphad, Kolhapur, Padegaon and KasbeDigraj station, respectively (Table 3). The spatial distribution maps of average annual crop water requirement were prepared separately using inverse distance weighted (IDW) method. It was observed that the average annual crop water requirement values varies from 210 to 315 mm over study area. The minimum values of crop water requirement (210 to 240 mm) were observed at Padegaon, Rahuri ,Niphad and Dhule station, while maximum value (286 to 315 mm) obtained at Solapur and Jalgaon

Table 3. Average CWR for wheat, *rabi* maize, tomato and potato

Station	Data period	Crop water requirement (mm)			
		Wheat	*Rabi* maize	Tomato	Potato
Dhule	1980-2021	364	254	475	233
Jalgaon	1980-2021	481	338	603	309
Pune	1980-2021	385	268	465	245
Rahuri	1980-2021	367	257	459	236
Solapur	1980-2021	448	308	562	279
Niphad	1980-2021	371	265	463	245
Kolhapur	1990-2021	412	285	501	257
Padegaon	1990-2021	341	239	425	219
K. Digraj	1995-2021	397	276	488	250

station. It was also observed that the values of CWR increases from central part (Pune region) to south-east (Solapur region) and relatively more increase towards north-east (Jalgaon region) of study area i.e., Western Maharashtra (Fig 5).

Conclusion

The crop water requirement is considered as important factor in life of Crop. Different parameters such as temperature, humidity, rainfall ,sunshine hour etc, plays vital role in crop growth period 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 (K_c) values, were used to estimate crop evapotranspiration (ET_c).The spatial variation of average crop water requirement (CWR) of wheat, rabi maize, tomato and potato ranges from 341 to 490 mm, 240 to 345 mm, 420 to 630 mm and 210 to 315 mm, respectively over a study area i.e., Western Maharashtra.As per the existing scenario of CWR there was variation in annual CWR for all crops (wheat, rabi maize, tomato and potato) over a period for all stations, whereas Jalgaon showed lower values of CWR for all crops.

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