ESTIMATION OF CROP WATER REQUIREMENT OF MAJOR *KHARIF* CROPS IN AURANGABAD DISTRICT

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B.Sc. (Agriculture)

MASTER OF SCIENCE

IN

AGRICULTURE

(AGRICULTURAL METEOROLOGY)

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BY

KHADAKE SNEHAL ANIL

B.Sc. (Agriculture)

A thesis submitted to
Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani
in partial fulfillment of the requirement for the degree of

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2021

DECLARATION BY THE CANDIDATE

I hereby declare that the thesis entitled, **"ESTIMATION OF CROP WATER REQUIREMENT OF MAJOR *KHARIF* CROPS IN AURANGABAD DISTRICT"**, submitted by me is based on the actual work carried out by me under the guidance and supervision of **Dr M. G. Jadhav**. The extent of information derived from the existing literature have been duly cited and referenced.The exciting research work or its any part is not submitted anywhere else for the award of any degree or diploma.

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Date: 06/08/2021

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This is to certify that the thesis entitled,**"ESTIMATION OF CROP WATER REQUIREMENT OF MAJOR *KHARIF* CROPS IN AURANGABAD DISTRICT"**submitted by **KHADAKE SNEHAL ANIL Reg. No: 2019A/22M** in partial fulfillment of the requirements for the award of degree of **MASTER OF SCIENCE (Agriculture)** in the subject of **AGRICULTURAL METEOROLOGY** submitted to the Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani is a record of bonafide research work carried out by her under my guidance and supervision. The thesis or its any part has not previously formed the basis for the award of any degree, diploma or other similar title.

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Dr. M. G. Jadhav

Research Guide

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Khadake

(Khadake Snehal Anil)

Place : Parbhani

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ABBREVIATIONS

%	:	Percent
/	:	Per
BSS	:	Bright Sunshine Hours
ET	:	Evapotranspiration
et al	:	Et alia, and others
ETc	:	Crop Water Requirement
etc	:	ET cetera (and so on)
ETo	:	Reference Evapotranspiration
EVP	:	Evaporation
FAO	:	Food and Agriculture Organization
Fig.	:	Figure
i.e.	:	That is
J	:	Julian day
Kc	:	Crop coefficient
Kcend	:	Crop coefficient at end growth stage of crop
Kcini	:	Crop coefficient at initial growth stage of crop
Kcmid	:	Crop coefficient at mid growth stage of crop
No.	:	Number
^{o}C	:	Degree celcious
P-M	:	Penman-Monteith
RHmax	:	Maximum Relative Humidity
RHmin	:	Minimum Relative Humidity
SMW	:	Standard Meteorological Week
Tmax	:	Maximum Temperature
Tmin	:	Minimum Temperature
Viz.	:	Videlic (namely)
VNMKV	:	Vasantrao Naik Marathwada Krishi Vidyapeeth
WS	:	Wind Speed

ABSTRACT

THESIS ABSTRACT

1	Title of the thesis	:	Estimation of Crop Water Requirement of Major *Kharif* Crops in Aurangabad District
2	Full name of the candidate	:	Khadake Snehal Anil
3	Full name of the Research Guide	:	Madhukar G. Jadhav
4	Department	:	Agricultural Meteorology
5	College / University	:	Vasantrao Naik Marathwada Krishi Vidyapeeth, Parbhani
6	Degree to be awarded	:	M.Sc. Agriculture

ABSTRACT

Sustainable food production depends on the judicious use of water resources as freshwater for human consumption and agriculture is becoming increasingly scarce. To meet future food demands and growing competition for clean water, more effective use of water in both irrigated and rainfed agriculture is crucial. One of the most important agrometeorological parameters which have been used in several applications, *viz.* climatic classification, agroclimatic characterization, water balance study, crop planning, water resource management, and irrigation scheduling, etc is evapotranspiration (ET) which is the amalgamation of two different processes commonly known as evaporation and transpiration.

An attempt has been made to estimate the reference evapotranspiration (ETo) and crop water requirement (ETc). The daily weather data (maximum temperature, minimum temperature, morning relative humidity, afternoon relative humidity, sunshine hour, and wind speed) of Aurangabad district were collected from CRIDA (Central Research Institute for Dryland Agriculture), Hyderabad. Daily mean data of all parameters were used to calculate reference evapotranspiration (ETo) on a daily, weekly, monthly, seasonal and annual basis by the universally accepted FAO-Penman-Monteith model.

The parameters needed for computing reference evapotranspiration (ETo) by FAO-Penman-Monteith method were determined step by step through a program developed in MS Excel from the mean of these six weather parameters (Tmax, Tmin,

RHmax, RHmin, n, u2), altitude, and latitude. Initially, the wind speed was transformed for height (3m to 2m) and unit (km h^{-1} to m s^{-1}), after that pressure was altered for an altitude of the selected location. The different parameters *viz.* mean temperature (^oC), the slope of saturation vapor pressure (K Pa $^oC^{-1}$), psychrometric constant (K Pa $^oC^{-1}$), actual vapor pressure (K Pa), saturation vapor pressure (K Pa), vapor pressure deficit (K Pa), extraterrestrial radiation (MJ m^{-2} day^{-1}), inverse relative distance Earth-Sun (radian), sunset hour angle (radian), solar declination (radian), daylight hours (hrs), or shortwave radiation (MJ m^{-2} day^{-1}), clear-sky solar radiation (MJ m^{-2} day^{-1}), net shortwave radiation (MJ m^{-2} day^{-1}), net outgoing longwave radiation (MJ m^{-2} day^{-1}), net radiation (MJ m^{-2} day^{-1}) and finally reference evapotranspiration (ETo) were computed on a daily basis, weekly, monthly, seasonal and annual basis.

The crop coefficients (Kc) for eight major *kharif* crops (cotton, soybean, pigeon pea, maize, pearl millet, onion, tomato, brinjal) under study were used from FAO-56 paper for four growth stages viz., initial, developmental stage, mid-stage, and late-season stage. The daily crop water requirement (ETc) was determined by multiplying the daily reference evapotranspiration (ETo) of the station with Kc, determined for each crop. The daily crop water requirement (ETc) computed were summed each for different growth stages of crop and total seasonal crop water was determined.

The result indicated that highest daily reference evapotranspiration (ETo) was 12.31 mm day^{-1} by Hargreaves-Samani method (H-S method) and the lowest was 3.39 mm day^{-1} by Modified Penman method. The highest weekly reference evapotranspiration (ETo) was 18.66 mm day^{-1} (H-S method) and the lowest was 0.94 mm day^{-1} (Penman-Monteith method). The highest monthly reference evapotranspiration (ETo) was 420.82 mm (H-S method) and the lowest was 122.29 mm (Modified Penman method). During the summer season reference evapotranspiration (ETo) was found to vary between Modified Penman method (522.44 mm) to H-S method (1858.73 mm) while during *kharif* season it varied between Turc method (331.81 mm) to H-S method (1407.99 mm) and in *rabi* season it was between Modified Penman method (340.70 mm) to H-S method (1836.16 mm). The highest annual reference evapotranspiration (ETo) is 4484.75 mm (H-S method) and the lowest is 1237.91 mm (Modified Penman method).

The results revealed that Hargreaves-Samani (H-S) method estimated the highest daily, weekly, seasonal and annual reference evapotranspiration (ETo) as compared to other methods for Aurangabad district.

The crop coefficient (Kc) values for all *kharif* crops were collected from FAO-56. The maximum amount of water is needed at the crop development and mid-season stages and relatively less water is needed in the initial and maturity stages. In case of Cotton mean water requirement differs between 0.92 mm day^{-1} to 9.25 mm day^{-1}. Similarly, for the Soybean crop, the mean crop water requirement (ETc) ranged between 1.07 mm day^{-1} to 6.87 mm day^{-1}. For the Pigeon pea crop, it differed between 1.17 mm day^{-1} to 9.17 mm day^{-1} while for Maize it differed from 0.83 mm day^{-1} to 11.15 mm day^{-1}. The crop water requirement (ETc) for Pearl millet crop ranged from 0.80 mm day^{-1} to 8.83 mm day^{-1}. For the Onion crop, it differed between 2.82 mm day^{-1} to 4.88 mm day^{-1}. For the Tomato crop, differed from 1.56 mm day^{-1} to 9.09 mm day^{-1} and for the Brinjal crop, it was between 1.57 mm day^{-1} to 10.24 mm day^{-1}.

Results of this investigation indicated that water requirement differs not only with the crops but also with their growth stages, depending upon climatic conditions and altitude. The information generated from this study will provide valuable information in planning irrigation scheduling for different *kharif* crops.

(**Keywords:** Reference evapotranspiration, FAO Penman-Monteith, Crop coefficient, Crop water requirement, Aurangabad)

CHAPTER -I

INTRODUCTION

CHAPTER - I

INTRODUCTION

Water is a censorious input for agricultural production and plays a key role in food security. Irrigated agriculture constitutes 20% of the total cultivated land and puts up 40% of the total food production universally. Irrigated agriculture is, on an average, at least twice as fruitful per unit of land as rainfed agriculture, thereby permitting for more production intensification and crop diversification. Due to population growth, urbanization, and climate change contesting for water resources is expected to increase, with a profound impact on agriculture. The population is anticipated to expand over 10 billion by 2050, and whether urban or rural, this population will need food and fiber to meet its necessities. Consolidated with the increased consumption of calories and more complex foods, which fulfill income growth in the developing world, it is estimated that agricultural production will need to expand around 70% by 2050.

However, future demand on the water by all sectors will need as much as 25 to 40% of water to be re-apportionment from lower to higher productivity and employment activities, especially in water emphasized regions. In most cases, such reallocation is expected to come from agriculture due to its elevated share of water use. Currently, agriculture accounts (on average) for 70% of all freshwater globally (and an even higher share of "consumptive water use" due to the evapotranspiration of crops). Superior irrigation practices show higher yields and incomes for producers but usually increases lead to higher yields and incomes for producers but generally increases water use. Inspite the advancement of technologies for water supply, irrigation management remains insufficient in most areas. The insufficiency of basic information on crop water needs is one of the causes for ineffectual water use and irrigation management (Carvalho *et al.,* 2013).

Climate variability and its influence on crop water requirement and food production are major concerns in the 21st century. It has now been accepted fact that the atmosphere is becoming warmer, rainfall is becoming more unpredictable, extreme events are becoming more recurring and enormous. Extended periods of drought, floods, and extreme weather events are influencing agricultural activities in

India and over the globe. Increasing temperature is anticipated to influence crop water requirement and food production all over the world. It is prognosticated that crop water requirement in arid and semiarid regions would increase due to the temperature rise. Though it is projected that crop water requirements in particular regions of the world would increase due to a temperature rise, the overall impact of climate change on crop water requirements is still undetermined. Some studies suggest that crop water requirements may not change due to variability in climate (Mane, 2013).

The effectual utilization of water both in the irrigated and rainfed areas for crop production is indispensable. The acquisition of an exact or accurate amount of water and precise timing of implementation is very crucial for planning or scheduling irrigations to meet the crop's water demands for optimum crop production (Mehta and Pandey, 2015). Crop water requirement is the measure of the amount of water needed for evapotranspiration when adequate soil water is maintained by precipitation or irrigation so that it doesn't prevent plant development and yield (Djaman *et al.,* 2017). With increasing paucity and growing competition for water, judicious utilization of water in the agricultural sector will be mandatory. This means that the exact or correct amount and correct timing of application should be acquired. In addition, it will need more extensive adoption of less irrigation, chiefly in arid and semiarid regions. Recent advances in new irrigation technologies will help to identify irrigation scheduling strategies that keep down water demand with the slightest impact on yields and yield quality, leading to better food security (Ali, 2010).

The amalgamation of two discrete processes whereby water is lost on the one hand from the soil surface by evaporation and on the other hand from the crop by transpiration is mentioned as evapotranspiration (ET) (Allen *et al.,* 1998). Evapotranspiration is a major element of the hydrological cycle and its accurate determination has a high significance in the studies of hydrological balance computation, designs, and management of water resources. At present, there are numerous methods for calculating reference evapotranspiration. FAO-Penman-Monteith method is the most accurate one for estimation of both dry and wet weather circumstances (Sharghi *et al.,* 2010). The resolution of the amount of water required for crops is one of the leading variables for correct irrigation planning. In this context, the FAO- Penman-Monteith (FAO-PM) method has been suggested as the finest for the reference evapotranspiration (ETo) estimates (Carvalho *et al.,* 2013).

The analysis of the performance of the various calculation methods reveals the need for identifying a standard method for the computation of reference evapotranspiration (ETo). The FAO-Penman-Monteith method is suggested as the unique standard method. It is a method with an indestructible likelihood of correctly estimating reference evapotranspiration (ETo) in a spacious range of locations and climates and has provision for application in data-short circumstances. Doorenbos and Pruitt (1977) define the crop coefficient (Kc) as the ratio between actual evapotranspiration (ET) of crop and the reference evapotranspiration (ETo) when the crop is grown in large fields under optimum growing condition or ETc = Kc × ET. The crop coefficient (Kc value) constituents the crop type and the development of the crop. The crop coefficient (Kc) values from FAO Paper 56 in predicts crop evapotranspiration under standard conditions. The crop coefficient combines the effect of characteristics that differentiate a typical field crop from the grass reference, which has a constant aspect and a complete ground cover. Consequently, different crops will have different crop coefficients (Kc). The replacement attributes of the crop over the growing season also affect the crop coefficients (Kc) (Allen *et al.,* 1998).

The evapotranspiration rate from a reference surface, not short of water, is called the reference crop evapotranspiration or reference evapotranspiration and it is indicated by ETo. The reference surface is a hypothetical grass reference crop with specific characteristics. The reference surface firmly looks like an extensive surface of green grass of uniform height, actively growing, completely shading the ground and with adequate water. The requirements that the grass surface should be extensive and invariable result from the supposition that all fluxes are one-dimensional uphill. The concept of reference evapotranspiration is established to study the evaporative demand of the atmosphere separately of crop type, crop development, and management practices. As water is abundantly available at the reference evapotranspiring surface, soil factors. The FAO-Penman-Monteith method is suggested as the must accurate method for determining reference evapotranspiration (ETo). The method has been chosen because it closely approximates grass reference evapotranspiration (ETo) at the location accessed, is physically based, and explicitly assimilates both physiological and aerodynamic parameters (Allen *et al.,* 1998).

Reference evapotranspiration (ETo) is an important variable in procedures accepted for the estimation of evapotranspiration rates of crops. In recent years there is a growing confirmation to manifest that the more accurate reference evapotranspiration (ETo) estimates across a wide range of climates and is being moved as the FAO Penman-Monteith for reference evapotranspiration (ETo) computations (Nandagiri and Kovoor, 2006). Estimation of reference evapotranspiration (ETo) is vital for planning irrigation water use in an arid and semiarid region. Estimation of reference evapotranspiration (ETo) is a key part of agricultural water management in local and regional water balance studies. At the field scale, estimation of reference evapotranspiration (ETo) is key in irrigation planning and scheduling and is a basic part of field management decision support tools (Tarate and Awari , 2017).

The Marathwada region forms a Deccan Plateau, the climate is extremely dry and subject to extremes, depends on judicious use of water resources as freshwater for human consumption and agriculture due to unequal dispersal of rainfall. To meet the future food demands growing competition for clean water, more effective use of water in both irrigated and rainfed agriculture will be required. The information on crop water requirements of different *kharif* crops of Aurangabad district in Marathwada region will be helpful for planners /irrigation engineers/ agronomists/ farmers in minimizing water loss and securing good yield.

Hence keeping in view these facts, the present research "**Estimation of crop water requirement of major *kharif* crops in Aurangabad district** "was undertaken with the following objectives.

Objectives:

1) To estimate reference evapotranspiration (ETo) on a daily, weekly, and monthly basis for major *kharif* crops (by FAO- Penman-Monteith method)

2) To estimate crop water requirement (using FAO-56 Kc values) for major *kharif* crops

CHAPTER -II

REVIEW OF LITERATURE

CHAPTER- II

REVIEW OF LITERATURE

The irrigation management program in agriculture demands evaluation of crop water use at the field level, which goals to quantify the amount of water required to refill the exhaust water in the crop root zone as a result of evaporative water loss called evapotranspiration (ET) (Allen *et al.,* 1998). The research reviews on numerous approaches for estimation of potential evapotranspiration (PET) and/or reference evapotranspiration (ETo) and computation of crop water requirements (ETc) are narrated hereunder discrete subheads for better transparency.

2.1 To estimate reference evapotranspiration(ETo) on a daily, weekly, and monthly basis for major *kharif* crops (by FAO-Penman-Monteith method)

Al-Ghobari (2000), estimated reference evapotranspiration by using five contrasting methods: FAO-Penman, Jensen-Haise, Blaney and Criddle, Pan evaporation, and calibrated FAO-Penman under local circumstances (Penman$_{\text{-SA}}$). The comparison was also made between the estimated ET_r of alfalfa grown in lysimeters in the Riyadh area. Regression analysis revealed that estimated ET_r values were mostly correlated with measured ET_r values. The results of this study stipulated that the calibrated Penman$_{\text{-SA}}$ method can be conveyed successfully to other locations, and this method could be used for the estimation of ET_r values in all areas in the southern region of Saudi Arabia.

Bhakar and Singh, (2003) used the ten most common reference evapotranspiration models for testing their validity under the climatic conditions of the Udaipur region. The key reference evapotranspiration models are: (i) Penman FAO-24 model, (ii) Penman-Monteith FAO-56 model, (iii) Priestley-Taylor model, (iv) Jensen-Haise Alfalfa Reference model, (v) Kimberley-Penman model, (vi) Hargreaves Grass Related model, (vii) SCS Blaney Criddle model, (viii) FAO-24 Blaney Criddle model, (ix) FAO-24 Pan Evaporation model, and (x) Christiansen Pan Evaporation model. Testing of these models was made based on the actual measurements of crops based on reference evapotranspiration (ET OA). Out of 10 models only 3 models, viz., Penman-Monteith FAO-56, Jensen-Haise Alfalfa

Reference, and Blaney-Criddle FAO-24 were established to prognosticate ET OA precisely undergoing climatic conditions of the Udaipur region.

Yoder *et al.,* (2005) estimated daily reference crop evapotranspiration (ETo) to determine the water requirement of crops using the crop factor method. In this study, pair-wise comparisons were made between daily reference evaoptranspiration (ETo) estimated from eight different reference evaoptranspiration (ETo) equations and reference evaoptranspiration (ETo) measured by lysimeter to supply information helpful in choosing a relevant reference evaoptranspiration (ETo) equation for the Cumberland Plateau discovered in the humid Southeast United States. Based on the standard error of the estimate, the relationship between the estimated and measured reference evaoptranspiration (ETo) was the best using the FAO-56 Penman-Monteith equation. These results support the acquiring of the FAO-56 Penman-Monteith equation for the climatological conditions happening in the humid southeast. However, Turcs equation may be an attractive alternative to the more complex Penman-Monteith method. The Turc method needs fewer input parameters, i.e., mean air temperature solar irradiance data only.

Nandagiri and Kovoor, (2006) evaluated the performance of seven reference evaoptranspiration (ETo) methods, representing temperature-based, radiation-based, pan-evaporation-based, and combination-type equations, were compared with the FAO-56 PM method using historical climate data from four stations located one each in arid (Jodhpur), semiarid (Hyderabad), Subhumid (Banglore), and humid (Pattambi) climates of India. For each location, reference evaoptranspiration (ETo) estimates by all the methods for assumed hypothetical grass reference crop were statistically compared using daily climate records over periods of 3-4 years. Comparisons were performed for daily and monthly computational time steps. Among the reference evaoptranspiration (ETo) methods evaluated, the FAO-56 Hargreaves method yielded reference evaoptranspiration (ETo) estimates closest to the FAO-56 PM method both for daily and monthly time steps, in all climates except the humid one where the Turc (radiation-based) was best.

Chavan *et al.,* (2009) estimated the reference evapotranspiration (ETo) with four discrete evapotranspiration estimation methods namely, Pan evaporation, Blaney-Criddle, Hargreaves-Samani, Priestly-Taylor. These methods were then compared with FAO-Penman-Monteith (FAO-56) to test abilities to prognosticate daily reference evapotranspiration (ETo) under the given climatic conditions of the southern hot and humid region of the Konkan plateau in Maharashtra state. Daily weather data of the Sindhudurg region for 15 years was used for the analysis. Results revealed that the Blaney-Criddle is the most definitive and precise method for estimation of reference evapotranspiration (ETo) for the Konkan region of Maharashtra.

Sharghi *et al.,* (2010) studied the amount of reference evapotranspiration (ETo), using FAO-Penman- Monteith method, in 29 selected synoptic and climatology stations of Yazd. Then they were classified in two ways: Firstly through a form of relationship between evapotranspiration parameters and the height and secondly through inverse distance weighting method or IDW. Finally, the difference in different land levels throughout the region was examined. Maps of reference evapotranspiration indicated that the degree of evapotranspiration is higher in central, southern, and some western areas of the province than in northern and eastern areas.

Meshram *et al.,* (2010) six reference crop evapotranspiration methods were studied based on their daily performance under given climatic conditions in the Western part of Maharashtra state. The Penman-Monteith equation standardized by Food and Agriculture Organization(FAO-PM) was used to differentiate with the Modified Penman, Hargreaves-Samani, Pan evaporation, Blaney-Criddle, and FAO Radiation methods using meteorological data of 33 years (1975-2007). Performance of these methods was evaluated based on least root mean square error and regression analysis. Radiation method gave higher values after Modified Penman, Blaney-Criddle, Pan evaporation Hargreaves-Samani, and Penman-Monteith. Out of the six methods Modified Penman gave the minimum value of root mean square error and higher correlation coefficients under climatic conditions of Ahmednagar district of Maharashtra.

Sabziparvar and Tabari, (2010) evaluated the performances of the Makkink, Priestly-Taylor, and Hargreaves models compared to the Penman-Monteith FAO-56 (PMF-56) method in arid and semiarid regions of Iran during 1993-2005 and to recognize the different reference evaoptranspiration (ETo) model that presents results closest to the PMF-56 method. In addition, a regional estimation of monthly reference evaoptranspiration (ETo) with the finest performed model is presented by using the spatially distributed physical parameters and geographical information system. The results showed that the Hargreaves model was the best model to estimate reference evaoptranspiration (ETo) in the eastern arid and semiarid regions of Iran.

Carvalho *et al.,* (2013) estimated reference evaoptranspiration (ETo) by FAO-PM method with only the maximum temperature and minimum temperature values and here known as the simplified FAO-PM and differentiate it to the standard method (FAO-PM) with all input data, for lavras, Minas Gerais State, Brazil. It was observed that the alternative method tends to overestimate the standard method however, this approach is feasible to estimate reference evaoptranspiration (ETo) for irrigation scheduling in localities where not all input data required is not available to estimate the FAO-PM method.

Rao *et al.,* (2013) studied the daily reference crop evapotranspiration (ETo) estimated from open pan evaporation data for 52 generally distributed locations across India (meteorological observations maintained by All India Coordinated Research Project on Agrometeorology) (AICRPAM) are differentiated with PM estimated reference evaoptranspiration (ETo). The annual and intraseasonal variability of reference evaoptranspiration (ETo) and the inter differentiate of these two methodologies have been carried out. Results indicated that estimates of reference evaoptranspiration (ETo) from the open pan were always lower than those of Penman-Monteith and error ranges were d" 29% across locations. Calibration coefficients evolved from the present study were established to decrease the error considerably in reference evaoptranspiration (ETo) estimates.

Paredes *et al.,* (2013) studies the FAO-PM method has been considered as a global standard to estimate reference evaoptranspiration (ETo) for more than a decade. This method considers many parameters related to the evapotranspiration process; net radiation, air temperature, vapor pressure deficit, and wind speed have presented the very finest results when compared to data from lysimeters populated with short grass or alfalfa. In some conditions, the FAO-PM method is restricted by the insufficiency of input variables. In these cases, when data are missing, the option is to calculate reference evaoptranspiration (ETo) by the FAO-PM method using estimated input variables, as recommended by FAO Irrigation and Drainage paper 56.

Bhagat and Patil, (2014) estimated a reference crop evapotranspiration at distinct probability levels for Solapur (North latitude 17 10" to 18 32" and east longitude 74 42" to 76 15") at 483.5msl in the semi-arid zone of Maharashtra. Weekly reference evapotranspiration values for the period of (1977-2007) were computed by the finest method Penman-Monteith FAO-56. The probability distribution that was fitted to reference crop evapotranspiration values is the log-normal, Gumbel, and Weibulls probability distribution function. A Chi-square test was performed to know the probability distribution of best fit. Reference crop evapotranspiration values at 10% to 90% probability level for Penman-Monteith method using the probability distribution of best fit.

Soundarrajan *et al,* (2014), estimated daily and mean weekly output from seven evapotranspiration models with indigenous constants (FAO-24 Blaney-Criddle, Hamon, Priestly Taylor, Hargreaves, Jenson-Haise, (Romanenko and Turc), which were tested against reference evapotranspiration data computed by FAO Penman-Monteith model to evaluate the correctness of each model in estimating gross reference evapotranspiration in Tamil Nadu. Models were differentiated at fourteen stations of the India Meteorological Department observatories using data from 1981 to 1992. From the seven models, five models were chosen for evaluation. In the first approach, it is supposed that the mean annual reference evaoptranspiration (ETo) estimated by each chosen model is equal to the mean annual reference evaoptranspiration (ETo) by the (PM) model. Therefore the percentage error between annual reference evaoptranspiration (ETo) estimated by each model and that of the Penman-Monteith (PM) model was determined.

Varija, (2015) studied evapotranspiration as a key element of the hydrological cycle and plays a notable role in regulating the crop water requirement. Evapotranspiration from a cropped surface is affected by several factors which may be mainly classified as crop associated factors and meteorological factors. FAO-56 Penman-Monteith method is globally accepted as the standard method for calculating reference evapotranspiration. However, the meteorological inputs for this method are tough to acquire. In these circumstances, the user is mandatory to reply on simple temperature and radiation-based empirical equations which need a lesser number of readily available inputs. Here, an attempt is made to statistically compare five separate empirical reference evapotranspiration estimation methods, with the Penman-

Monteith method as a reference, in six different climate types prevailing in Karnataka. The calculations are done on daily and monthly time scales using computer programs evolved in Microsoft Excel.

Debnath *et al.,* (2015) examined the sensitivity of reference evapotranspiration (ETo) to climatic variables for different agro-ecological regions of India: Semi-arid (Kovilpatti and Parbhani), humid (Mohanpur), and sub-humid (Ludhiana and Ranichauri). The FAO-56 Penman-Monteith (FAO-56 PM) method is used to estimate reference evaoptranspiration (ETo), and sensitivity of reference evaoptranspiration (ETo) has been studied in terms of change in maximum air temperature (T_{max}), minimum air temperature (T_{min}), solar radiation (R_s), average relative humidity (RH_{avg}), and wind speed (W_s). The result revealed that the change in reference evaoptranspiration (ETo) is linearly related to change in all-climate elements at all sites.

Garg *et al.,* (2016) used the FAO-PM method for estimating reference evapotranspiration (ETo) for the state of Himachal Pradesh in India from 1980 to 2009. The study differentiates the evapotranspiration of the several regions of the state including the highest reference evaoptranspiration (ETo) during May with the peak being found in the Hamirpur district of the state(11.77mm/day). The month from April to June have considerably high reference evaoptranspiration (ETo) while other months have low reference evaoptranspiration (ETo). Among the 14 regions, Lahaul has the lowest reference evaoptranspiration (ETo) (2.52mm/day for May). Decisively a wide spatial variability in the distribution of reference evaoptranspiration (ETo) is noticed in Himachal Pradesh owing to varying internal topography as well as adjoining topographical boundaries.

Panchal *et al.,* (2016) investigated the assessment of discrete methods for estimating daily reference evapotranspiration (ETo) of three meteorological stations, viz. Akola, Amraoti, and Buldana, in Purna river basin, Maharashtra, India. The detailed analyses of reference evaoptranspiration (ETo) have been carried out for 36 years (from 1969-2004), using meteorological data collected from India Meteorological Department (IMD) Pune, wherein data for one year (1997) was found missing. The reference evapotranspiration at the aforementioned stations has been estimated using temperature-based methods (Hargreaves-Samani and Blaney-Criddle) and radiation-based methods (Turc and Priestly-Taylor). The reference evaoptranspiration (ETo) estimated using aforementioned methods have been differentiated with the corresponding value of Food and Agriculture Organization, Irrigation and drainage paper 56 (FAO-56) Penman-Monteith (PM) method, through statistical performance indices like the coefficient of determination (R^2) and root mean square error (RMSE) to assess the performance of former methods.

Kumar, (2017) studies for estimation of daily reference evapotranspiration (ETo) by FAO-PM method using 30 years (1985-2015) mean meteorological data of two coefficients of distinct crops like rice, *kharif* maize, wheat, *rabi* maize, green gram, and summer maize at Sabour and Patna locations. Irrigation water requirement for distinct crops was estimated based on crop evapotranspiration and effective rainfall during the growing period of the crop. The mean annual reference evapotranspiration (ETo) was found 3.6mm/day at Sabour and 4.1mm/day at Patna.

Tarate and Awari, (2017) estimated reference evapotranspiration (ETo) using 32 years of meteorological data of Parbhani district by CROPWAT software. The FAO-56 Penman-Monteith method has been suggested as the standard method for estimating reference evapotranspiration (ETo) was used.

Jadhav *et al.,* (2017) studied evapotranspiration demands, and trends were analyzed for the Rahuri region in western Maharashtra by assessing reference evapotranspiration (ETo), energy balance, and aerodynamic components for 38 years (1975-2013). Analysis of 38 years of daily meteorological data of Rahuri indicated that the energy balance component of reference evaoptranspiration (ETo) has shown an increasing trend, while a decreasing trend is seen in the aerodynamic constituents as well as in the reference evaoptranspiration (ETo). Seasonal analysis has manifested that reference evaoptranspiration (ETo) has an increasing trend during the summer season. The mean annual reference evaoptranspiration (ETo) is 1724 mm with 1035 mm for the energy balance element and 689 mm for the aerodynamic element. Mean annual reference evaoptranspiration (ETo), energy balance element, and aerodynamic element noticed maximum in May while lowest in December. Crop water requirements are more from March to June as reference evaoptranspiration (ETo) is noticed to be highest during this period.

Chowdhury *et al.,* (2017) investigated the potential of artificial neural network models to estimate reference evapotranspiration (ETo) for the Mohanpur area and differentiates the performance of ANN models with reference evapotranspiration (ET) estimated by the FAO-Penman method. The analysis was carried out in MATLAB software. The result of the study concludes that ANN performed very well with all the input parameters which were used in reference evapotranspiration (ET) estimation by FAO-Penman method but the ANN models with fewer input variables also yielded the very finest estimation of reference evaoptranspiration (ETo).

Lang *et al.,* (2017) studied three radiation-based methods, Makkink (Mak), Abtew (Abt) and Priestly-Taylor (PT), and five temperature-based methods, Hargreaves-Samani (HS), Thornthwaite (Tho), Hamon (Ham), Linacre (Lin) and Blaney-Criddle (BC) were compared with PM at the yearly and seasonal scale, using long term (50 years) data from 90 meteorology stations in southeast China. The result showed that the performance of the methods in potential evapotranspiration (PET) estimation varied among regions; HS, PT, and Abt overestimated potential evapotranspiration (PET) while others underestimated it.

Djaman *et al.,* (2017) evaluated the FAO-56 Penman-Monteith (FAO-PM) reference evapotranspiration (ETo) equation and two variants equations for estimating daily reference evapotranspiration under limited data and four other reference evaoptranspiration (ETo) equations across Tanzania and southwestern Kenya. The result indicated the relevancy of the FAO-PM equation under missing solar radiation (Rs), relative humidity (RH), and wind speed (u_2) data with regression slopes varying from 0.68 to 0.89, from 0.79 to 1.00, and from 0.79 to 0.96, respectively, and root mean squared error (RMSE) lower than 0.63, 0.53, and 0.44 mm/day under the respective conditions. Under lack of relative humidity data, the simplified method provided the very finest reference evaoptranspiration (ETo) estimates. There were large disparities in reference evaoptranspiration (ETo) estimates with the FAO-PM equation when two or three weather variables were missing.

Phad *et al.,* (2020) a study has been carried out to estimate the mean daily reference evaoptranspiration (ETo) characteristics of Parbhani in Maharashtra. It is noticed that there is a gradual decrease in total seasonal reference evaoptranspiration (ETo) from summer season (February to May) to *kharif* (June to September) and *rabi*

(October to January) seasons. The average annual reference evaoptranspiration (ETo) was 2155.85mm.

Rodrigues and Braga, (2021) studied nine temperature-based methods that were evaluated for reference evaoptranspiration (ETo) estimation during the irrigation at fourteen locations dispensed through a hot-summer Mediterranean climate region of Alentejo, Southern Portugal. In addition to that, for each location, the Hargreaves-Samani radiation adjustment coefficient (k Rs) was calibrated and validated to evaluate the appropriateness of using the standard value, generating a locally adjusted Hargreaves-Samani (HS) equation. The exactness of each method was evaluated by statistically differentiating their results from those acquired by PM. Results indicated that the calibration of the k Rs, a locally adjusted HS method can be used to estimate daily reference evaoptranspiration (ETo) acceptably well.

2.2 To estimate crop water requirement (using FAO-56 KC values) for major *kharif* crops in Aurangabad district.

Abdelhadi *et al.,* (2000) studied the recommended method Penman-Monteith reference crop evapotranspiration (ETo) with acquired crop coefficients (Kc) from the phenomenological stages of Acala cotton is used to estimate the crop water requirements (CWRs) of Acala cotton in the Gezira area of Sudan. The published basal crop factors of Acala cotton were used with the Penman-Monteith equation as well to estimate reference evaoptranspiration (ETo). The result was compared with the current practices that use penman evaporation (Eo) from the free water surface and crop factor (K_f) derived from Farbrother, H.G., 1970. Penman-Monteith equation was found to be better than Farbrother method in terms of the total predicted crop water requirement (CWR), coefficient of determination (r^2), the slope of the linear regression line and the standard error of estimate with both basal and derived values. The trends of weather examined for the period 1966-1993 showed an increasing reference evaoptranspiration (ETo) during the rainy season due to the recent drought conditions that prevailed in the region

Bergamaschi *et al.,* (2001) revealed fieldwork was carried at the Agronomic Experimental Station of the Federal University of Rio Grande do Sul State, Brazil, from 1993/94 to 1996/97, to quantify the crop maximum evapotranspiration (ETm) and crop coefficient (Kc) using the reference evapotranspiration (ETo) estimated by

Penman method. ETmm was measured in a weighing lysimeter, on a planting density of 6.7 plants/m^2. An average ETm of around 650 mm for the entire crop cycle was obtained, ranging from 575 to 732 among the four seasons.

Allen *et al.,* (2005) indicated that the crop coefficient during the initial period (KCini) differs with wetting frequency, evaporative demand, and water holding capacity of the upper layer of soil. It is feasible to evolve a semi theoretical non-segregated function to prognosticate the average KC ini constituting the initial period of the growing season when the soil is mostly bare and that assimilates these three factors. The function is based on a two-stage evaporation function as used in Food and Agriculture Organization Irrigation and Drainage Paper No. 56 (FAO-56) dual crop coefficient method.

Hajare *et al.,* (2008) studied crop water requirements, the chief aim of the study is to standardize the fortnightly crop water requirement by establishing the notion of the development of iso-lines for crop water requirements for the Nagpur region. This concept is developed based on 10-15 years past data for the present requirement considering that there are little changes in the meteorological factors may affect very little on crop water requirement.This will give an idea about the place and the type of crop to be sown.

Ayars, (2008) studied a replicated field trial was conducted on the west side of the San Joaquin Valley to determine the crop coefficient and water requirements of irrigated garlic. The result indicated that the crop water use at 100% crop water requirement (ETc) for the interval 1 March to 21 May 2006 was 426 mm, including 108 mm of rainfall.

Chavan *et al.,* (2009) collected daily weather data of 16 years (from 1984 to 2001) for five locations i.e. Aurangabad, Beed, Nanded, Parbhani, and Osmanabad of Marathwada region was used to calculate reference crop evapotranspiration (ETo). The rainfall and reference evaoptranspiration (ETo) data were analyzed to ascertain their fit to various probability distributions. The goodness of fit was determined by chi-square tests. The study revealed that normal distribution gave the closest fit to the weekly rainfall and reference evaoptranspiration (ETo) data.

Pakhale *et al.,* (2010) analyzes the irrigation water requirement of the wheat crop for the *rabi* season from 1999 to 2003 in Karnal district of Haryana state, India. The area under wheat cultivation has been determined by using Landsat ETM + image by applying Artificial Neural Network (ANN) classification techniques. Potential evapotranspiration has been estimated using the Hargreaves model. Potential evapotranspiration and crop Coefficient for wheat were used for estimating crop water requirement. Effective rainfall was determined using India Meteorological Department gridded rainfall data. Effective rainfall and crop water requirement was used for determining irrigation water requirement. By assuming 35% losses, net irrigation water requirement was estimated. Multiplying the wheat cropped area and net irrigation water requirement the volume of water required for wheat during the *rabi* season was estimated.

Naheed and Rasul, (2010) studied the FAO-Modified Penman-Monteith method was used to estimate the water requirement of the cotton crop by using the climatic data (1917-2000) of mean daily temperature, relative humidity, relative sunshine hours, and wind speed of sixteen meteorological stations of Pakistan. Precipitation data was used to calculate the supplementary water requirement to differentiate the deficiency. After analysis it was observed that only the upper parts of Punjab cotton may be sown under rainfed conditions but it is very rare in this area. In central Punjab, cotton may not be sown under rainfed conditions without supplementary irrigation in May. In southern Punjab and Sindh regions, cotton requires supplementary irrigation throughout its life cycle. Therefore, proper irrigation is required to fulfill the water needs of the cotton crop throughout its life cycle for successful growth.

Gadge *et al.,* (2011) studied the crop water requirement for this the climatological data acquired from the meteorological observatory situated at All India Co-ordinated Research Project on Water Management, MPKV, Rahuri for the period from 1975 to 2005 was used for this study. The crops considered in this study were *kharif* soybean, *rabi* tomato, *rabi* onion, cotton *kharif* brinjal etc. Usually the microirrigation method are designed for 95% efficiency. The percent saving in microirrigation methods was observed to be 68% for *kharif* soybean, 61% for *rabi* tomato, 51% for , *rabi* onion, 65% for cotton, 70% for *kharif* brinjal etc.

Rao and Poonia, (2011) estimated crop water requirements from daily potential evapotranspiration at ambient and projected air temperature by 2020, 2050, 2080, and 2100 using modified Penman-Monteith equation and then by multiplying with crop coefficient. The increased crop water requirements in the region resulted in a reduction in crop growing period by 5 days for long duration crops, but the crop acreage where rainfall satisfies crop water requirements, reduced by 23.3% in pearl millet, 15.2% in cluster bean, 6.7% in green gram, 13% in moth bean.

Mane, (2013) evaluated the trend and variability of rainfall and temperature, to access their effect on crop water requirement and yield of major crops and to recommend a probable land use plan for intensifying agricultural production in the Central Vidarbha region of Maharashtra. Rainfall and temperature were analyzed using parametric and non-parametric tests such as regression analysis and Mann Kendall test, Modified Mann Kendall test, Sen's slope estimator. Auto-Regressive Integrated Moving Average (ARIMA) model was used for forecasting future rainfall and temperature trend. Calculation of crop water requirement was done by standard Penman-Monteith method using CROPWAT 8.0 model. Results revealed that average annual temperature and reference evapotranspiration increased marginally from 1969 to 2009, whereas total annual and monsoon rainfall decreased during this period.

Kumari *et al.,* (2013) investigated a remote sensing-based approach of large-area crop water requirement using vegetation indices as a proxy indicator of crop coefficient (Kc). The result revealed that after including Ws with fc for rice, the degree of fit (R^2) has been remarkably improved from 0.72 to 0.94 for Kc estimation of rice.

Singh and Bhandarkar, (2014) studied different methods of estimating evapotranspiration to prognosticated water requirement of soybean and wheat crops for nine chosen districts of Madhya Pradesh under vertisols. Four methods (Penman-Monteith, Hargreaves, SCS-Blaney-Criddle, and Thornthwaite) of reference evapotranspiration (ETo) estimation were differentiated for assessing their prognosticative capability for Bhopal and Indore districts using meteorological data. The study revealed that among the four methods, the Hargreaves method estimated reference evaoptranspiration (ETo) values with minimum deviation (4.24%) for Bhopal as compared to Penman-Monteith.

Mehta and Pandey, (2015) determine daily reference evapotranspiration for 16 stations of Gujrat having long period (10-20 years) weather data following PM approach. The crop coefficient (Kc) values for maize and wheat as given in FAO-56 were used in which Kc mid and Kc end were corrected for climatic conditions of stations. The corrected crop coefficient (Kc) values were used to calculate the daily crop water requirement (ETc) for wheat and rabi maize crops grown at discrete locations of Gujrat. The result observed that during the winter season (Nov.15 to Mar.13) the mean daily reference evaoptranspiration (ETo) differs from 4.2-7.6 mm/day. However, a large difference in reference evaoptranspiration (ETo) beyond the locations 2.9-9.8 mm/day was noticed. The lowest being at Khedbrahma and the highest being at Targadia.

Sachan *et al.,* (2016) studied for optimum crop planning and also for a finer understanding of rainfall behavior probability analysis of rainfall was conducted. Probability analysis of monthly rainfall data of 13 rain gauge stations of the left bank of the canal of upper Bhima basin viz., Urali, Loni Karbol, Kasurdi, Tajuproject, Yewat, Dahitane, Bhigwan, Madanwadi, Pondewadi, Kedgaon, Patas, Pimplegaon and Daund for the period from 1975 to 2002 was conducted. Reference evapotranspiration (ETo) has been calculated from the year 1993-2005 by the CROPWAT model. It was found that reference evapotranspiration (ETo) is maximum (7.72 mm/day) during April and low in December (3.10 mm/day) Effective rainfall of existing rain guage stations falling in different sub-basins, BM48, BM49,BM50, BM51 and BM68 have been estimated using the CROPWAT model. Ultimately net irrigation of crops *Kharif* cotton, summer cotton, sugarcane, and *rabi* sorghum have been established out for all the sub-basin. From this study, it has been concluded that the crop planning in the area, constituted by Pimplegaon and Urali stations should be done keeping in mind a maximum shortage of 187 mm and 113 mm of water respectively during July. Likewise in other stations, the maximum shortage of water was noticed during September which specifies that while a selection of crops for the areas represented by these stations the crops that need less water during September should be selected.

Guerra *et al.,* (2016) crop water requirement (ETc) is frequently calculated as a product of two factors, the reference evapotranspiration (ETo) and crop coefficient (Kc) values that transform reference evaoptranspiration (ETo) into crop water requirement (ETc). This paper reviews crop coefficient (Kc) values, measured in distinct parts of the world and different climates, to offer a practical tool for choosing the most suitable crop coefficients (Kc) values for water balance irrigation schedule which results in more efficient irrigation.

Zhou *et al.,* (2017) studied Statistical Downscaling Model (SDSM) to simulate future meteorological parameters in the Hetao irrigation district (HID) in the periods 2041-2070 and 2071-2099 and used the Penman-Monteith equation to calculate reference evaoptranspiration (ETo), which was further used to calculate crop water requirement (CWR). Based on the current growing area, the CIR would increase by 198×10^6 to 242×10^6 m^3 by the year 2041-2070, and by 342×10^6 to 456×10^6 m^3 by the years 2071-2099 respectively.

Ragab *et al.,* (2017) showed remarkable differences between actual evapotranspiration measured by eddy covariance and scintillometer when differentiated with the potential reference evapotranspiration (ETo), calculated from meteorological data using the Penman-Monteith equation and the crop potential evapotranspiration (ETc), which is based on the reference evaoptranspiration (ETo), and the crop coefficient (Kc). The crop water requirement (ETc) and reference evaoptranspiration (ETo) indicated higher values than those of ETa acquired by eddy covariance and scintillometer.

Ai *et al.,* (2018) calculated and analyzed Kc of a drip-irrigated and plastic mulched cotton field in Aksu Oasis of the arid Tarim river basin, China, and its relationship with numerous crop, soil, and management variables such as relative growth days(RGD), leaf area index(LAI), extractable soil water(ESW) and irrigation based on 2 years observations. The result indicated that the daily Kc varied within the range of 0.08-1.28, with an average of 0.54 for the entire cotton growing season in 2013 and 2014. Compared to non-mulched conditions already published, the Kc of mulched cotton for the entire growth season decreased by 16-39%.

Boonwichai *et al.,* (2018) accessed the influence of climate change on irrigation water requirement (IWR), rice yield, and crop water productivity (CWP) on Thai Jasmine rice in the Songkhram River Basin of Thailand. The analysis was conducted using a DSSAT crop simulation model with a group of five Regional Circulation Models (RCMs) under RCP 4.5 and RCP 8.5 scenarios. Results established that substitutes in the rainfall have a more significant effect on rice yield than temperature, perhaps increasing water stress in the future.

Memon and Jamsa, (2018) studied crop water requirement and irrigation scheduling of Soybean and Tomato crops using FAO-Cropwat 8.0 software. The study area considered here is Godhra Taluka of District-Panchmahals in Gujrat, India. Crop water requirement (CWR) for soybean is acquired 426.0 mm/dec and Irrigation requirement is 381.0 mm/dec with no yield depletion and crop water requirement (CWR) for tomato is 1180.7 mm/dec and irrigation requirement is 1135.7 mm/dec with 0.1 % yield depletion.

Dauda and Olayaki-Luqman, (2020) estimated crop water requirement by FAO Penman-Monteith model is a global standard model used with other five evapotranspiration models such as; Priestley-Taylor model, ASCE-Penman Monteith model, and Blaney-Criddle model to compute the mean monthly reference evapotranspiration (ETo) for the six agro-ecological zones of Nigeria. Statistical Regression analysis was performed to examine the relationship of the reference evapotranspiration (ETo) estimates from the five models with the estimates by the FAO-Penman-Monteith model. The result of the analysis manifest that the mean monthly average reference evaoptranspiration (ETo) estimates by the FAO-Penman-Monteith model, Priestley-Taylor model, Thornthwait model, Hargreaves model, ASCE-Penman Monteith model, and Blaney-Criddle model across the six weather stations are; 6.48, 7.66, 14.14, 11.16, 5.57, and 3.70 mm/day, respectively. The best predictor is the ASCE-Penman-Monteith model which correlated well with the FAO-Penman Monteith model while the Priestley-Taylor model is the second finest model.

Xu *et al.,* (2021) studied the feasibility of synergistically using phenological characteristics, Savitzky-Golay filter, harmonic analysis, and decision tree to extract crop planting structures (CPS) from MODIS EVI, and meanwhile analyzed the spatiotemporal variation in the estimated crop water requirement (CWR). The results indicate that the non-segregated method for CPS identification and extraction is realizable and reliable with a classification precision of over 80%. The mid-season stage needs the most water and cash crop requires more water than cereal crops. Summer accounts for 69% of the total growing season water use.

CHAPTER -III

MATERIALS AND METHODS

CHAPTER-III

MATERIALS AND METHODS

To meet the objective of research work entitled "**Estimation of Crop Water Requirement of Major *Kharif* Crops in Aurangabad District"** the analysis was carried out using the weather data of CRIDA (Central Research Institute for Dryland Agriculture) Hyderabad. Daily weather data of selected stations for 30 years period was used to calculate the daily mean of each parameter. These daily average data were used for calculating reference evapotranspiration (ETo). Incorporating the crop coefficient (Kc) value of selected crops, the water requirement was determined for different growth stages of the crop.

3.1 Meteorological Weather Data

The agrometeorological observatories are stations wherein the physical component of climate and biological, agricultural constituents, normally of phenological or phenometric nature or both relating to agriculture are noticed to explore the crop-environment relationship. The weather data are recorded twice a day (0700 and 1400 hours LMT) for all parameters excluding rainfall and evaporation that are recorded at 0830 hours IST. The following parameters were daily reported from CRIDA (Central Research Institute for Dryland Agriculture), Hyderabad:

Table 3.1: Data requirement for estimating reference evapotranspiration (ETo) by FAO Penman-Monteith method

Sr. No.	Climatic Parameters	Unit
1.	Maximum temperature	^oC
2.	Minimum temperature	^oC
3.	Maximum relative humidity	%
4.	Minimum relative humidity	%
5.	Bright sunshine hours	hours day^{-1}
6.	Wind speed	m s^{-1}
7.	Evaporation	mm day^{-1}
8.	Rainfall	mm day^{-1}

3.2 Location of Study Area

Geographically Aurangabad District is located between latitude 19^o 51´, longitude 75^o 24´ and altitude 586.60 m. The location of the selected station, where needed data were accessible in Table 3.1 (Fig. 3.1). Aurangabad is located in a hilly upland region on the Kaum river. The district is originally called Khadki and was founded by Malik Ambar in 1610.

3.3 Collection of meteorological data

The weather data was recorded and collected from CRIDA (Central Research Institute for Dryland Agriculture), Hyderabad. Daily weather data of chosen station for at least 30 years periods were used to work out the mean of each parameter of the station and those daily mean data of all parameters were used to calculate reference evapotranspiration (ETo) on daily, weekly, monthly, seasonal, and annual basis. The succeeding weather parameters were acquired for the present study:

1. Maximum temperature (Tmax),
2. Minimum temperature (Tmin),
3. Morning relative humidity (RHmax),
4. Afternoon relative humidity (RHmin),
5. Bright sunshine hours/ Actual duration of sunshine hours (n) and
6. Wind speed (u_z),
7. Evaporation (Epan)
8. Rainfall

Temperature

The (average) daily maximum and minimum air temperatures in degrees celcius (^{o}C) are required. Where only (average) mean daily temperatures are available, the calculations can still be executed but some underestimation of reference evapotranspiration (ETo) will probably occur due to the non-linearity of the saturation vapor pressure-temperature relationship. Using mean air temperature instead of maximum and minimum air temperatures yields a lower saturation vapor pressure e_s, and hence a lower vapor pressure difference (e_s-e_a), and a lower reference evapotranspiration estimate.

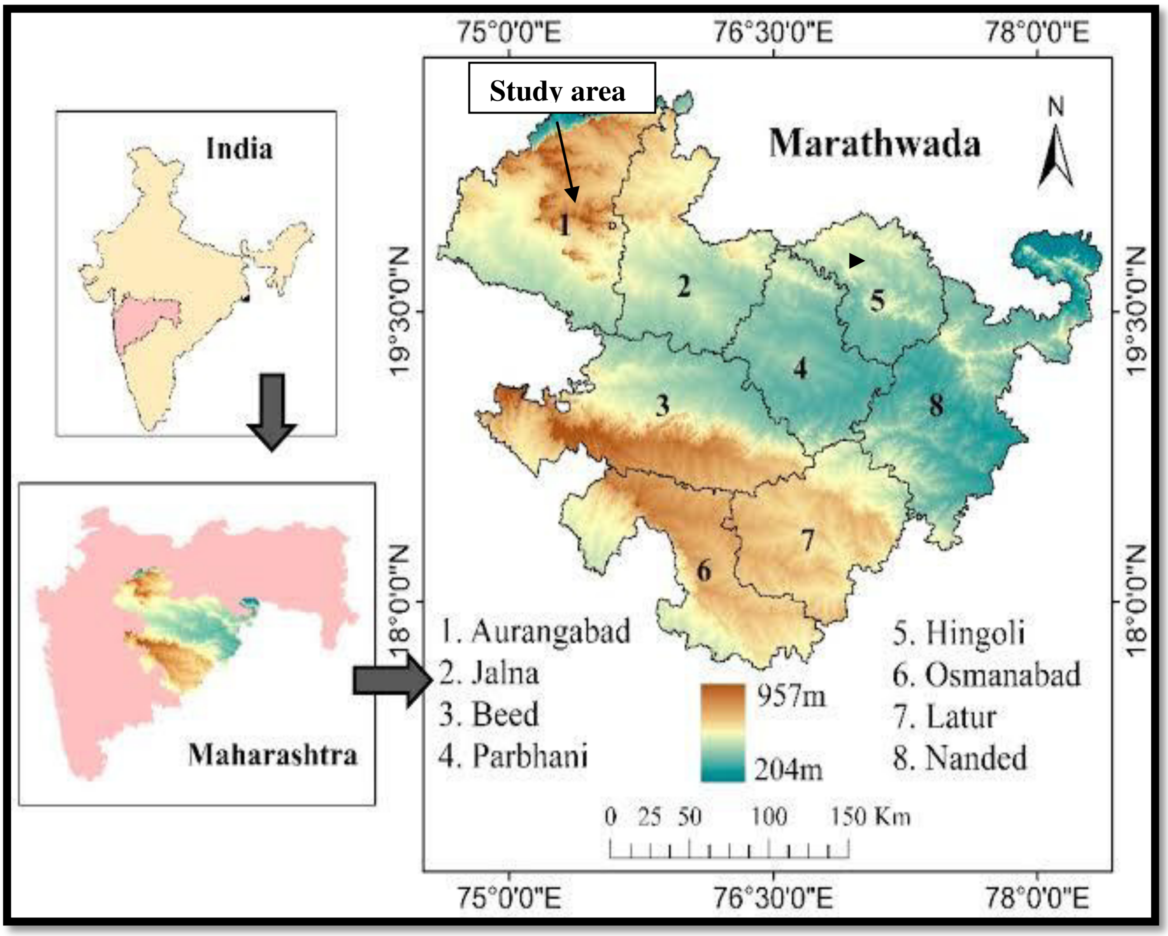

Fig. 3.1: Map of Marathwada region

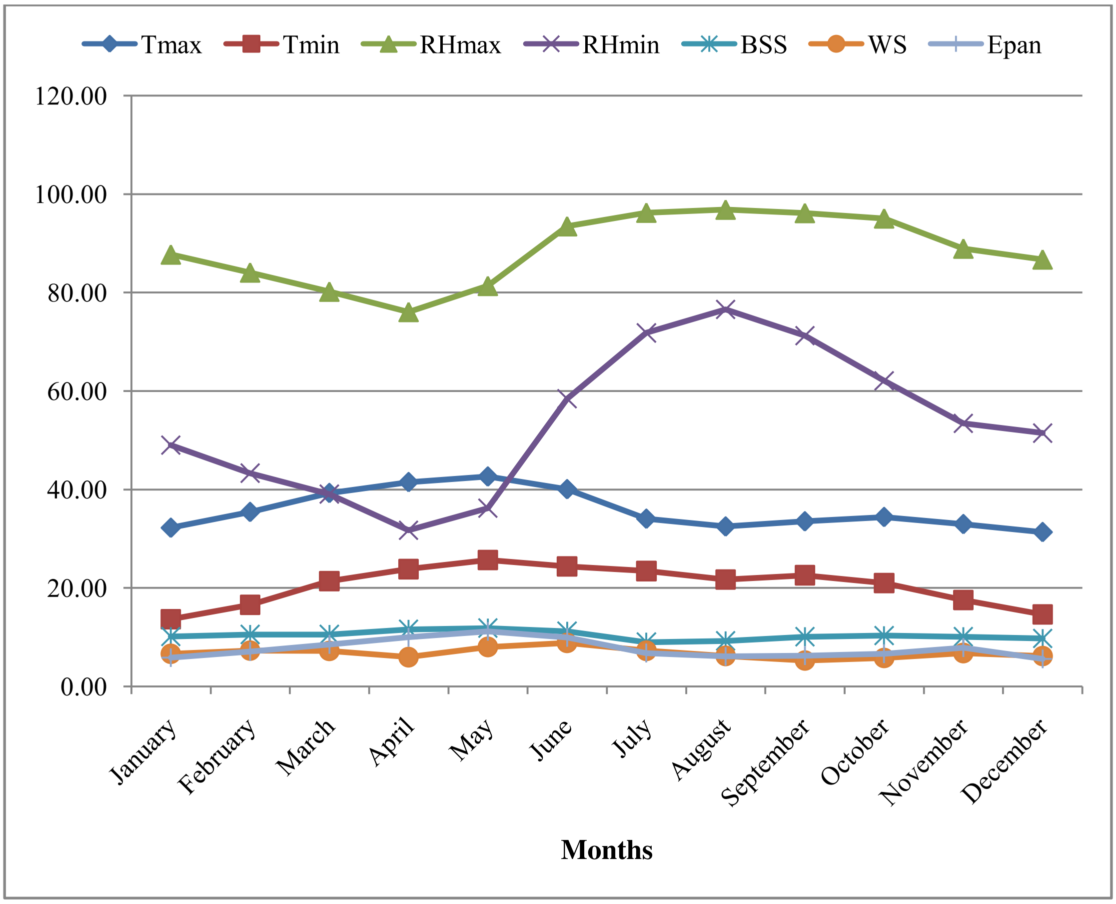

Fig. 3.2: Pattern of weather parameters (T_{max}, T_{min}, RH_{max}, RH_{min}, BSS, WS, and E_{pan}) for Aurangabad district.

Humidity

The (average) daily actual vapor pressure, e_a, in kilopascals (kPa) is required. The actual vapor pressure was not available, can be derived from maximum and minimum relative humidity (%), psychrometric data (dry and wet bulb temperatures in (^oC), or dewpoint temperature (^oC) according to the procedure outlined in the succeeding part.

Radiation

The (average) daily net radiation expressed in megajoules per square meter per day (MJ m^{-2} day^{-1}) is required. These data are not commonly available but can be derived from the (average) shortwave radiation measured with a pyranometer or from the average daily actual duration of bright sunshine (hours per day) measured with a (Campbell-Stokes) sunshine recorder. The calculation procedures are outlined in the succeeding part.

Wind speed

The (average) daily wind speed in meters per second (m s^{-1}) measured at 2 m above the ground level is required. It is important to verify the height at which wind speed is measured, as wind speeds measured at different heights above the soil surface differ. The calculation procedure to adjust wind speed to the standard height of 2 m is outlined in the succeeding part.

The pattern of all six parameters which has taken for computation of reference evapotranspiration (ETo) is shown in fig (3.2). The Tmax is the maximum temperature of the day (^oC), Tmin is a minimum temperature of the day ((^oC), RHmax is morning relative humidity (%), RHmin is afternoon relative humidity (%), n is a bright sunshine hour (hour) and u_2 is the wind speed at 2 m height (m $s^{-1)}$.

3.4 Selection of Crops

To workout crop water requirements the major *kharif* crops were chosen as stated below:

1) Cotton
2) Pigeon pea
3) Soybean
4) Maize
5) Pearl millet
6) Onion
7) Tomato
8) Brinjal

3.5 Methodology

The daily weather data (maximum temperature, minimum temperature, morning relative humidity, afternoon relative humidity, sunshine hour, and wind speed) of Aurangabad station were obtained from CRIDA (Central Research Institute for Dryland Agriculture), Hyderabad. Daily weather data (30 years) were used to work out the mean of each parameter of the station and those daily mean data of all parameters were used to calculate reference evapotranspiration (ETo) on a daily, weekly, monthly, seasonal, and annual basis by the worldwide accepted FAO-Penman-Monteith model. The daily crop water requirement (ETc) was determined for each crop. Thus daily crop water requirement (ETc) computed were summed for discrete growth stages of crop and total seasonal crop water was determined.

Each parameter needed for computing reference evapotranspiration (ETo) by FAO-Penman-Monteith method was determined step by step through a program developed in MS Excel from the mean of these six weather parameters (T_{max}, T_{min}, RH_{max}, RH_{min}, n, and u_2), altitude, and latitudes. Firstly, the wind speed was transformed for height (3m to 2m) and unit (km h^{-1} to m s^{-1}) afterwards, the pressure was altered for the altitude of the selected station. The several parameters *viz*., mean temperature (^oC), the slope of saturation vapor pressure (kPa $^oC^{-1}$), psychrometric constant (kPa $^oC^{-1}$), actual vapor pressure (kPa), saturation vapor pressure (kPa), vapor pressure deficit (kPa), extraterrestrial radiation (MJ m^{-2} day^{-1}), inverse relative

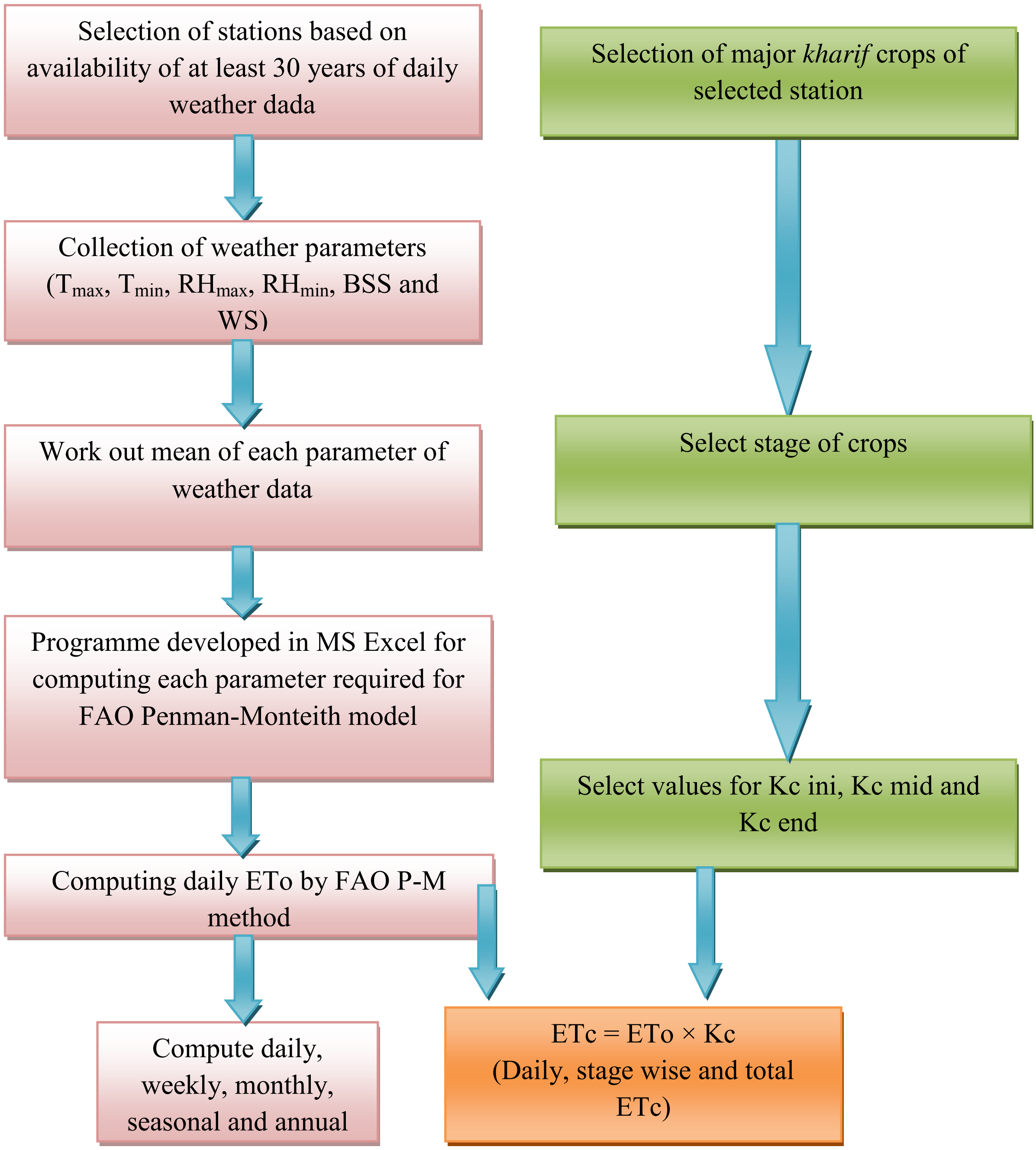

Fig. 3.3: Flow chart of the methodology adopted for the present study

distance Earth-Sun (radian), solar declination (radian) daylight hours (hrs), or shortwave radiation (MJ m^{-2} day^{-1}), net outgoing longwave radiation (MJ m^{-2} day^{-1}), net radiation (MJ m^{-2} day^{-1}), and finally reference evapotranspiration (ETo) was computed on daily basis and weekly, monthly, seasonal and annual basis were derived.

The methodology used for computation of reference evapotranspiration (ETo), Crop coefficient (Kc) values, crop water requirement (ETc) is presented as:

Estimation of Reference Evapotranspiration (ETo)

Climatological Methods

Based on the availability of climatic data various approaches have been suggested for estimation of reference evapotranspiration (ETo). There are: Temperature based (Hargreaves, 1985), Pan evaporation based (Christiansen, 1968; FAO-24 Open pan method, 1977), Radiation based (Makkink, 1957; Turc, 1961; Priestly-Taylor, 1972; FAO-24 Radiation method, 1975; Hargreaves-Samani,1985; Jensen and Haise method, 1963) and Energy balance based (Modified Penman, 1975; FAO Penman-Monteith, 1998).

3.5.1 Temperature Based Methods

In certain regions of the world, meteorological and climatological data may be quite limited. Hence the air temperature based models may be used in such cases to provide estimate of evapotranspiration (ET). Some of the more common temperature based models are described.

3.5.1.1 Hargreaves method: Hargreaves developed a method in 1985 to estimate evapotranspiration is an empirical relation based on air temperature and radiation. (Bsanagouda, 2016). The Hargreaves method is given by:

$$ETo = 0.0023\ R_a\ T_d^{0.5}\ (T_m + 17.8)$$

Where,

ETo is reference evapotranspiration (mm day^{-1})

R_a is extra-terrestrial radiation (mm day^{-1})

T_d is difference between maximum and minimum temperature (^oC)

T_m is mean temperature (°C)

3.5.2 Pan Evaporation Based Methods

3.5.2.1 Christiansen method: Christiansen (1968) proposed an empirical formula to estimate pan evaporation, from climatic data when reliable measured pan evaporation data are not available, for estimation of evapotranspiration, which is given as:

$$ETo = 0.755\ E_{pan} \times C_T \times C_W \times C_H \times C_S$$

Where,

ETo is reference evapotranspiration (mm day^{-1})
E_{pan} is pan evaporation (mm day^{-1})
C_T is temperature coefficient
C_W is wind velocity coefficient
C_H is humidity coefficient and
C_S is solar radiation coefficient.

3.5.2.2 FAO-24 Pan evaporation method: Doorenbos and Pruitt (1977) suggested an equation for estimating reference evapotranspiration from pan coefficient on daily time period as:

$$ETo = K_p \times E_{pan}$$

Where,

ETo is reference evapotranspiration (mm day^{-1})
K_p is pan coefficient (varies from 0.67 to 0.83)
E_{pan} is pan evaporation (mm day^{-1})

3.5.3 Radiation Based Methods

Evapotranspiration is correlated with solar radiation, and changes in climate and surface condition with season of year. There are certain methods based on solar radiation also involve a temperature, wind and other terms.

3.5.3.1 Makkink method: Makkink (1957) gave a simplified form of the Priestly-Taylor method was developed for grass lands in Holland. The difference is that the

Makkink method uses incoming short-wave radiation R_s and temperature, instead of using net radiation, R_n, The equation is given below as:

$$ETo = 0.65\frac{\Delta}{\Delta+\gamma}(R_s - G)$$

Where,

ETo is reference evapotranspiration (mm day^{-1})

Δ is saturation of vapor pressure (kPa $^oC^{-1}$)

Υ is psychrometric constant (kPa $^oC^{-1}$)

R_s is solar radiation (MJ m^{-2} day^{-1})

G is ground heat flux (MJ m^{-2} day^{-1})

3.5.3.2 Turc method: Turc (1961) used data from the humid climate of Western Europe and gave an equation also known as the Turc radiation equation. This method uses only two parameters, average daily radiation and temperature and expressed as:

$$ETo = 0.013\ (23.88 \times R_s + 50)\ T_a\ (T_a + 15)^{-1}$$

Where,

ETo is reference evapotranspiration (mm day^{-1})

T_a is mean air temperature (^oC)

R_s is solar radiation (MJ m^{-2} day^{-1})

3.5.3.3 Priestly-Taylor method: Priestly-Taylor (1972) gave an equation that only needs net radiation and temperature to calculate reference evapotranspiration (ETo). This method is basically the radiation driven part of the Penman equation and expresses as:

$$ETo = \frac{\propto\Delta}{\lambda\Delta+\gamma}(Rn - G)$$

Where,

ETo is reference evapotranspiration (mm day^{-1})

$\propto$ is the calibration factor, assuming values of 1.26

Δ is slope of saturation vapor pressure (kPa $^oC^{-1}$)

λ is latent heat of vaporization (J kg^{-1})

R_n is net solar radiation (MJ m^{-2} day^{-1})

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

ϒ is psychrometric constant (kPa $^{o}C^{-1}$)

3.5.3.4 FAO radiation method: Doorenbos and Pruitt (1975) described FAO radiation method as another approach to compute reference evapotranspiration (ETo) using weather variables like radiation and air temperature. The empirical relation of reference evapotranspiration (ETo) is written as:

$$ETo = c\ (0.408W \times R_s)$$

Where,

ETo represents reference evapotranspiration (mm day^{-})

c is constant that varies with mean relative humidity and daytime wind speed

W is another constant that varies with temperature and altitude

R_s is shortwave solar radiation (MJ m^{-2} day^{-1})

3.5.3.5 Hargreaves-Samani method: Hargreaves and Samani (1985) suggested an equation for estimating reference evapotranspiration (ETo) which is based on air temperature, difference between maximum and minimum air temperature, and extraterrestrial solar radiation. The equation is given as:

$$ETo = 0.0023\ (T_a + 17.8)\ R_a \sqrt{Td}$$

Where,

ETo is reference evapotranspiration (mm day^{-1})

T_d is difference between maximum and minimum daily air temperature (^{o}C)

T_a is mean temperature (^{o}C)

R_a is extraterrestrial solar radiation (MJ m^{-2} day^{-1})

3.5.3.6 Jensen and Haise method: It is a simple empirical method and requires mean temperature and solar radiation data. It is expressed as:

$$ETo = R_s\ (0.025\ T + 0.08)$$

It mostly underestimates reference evapotranspiration (ETo) under conditions of high movement of atmospheric air masses and gives reliable results for calm atmospheric conditions.

3.5.4 Energy balance based methods

The energy balance/ combination based method has served as a fundamental approach for reference evapotranspiration (ETo) estimation.

3.5.4.1 Modified Penman method: Doorenbos and Pruitt (1975) recommended a method after some modification like adding shortwave reflection coefficient 0.25 for grass and 0.05 for water, wind function in aerodynamic to the Penman method for estimation of reference evapotranspiration (ETo) from a grass surface of 8 to 15 cm height and not short of water supply instead of water surface. The modified FAO Penman method is given as:

$$\text{ETo} = \text{C}\left[\frac{\Delta}{\Delta+\gamma} \times Rn + \frac{\gamma}{\Delta+\gamma} \times (0.27)(1-0.1u2)(es-ea)\right]$$

Where,

ETo is reference evapotranspiration (mm day^{-1})
Δ is slope of saturation vapor pressure (kPa $^{o}C^{-1}$)
ϒ is psychrometric constant (kPa $^{o}C^{-1}$)
R_n is net radiation (mm day^{-1})
u_2 is wind speed at 2 m height
(e_s –e_a) is difference between saturated vapor pressure and actual vapor pressure of air (kPa)
C is correction/ calibration factor.

3.5.4.2 FAO Penman-Monteih method: Monteith (1965) brought another modification to Penman's method by introducing the term canopy resistance (rc). This modification led to a new method of reference evapotranspiration (ETo) estimation, called the Penman-Monteith equation.

In FAO Irrigation and Drainage Paper 56 (Allen *et al.,* 1998), Penman-Monteith equation has been recommended as a standard method of reference evapotranspiration (ETo) estimation worldwide by defining the reference surface as a hypothetical grass surface with an assumed height of 0.12 m, with surface resistance of 70 s m^{-1} and albedo of 0.23 closely resembling the evaporation from extensive green grass of uniform height, actively growing, and sufficiently watered. The FAO-56 paper provides guidelines for computation of reference evapotranspiration (ETo) which involves estimating meteorological data and a standardized calculation procedure depending upon available weather data. The FAO Penman-Monteith method is given as:

$$ETo = \frac{0.408\Delta\ (Rn - G) + \gamma \frac{900}{Ta + 273} u2\ (es - ea)}{\Delta + \gamma\ (1 + 0.34u2)}$$

Where,

ETo = reference evapotranspiraton (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}),

Ta = mean daily air temperature (^0C),

u_2 = wind speed at 2 m height (m s^{-1}),

es = saturation vapor pressure (kPa),

ea = actual vapor pressure (kPa),

es-ea =saturation vapor pressure deficit (kPa),

Δ = slope saturation vapor pressure curve (kPa $^0C^{-1}$),

ϒ = psychrometric constant ((kPa $^0C^{-1}$).

The mean of six weather parameters (Tmax, Tmin, RHmax, RHmin n, and u2), altitude, and latitudes was used to compute each parameter needed for the FAO Penman-Monteith model, through a program developed in MS Excel as follows:

Mean daily temperature (Ta)

The mean daily air temperature (Ta) is only employed in the FAO Penman-Monteith equation to calculate the slope of the saturation vapor pressure curves (Δ) and the impact of mean air density (Pa) as the effect of temperature variations on the value of the climatic parameter is small in these cases. For standardization, Ta for 24-hour periods is defined as the mean of the daily maximum (T_{max}) and minimum temperatures (T_{min}) rather than as the average of hourly temperature measurements.

The mean value of the daily maximum and minimum air temperatures in degrees Celcius (^{o} C) were used to calculate mean daily temperatures. Mean daily temperature calculated by:

$$T_a = \frac{T_{max} + T_{min}}{2}$$

Where,

Ta= mean daily air temperature (^{o}C) ,

Tmax= maximum daily air temperature (^{o}C),

Tmin= minimum daily air temperature (^{o}C).

Wind speed (u2)

The average daily wind speed in meters per second (ms^{-1}) measured at 2m above the ground level is needed, but the collected wind speed data was measured in km $hour^{-1}$ at 3 m height. The wind speed was adjusted for height and unit conversion according to the following equation:

$$u_2 = u_z \frac{4.87}{\text{In}\,(67.8h - 5.42)} \times \frac{5}{18}$$

Where,

u_2 = wind speed 2 m above the ground surface (m s^{-1}),

u_z = measured wind speed at z m above the ground surface (km s^{-1}),

h = height of the measurement above the ground surface (m).

Atmospheric pressure (P)

The atmospheric pressure, P is the pressure endeavor by the weight of the earth's atmosphere. An equation of the ideal gas law, assuming 20^{o}C for a standard atmosphere, was worked to calculate P in kPa at a specific elevation as:

$$P = 101.3\left[\frac{293 - 0.0065z}{293}\right]^{5.26}$$

Where,

P = atmospheric pressure (kPa),

Z = elevation above sea level (m).

Psychrometric constant (ϒ)

The values of ϒ as a purpose of altitude, calculated by using following parameters as:

$$\Upsilon = \frac{Cp \times P}{\epsilon\lambda} \text{-}0.665 \times 10^{-3}\,P$$

Where,

ϒ = psychrometric constant (kPa ^{o}C),

Cp = specific heat at constant pressure = 1.013×10^{-3} (MJ kg^{-1} ^{o}C),

ε = ratio molecular weight of water vapour/dry air = 0.62

λ = latent heat of vaporization = 2.45 MJ kg^{-1} (at 20^{0}C)

Slope of saturation vapor pressure (Δ)

For the calculation of evapotranspiration, the slope of the association between saturation vapor pressure and the temperature was needed. Using mean air temperature instead of daily minimum and maximum temperatures results in lower estimates for the mean saturation vapor pressure. The corresponding vapor pressure deficit (a parameter expressing the evaporating power of the atmosphere) will also be smaller and the result will be some underestimation of the reference crop evapotranspiration. Therefore, the mean saturation vapor pressure should be calculated as the mean between the saturation vapor pressure at both the daily maximum and minimum air temperature.

$$\Delta = \frac{4098\left[0.6108\,exp\left(\frac{1727 + T_a}{T_{a+237.3}}\right)\right]}{(T_{a+237.3})^2}$$

Where,

Δ = slope of saturation vapor pressure (kPa $^{o}C^{-1}$),

Ta = mean daily air temperature (^{o}C),

exp = 2.7183 (base of natural logarithm).

Saturation vapor pressure (e_s) derived from air temperature

Saturation vapor pressure associated to air temperature and calculated from the air temperature as:

$$e_{(Tmax)} = 0.6108\exp\left[\frac{17.27 \times T_{max}}{T_{max} + 237.3}\right]$$

$$e_{(Tmin)} = 0.6108\exp\left[\frac{17.27 \times T_{min}}{T_{min} + 237.3}\right]$$

Where,

T_{max} = maximum daily air temperature (^oC),

T_{min} = minimum daily air temperature (^oC).

The mean saturation vapor pressure for a day, week, or month was computed as the mean between the saturation vapor pressure at the mean daily maximum and minimum air temperature for that period:

$$e_s = \frac{e(T_{max}) + e(T_{min})}{2}$$

Where,

e_s = saturation vapor pressure derived from air temperature (kPa).

Actual vapor pressure (e_a) derived from relative humidity

$$e_a = \frac{e(T_{min})\left[\frac{RHmax}{100}\right] + e(T_{max})\left[\frac{RHmin}{100}\right]}{2}$$

Where,

e_a = actual vapor pressure (kPa),

e(Tmin) = saturation vapor pressure at daily minimum temperature (kPa),

e(Tmax) = saturation vapor pressure at daily maximum temperature (kPa),

RHmax = maximum relaive humidity (%),

RHmin = minimum relative humidity (%).

Vapor pressure deficit ($e_s - e_a$)

The vapor pressure deficit is the differentiation between the saturation (e_s) and actual vapor pressure (e_a) for a specified period.

Extraterrestrial radiation (R_a)

The solar radiation collected at the top of the earth's atmosphere on a horizontal surface is called extraterrestrial solar radiation, (R_a). The radiation striking a surface perpendicular to the sun's rays at the top of the earth's atmosphere, called the solar constant and its value is 0.082 MJm^{-2} min^{-1} or 1.94 cal cm^{-2} or 1370 W m^{-2}. The extraterrestrial radiation (R_a), for each day of the year and distinct latitudes, was estimated from the solar constant, the solar declination, and the time of the year by :

$$R_a = \frac{24(60)}{\pi} G_{sc} \times d_r \left[\omega_s \sin(\varphi) \sin(\delta) + \cos(\varphi)\cos(\delta)\sin(\omega_s)\right]$$

Where,

Ra = extraterrestrial radiation (MJ m^{-2} day^{-1}),
G_{sc} = solar constant (0.0820 MJ m^{-2} min^{-1}),
d_r = inverse relative Earth-Sun distance (radian),
ω_s = sunset hour angle (radian),
φ = latitude (radian),
δ = solar declination (radian).

Conversion of latitude in degrees to radians

The latitude (φ) expressed in radians is positive for the northern hemisphere and negative for the southern hemisphere. The transforming from decimal degrees to radians was done as :

$$\varphi \text{ (radian)} = \frac{\pi}{180} \varphi \text{ (decimal degree)}$$

Inverse relative earth-sun distance (d_r)

$$d_r = 1 + 0.033 \cos\left[\frac{2\pi}{365} J\right]$$

Solar declination (σ)

$$ȝ = 0.409 \sin\left[\frac{2\pi}{365} J - 1.39\right]$$

Where,

J = Julian day/ Number of the day in the year between 1 (1^{st} January) and 365 or 366 (31^{st} December).

Note: 1. To change the date (MM/DD/YYYY) to Julian in Microsoft Excel the following command was used:

= (MM/DD/YYYY)- DATE(YEAR((MM/DD/YYYY)), 1", 1")+1)

Note 2. When normalized the weather data according to Julian day, one more command was used since there was a total of 366 normal weather data acquired. The command used after 28^{th} February i.e; from 1^{st} March excluding in the leap year as:

= ((MM/DD/YYYY)-DATE (YEAR ((MM/DD/YYYY)),1", 1")+**2**)

Sunset hour angle (ω_s)

$$\omega_s = \text{across} \; [-\tan(\varphi) \tan(ȝ)]$$

Where,

φ = latitude (radian),

ȝ = solar declination (radian).

Daylight hour (N)

The daylight hours/maximum possible duration of sunshine N is stated by :

$$N = \frac{24}{\pi}\omega_s$$

Where,

ω_s = sunset hour angle (radian),

N = maximum possible duration of sunshine or daylight hours (hour).

Solar radiation/Short wave radiation (R_s)

The solar radiation R_s calculated with the Angstrm formula which associates solar radiation to extraterrestrial radiation and relative sunshine duration as:

$$R_s = \left(a_s + b_s \frac{n}{N}\right) R_a$$

Where,

R_s = solar or shortwave radiation (MJ m^{-2} $day^{-1),}$
n = actual duration of sunshine (hours),
N = maximum possible duration of sunshine or daylight hours (hour),
n/N = relative sunshine duration,
R_a = extraterrestrial radiation (MJ m^{-2} day^{-1}),
a_s = regression constant, expressing the fraction of extraterrestrial radiation reaching the earth on overcast days (n=0),
$a_s + b_s$ = fraction of extraterrestrial radiation reaching the earth on clear days (n=N). The values of a_s = 0.25 and b_s = 0.50 were taken in present computation.

Clear-sky solar radiation (R_{so})

The calculation of the clear-sky radiation R_{so}, when n=N, was needed for computing net longwave radiation.

$$R_{so} = (a_s + b_s)\ R_a$$

Where,

R_{so} = clear sky solar radiation (MJ m^{-2} day^{-1}),
$a_s + b_s$ = fraction of extraterrestrial radiation reaching earth on clear sky days (n=N).

Net solar or net shortwave radiation (R_{ns})

The net shortwave radiation derived from the balance between incoming and reflected solar radiation was computed as:

$$R_{ns} = (1-\propto)\ Rs$$

Where,

R_{ns} = net solar or shortwave radiation (MJ $m^{-2}day^{-1}$),

$\propto$ = albedo or canopy reflection coefficient (0.23 for the hypothetical grass reference crop), (dimensionless),

R_s = incoming solar radiation (MJ $m^{-2}day^{-1}$).

Net longwave radiation (R_{nl})

The rate of longwave energy release is proportional to the absolute temperature of the surface elevated to the fourth power (Stefan-Boltzmann law). The water vapor, clouds, carbon dioxide, and dust are absorbers and emitters of longwave radiation. Since humidity and cloudiness play a key role, the Stefan-Boltzmann law was rectified by these two factors when estimating the net outgoing flux of longwave radiation as :

$$R_{nl} = \sigma\left[\frac{(T_{\max .K})+(T_{min .K})}{2}\right](0.34\text{-}0.14e_{a)}\left(1.35\frac{R_s}{R_{so}} - 0.35\right)$$

Where,

R_{nl} = net outgoing long wave radiation (MJ $m^{-2}day^{-1}$)

σ = Stefan-Boltzmann constant (4.903×10^{-9}) (MJ $m^{-2}day^{-1}$)

Tmax,K = maximum absolute temperature during 24 hour period

$$K = {}^{o}C + 237.16$$

Tmin,K = minimum absolute temperature during 24 hour period

$$K = {}^{o}C + 237.16$$

e_a = actual vapor pressre (kPa)

R_s/R_{so} = relative shortwave radiation

R_s = solar radiation (MJ $m^{-2}day^{-1}$)

Rso = clear sky solar radiation (MJ $m^{-2}day^{-1}$)

An average of the maximum air temperature to the fourth power and the minimum air temperature to the fourth power is commonly used in the Stefan-Boltzmann equation for 24- hour time steps. The term $(0.34 – 0.14\sqrt{ea})$ expresses the correction for air humidity and will be smaller if the humidity increases. The effect of the cloudiness was expressed by (1.35 R_s/R_{so}-0.35) in the above formulation. The term becomes smaller if the cloudiness increases and hence R_s decreases. The smaller the correction terms, the smaller the net outgoing flux of longwave radiation.

Net radiation (Rn)

The net radiation (Rn) is the difference between the incoming net shortwave radiation (Rns) and the outgoing net longwave radiation (R_{nl}) and it was calculated as:

$$R_n = R_{ns} - R_{nl}$$

Where,

Rn = net radiation (MJ m^{-2} day^{-1})

Soil heat flux density (G)

For daily ten days period calculation, G is taken as zero (0) since soil heat flux is small differentiated to R_n. As the magnitude of soil heat flux beneath the grass reference surface is relatively small, it may be disregarded.

$$G_{day} = 0$$

3.5.5 Statistical analysis:

Root Mean Square Error (RMSE):

$$\text{RMSE} = \{\frac{1}{N}\sum (\text{Estimated ETo} – \text{Calculated ETo})^{2}\}^{1/2}$$

3.5.2 Determination of crop coefficient (Kc)

Firstly choose the major *kharif* crops, then choose the stages of the crop (initial stage, crop development stage, mid-season stage, and late-season stage), then select the Kc values (Kc_{ini}, Kc_{mid}, Kc_{end}) from FAO-56.

The crop coefficient (Kc) values constituents the consolidated effects of changes in leaf area, plant height, crop characteristics, irrigation method, rate of crop development, crop planting date, degree of canopy cover, canopy resistance, soil, and climate conditions, and management practices. Each crop will have a set of particular crop coefficients and will predict different growth stages. An example of a Kc curve as a function of days or weeks after planting for a plant for initial, developmental, mid-season, and end season stages is given in Fig 3.4.

In general, crop growth stages can be cleaved into four main growth stages: Initial, crop development, mid-season, and late season. The duration of each of these stages depends on the climate, latitude, elevation, planting date, crop type, and cultural practices. Local field monitoring is best for deciding the growth stage of the crop and adjusting the empirical Kc values appropriately. Early in the season when the plant is small, the water-use rate and kc value are too small (Kc initial stage) and crop ET rate increases as the plant develops. For agronomic plants, the crop ET rate is at the maximum level when the plant is fully developed (Kc mid-season). The ET rate reduces again when the plant concludes development and reaches physiological maturity toward the end of the season (Kc end season).

Table 3.2: FAO crop coefficients (Kc) for non stressed, well managed crops in semi-arid climates (RHmin= 45%, u_2 = 2 m s^{-1}) (Source : FAO-56 Richard G A *et.al.* 1990)

Crops	Total	Stages (in duration)				Kc values for different stages		
		Initial Stage (I)	Crop Dev. (II)	Mid Season (III)	Late Season (IV)	Initial Stage (I)	Mid stage (II)	End stage (III)
Cotton	195	30	50	60	55	0.35	1.15	0.50
Pigeon pea	200	55	45	60	40	0.50	1.15	1.10
Soybean	150	20	25	75	30	0.40	1.15	0.50
Maize	125	20	35	40	30	0.30	1.20	0.35
Pearl millet	95	15	28	35	17	0.30	1.00	0.30
Onion	150	15	25	70	40	1.05	0.75	0.40
Tomato	155	35	40	50	30	0.6	1.15	0.70
Brinjal	140	30	45	40	25	0.60	1.05	0.90

The growth period is therefore divided into four stages (Allen *et al.,* 1998)

1. Initial stage: Germination period and early growth of the crop when the soil cover by the crop is less than 10%.

2. Crop developmental stage: The end of the initial stage till the soil cover by the crop is about 70 to 80%.

3. Mid-season stage: From the end of the crop development stage to the start of maturity, which is indicated by discoloring of leaves or falling off the leaves. For most crops, this may extend well past the following stage.

4. Late-season stage: From the end of mid-season stage to the full maturity or harvesting.

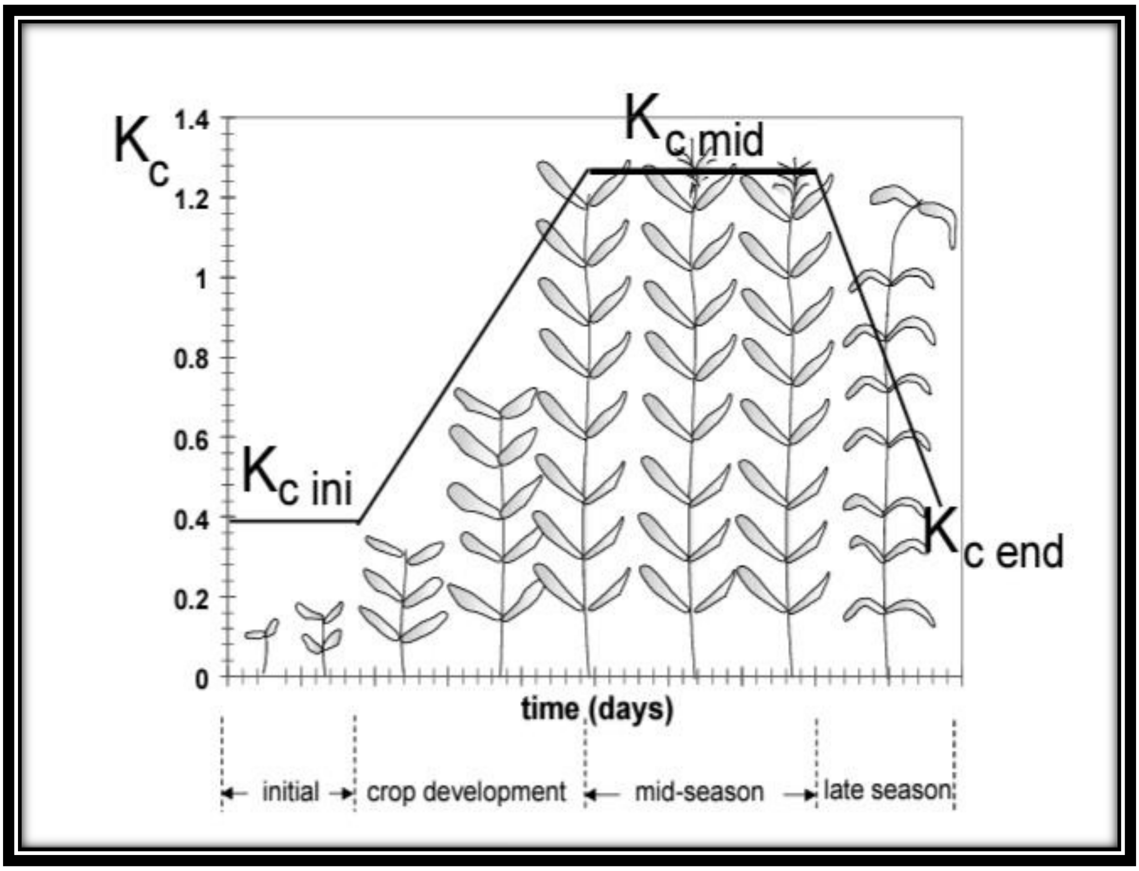

Fig.3.4: The variation in Kc for crops as influenced by weather factors and crop development (Source: FAO-56 Allen *et al.,* 1998).

3.5.3 Crop Water Requirement (ETc)

The amount of water needed to compensate for the evapotranspiration loss from the cropped field is defined as a crop water requirement. Crop water requirement encloses the total amount of water used in evapotranspiration. Out of the total evapotranspiration, evaporation accounts for about 10 percent and plant transpiration for the abiding 90 percent. The crop evapotranspiration varies distinctly from the reference evapotranspiration (ETo) as the ground cover, canopy properties and aerodynamic resistance of the crop are different from grass. The difference in evaporation and transpiration between both surfaces was incorporated into a single coefficient Kc. In the current study, the crop coefficient approach was used for the computation of crop water requirements (Doorenbos and Pruitt, 1975).

$$ETc = Kc \times ETo$$

Where,

ETc = crop evapotranspiration/Crop water requirement (mm day^{-1}),

ETo = reference evapotranspiration (mm day^{-1}),

Kc = crop coefficient.

CHAPTER -IV

RESULTS AND DISCUSSION

CHAPTER-IV

RESULTS AND DISCUSSION

The present study entitled **"Estimation of crop water requirement of major *kharif* crops in Aurangabad District"** was accomplished to evaluate the usefulness of agrometeorological observatory data in acquiring useful parameters for agriculture purpose. The data analysis and results acquired from reference evapotranspiration (ETo), crop coefficient (Kc) values and crop water requirement (ETc) to meet the objectives of research are introduced in the succeeding sections under discrete subheads.

4.1 Reference Evapotranspiration (ETo) by different methods at Aurangabad district

The daily climatic data derived from 30 years were used to calculate reference evapotranspiration (ETo) on daily, weekly as per Standard Meteorological Weeks (SMW), monthly, seasonal (summer*, kharif, and rabi* season), and annual reference evapotranspiration (ETo). In the following section variations of reference evapotranspiration (ETo) are described.

4.1.1 Mean daily variation in reference evapotranspiration (ETo)

The daily variation of reference evapotranspiration (ETo) for Aurangabad district was observed that there is a large fluctuation in daily reference evapotranspiration (ETo). Although the daily reference evapotranspiration (ETo) increases continuously from January and reaches the maximum during May, there are quite differences among the different methods. The reference evapotranspiration (ETo) reaches its peak value from 16th April to 1st June over all reference evapotranspiration (ETo) estimated methods. During June reference evapotranspiration (ETo) decreases sharply and remains low during July and August and with a slight increase during the month of September, October, November then it decreases afterwards.

Among the different methods, Pan evaporation based methods, Radiation based methods, Temperature based methods, and energy balance based methods the estimated reference evapotranspiration (ETo) ranged from 0.12 to 19.88 mm day^{-1}.

The mean highest daily reference evapotranspiration (ETo) is 12.31 mm day^{-1} (Hargreaves-Samani method) and the mean lowest daily reference evapotranspiration (ETo) is 3.39 mm day^{-1} (Modified Penman method) is presented in Fig. 4.1 and Table 4.1. Makkink and Hargreaves-Samani method overestimated the FAO-Penman-Monteith method and Priestly-Taylor, FAO-24 Radiation, Turc, Jensen-Haise, Modified-Penman method, Christiansen, Pan evaporation, and Hargreaves method underestimated FAO-Penman-Monteith method. The similar result was found by Mehta and Pandey, (2015) at Gujrat.

4.1.2 Mean weekly variation in reference evapotranspiration (ETo)

The weekly mean variation of all different reference evapotranspiration (ETo) estimated methods was observed that there is a large fluctuation in reference evapotranspiration (ETo) for different methods. The weekly reference evapotranspiration (ETo) increases continuously from 1^{st} SMW and reaches a maximum during 17^{th}- 20^{th} SMW at all the estimated reference evapotranspiration (ETo) methods and it decreases afterwards it is presented in Fig 4.2.

Among the different methods, pan evaporation based methods, radiation-based methods, temperature-based methods, energy balance based methods are estimated reference evapotranspiration (ETo) ranged from 0.94 to 18.66 mm day^{-1}. The mean highest weekly reference evapotranspiration (ETo) is 12.35 mm day^{-1} (Hargreaves-Samani method) and the mean lowest weekly reference evapotranspiration (ETo) is 3.39 mm day^{-1} (Modified Penman method) it is presented in Fig 4.2. Makkink, Priestly-Taylor, and Hargreaves-Samani method overestimated the FAO-Penman-Monteith and Turc, Modified Penman, Christiansen, Jensen-Haise, FAO-24 Radiation, pan evaporation, and Hargreaves method underestimated FAO-Penman-Monteith method . The similar result was established by Phad *et al.,* (2020) in Parbhani, Maharashtra.

Table 4.1: Ranges of daily reference evapotranspiration (ETo) (mm day^{-1}) by different methods

ETo Methods	Maximum	Minimum	Mean
Penman-Monteith	13.64	0.46	4.44
Makkink	14.30	0.22	7.91
Turc	6.19	0.48	3.55
Priestly-Taylor	12.70	0.20	7.30
Hargreaves-Samani	19.88	4.82	12.31
Hargreaves	8.12	1.97	5.02
Jensen-Haise	10.03	0.12	4.81
FAO-24 radiation	9.87	0.18	5.58
Modified Penman	6.70	0.89	3.39
Christiansen	10.03	1.14	4.06
Open pan evaporation	9.92	0.99	3.97

Table 4.2: Ranges of weekly reference evapotranspiration ETo (mm $week^{-1}$) by different methods

ETo Methods	Maximum	Minimum	Mean
Penman-Monteith	9.82	0.94	4.43
Makkink	13.28	2.31	7.92
Turc	5.77	1.32	3.56
Priestly-Taylor	11.82	2.15	7.30
Hargreaves-Samani	18.66	8.09	12.35
Hargreaves	7.62	3.30	5.04
Jensen-Haise	8.98	1.43	4.80
FAO-24 radiation	9.11	1.79	5.55
Modified penman	5.77	1.68	3.39
Christiansen	7.00	2.20	4.08
Open pan evaporation	7.39	2.02	4.01

4.1.3 Mean monthly variation in reference evapotranspiration (ETo)

The monthly total and mean variation of reference evapotranspiration (ETo) among all reference evapotranspiration (ETo) estimated methods are presented in Fig. 4.3, and in Table 4.3, 4.4. The monthly reference evapotranspiration (ETo) increases continuously from January to May and reaches its peak in the month of May. During June, July, and August reference evapotranspiration (ETo) decreases continuously. The reference evapotranspiration (ETo) slightly increases in the month of September and October, it decreases afterwards.

Among the different methods, pan evaporation based methods, radiation-based methods, temperature-based methods, energy balance based methods the estimated reference evapotranspiration (ETo) ranged from total monthly maximum reference evapotranspiration (ETo) is 420.82 mm with mean 13.80 mm month^{-1} (Hargreaves-Samani method) and total mean minimum reference evapotranspiration (ETo) is 122.29 mm with 4.30 mm month^{-1} (Modified Penman method). Makkink, Priestly-Taylor, Hargreaves-Samani, Hargreaves, Jensen and Haise method, FAO-24 Radiation method, Christiansen, and Open pan evaporation method overestimated the FAO-Penman-Monteith method and Turc, and Modified Penman method underestimated FAO-Penman-Monteith method.

This might be due to high temperature and wind speed during May but the decreasing values of reference evapotranspiration (ETo) in June, July and August may be attributed to intermittent rains and cloudy condition accompanied by lower wind speed.The similar result was established by Phad *et al.,* (2020) in Parbhani, Maharashtra.

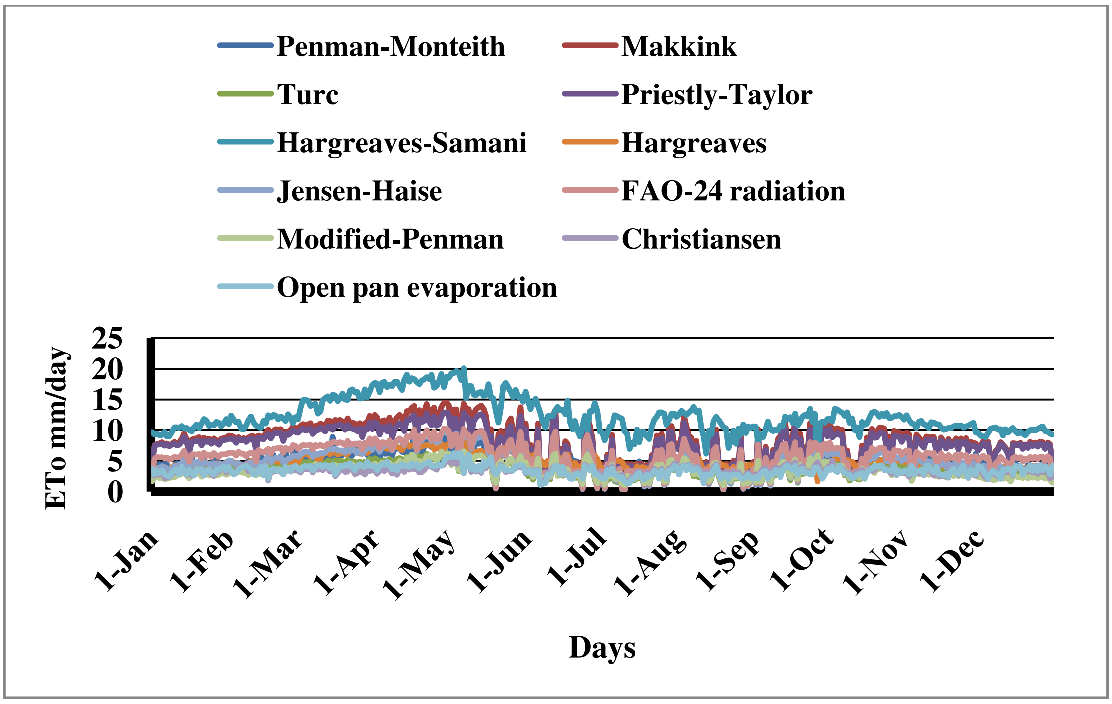

Fig. 4.1: Mean daily variation in reference evapotranspiration (ETo) (mm day^{-1}) by different methods at Aurangabad

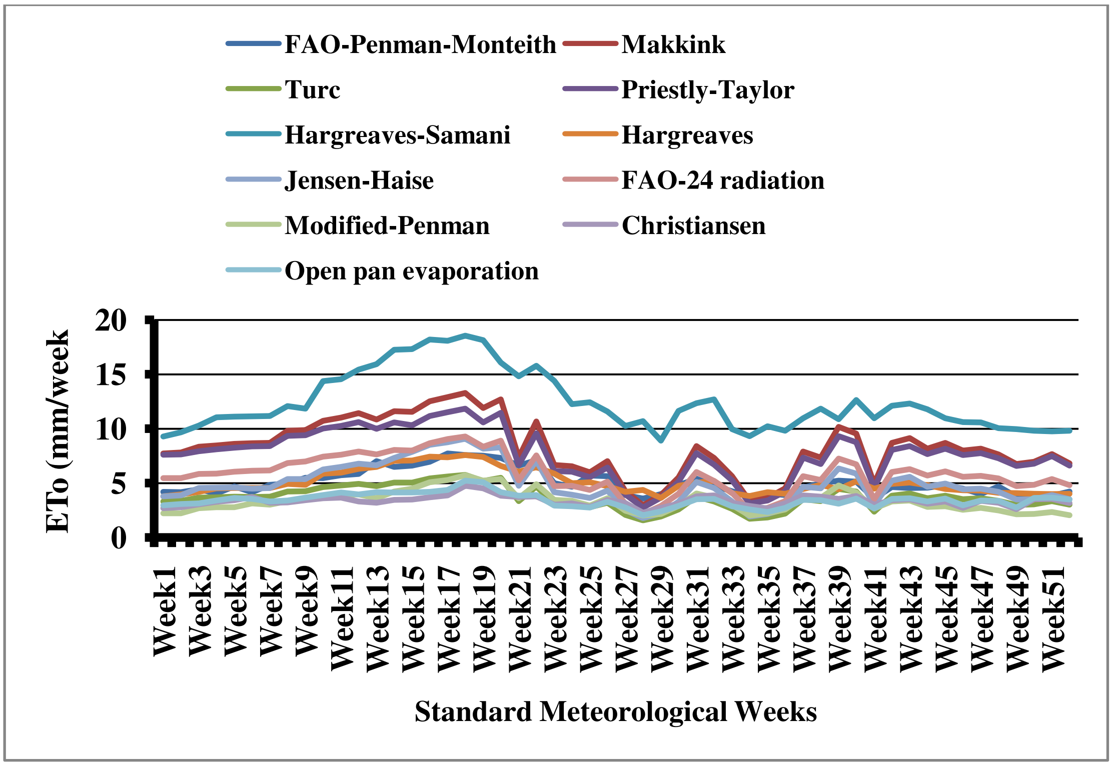

Fig. 4.2: Mean weekly variation in reference evapotranspiration (ETo) (mm week^{-1}) by different methods at Aurangabad

Table 4.3: Total monthly reference evapotranspiration (ETo) (mm month^{-1}) by different methods at Aurangabad district

Month	Penman-Monteith	Makkink	Turc	Priestly-Taylor	Hargreaves-Samani	Hargreaves	Jensen and Haise	FAO-24 Radiation	Modified Penman	Christiansen	Open Pan Evaporation
JAN	141.28	245.39	108.75	234.83	323.79	132.16	134.78	172.66	87.31	132.07	124.53
FEB	155.32	335.41	121.41	257.54	365.19	149.06	165.43	193.50	107.30	138.18	135.24
MAR	193.11	320.37	141.06	293.21	507.08	206.97	201.17	223.39	128.91	186.16	205.38
APR	213.97	353.20	154.91	315.49	571.18	233.14	239.04	243.15	155.76	210.83	247.66
MAY	271.50	407.21	176.94	364.19	595.34	243.00	274.20	289.61	189.56	238.50	299.46
JUN	211.91	311.49	137.81	280.19	484.67	197.83	205.50	225.46	153.37	172.81	184.66
JUL	172.19	201.18	93.46	183.19	394.56	161.05	127.10	148.49	102.64	141.19	125.65
AUG	143.58	198.53	92.13	182.11	368.91	150.57	122.20	146.05	105.18	129.04	107.87
SEP	139.93	229.26	104.07	209.82	368.30	150.33	289.01	166.73	117.85	179.38	111.02
OCT	165.98	280.77	125.14	256.93	387.43	158.14	174.27	195.44	115.31	139.91	134.40
NOV	143.85	252.68	111.53	239.05	324.15	132.31	306.08	228.48	107.01	241.46	135.45
DEC	126.69	221.67	98.81	212.20	302.77	123.58	118.54	158.94	76.13	114.44	107.17
Max	271.50	407.21	176.94	364.19	595.34	243.00	306.08	289.61	189.56	241.46	299.46
Min	126.69	198.53	92.13	182.11	302.77	123.58	118.54	146.05	76.13	114.44	107.17
Mean	162.81	283.06	123.93	255.36	420.82	171.76	198.71	201.97	122.29	169.99	166.08
Total	2442.09	4245.96	1859.02	3830.41	6312.30	2576.46	2980.66	3029.53	1834.31	2549.86	2491.20

Table 4.4: Mean Monthly reference evapotranspiration (ETo) (mm month^{-1}) by different methods at Aurangabad district

Month	Penman-Monteith	Makkink	Turc	Priestly-Taylor	Hargreaves-Samani	Hargreaves	Jensen and Haise	FAO-24 Radiation	Modified Penman	Christiansen	Open Pan Evaporation
JAN	4.56	3.51	7.58	7.58	10.44	4.26	4.35	5.57	2.82	4.26	4.02
FEB	5.55	4.22	8.96	8.96	12.92	5.27	5.70	6.67	3.70	4.94	4.83
MAR	6.23	4.61	9.63	9.63	16.51	6.74	6.55	7.29	4.16	6.09	6.75
APR	7.13	5.16	10.52	10.52	19.08	7.79	7.83	8.81	5.11	6.49	8.29
MAY	8.76	5.70	11.75	11.75	19.11	7.80	8.92	9.34	6.11	7.89	9.67
JUN	7.06	4.59	9.34	9.34	16.13	6.59	6.85	7.52	5.11	5.58	5.90
JUL	5.55	2.99	5.85	5.85	12.89	6.45	4.06	4.74	3.31	4.55	4.05
AUG	4.63	2.97	5.87	5.87	11.90	6.51	6.76	7.30	4.25	5.58	5.89
SEP	4.66	3.47	6.99	6.99	12.28	6.54	4.75	5.56	3.93	4.55	3.70
OCT	5.35	4.04	8.29	8.29	12.50	6.60	6.77	7.29	4.27	5.72	6.03
NOV	4.79	3.72	7.97	7.97	10.81	6.62	6.78	7.28	4.25	5.72	6.07
DEC	4.09	3.19	6.85	6.85	9.77	6.66	6.83	7.31	4.28	5.78	6.13
Max	8.76	5.70	11.75	11.75	19.11	7.80	8.92	9.34	6.11	7.89	9.67
Min	4.09	2.97	5.85	5.85	9.77	4.26	4.06	4.74	2.82	4.26	3.70
Mean	5.8	4.06	8.37	8.37	13.80	6.42	6.37	7.05	4.30	5.66	6.05
Total	87.02	60.90	125.56	125.56	207.00	96.31	95.51	105.81	64.54	84.97	90.75

4.1.4 Variation of reference evapotranspiration ETo on Seasonal Basis

Total seasonal reference evapotranspiration (ETo) estimated by different methods are presented in Fig 4.4 and Table 4.5.

4.1.4.1 Summer season

During the summer season, the maximum total seasonal reference evapotranspiration (ETo) estimated by the Hargreaves-Samani method (1858.73 mm) and minimum by the Modified Penman method (522.44 mm) with a mean of 937.89 mm. Makkink, Priestly-Taylor, Hargreaves-Samani, Hargreaves, Jensen and Haise, FAO-24 Radiation method overestimated the FAO-Penman-Monteith method and Turc, Modified Penman, Christiansen, and Open pan evaporation underestimated FAO-Penman-Monteith method.

4.1.4.*2 Kharif* season

During the *kharif* season, the maximum total seasonal reference evapotranspiration (ETo) was predicted by the Hargreaves-Samani method (1407.99 mm) and minimum by the Turc method (331.81 mm) with a mean of of 627.54 mm. Makkink, Priestly-Taylor, Hargreaves-Samani, Hargreaves method overestimated the FAO-Penman-Monteith method and Turc, Jensen and Haise, FAO-24 Radiation, Modified-Penman, Christiansen, Open pan evaporation method underestimated FAO-Penman-Monteith method.

4.1.4.3 *Rabi* season

During the *rabi* season, the maximum total seasonal reference evapotranspiration (ETo) was predicted by the Hargreaves-Samani method (1218.03 mm) and minimum by the Modified Penman method (340.70 mm) with a mean of 718.73 mm. Priestly-Taylor, Hargreaves-Samani, Hargreaves, Jensen and Haise, FAO-24 Radiation method overestimated the FAO-Penman-Monteith method and Turc, Modified Penman, Christiansen, Open pan evaporation method underestimated FAO-Penman-Monteith method. The similar result was found by Phad *et al.,* (2020) in Parbhani, Maharashtra.

4.1.5 Average seasonal reference evapotranspiration (ETo) for different Seasons

The mean seasonal reference evapotranspiration (ETo) for the FAO-Penman-Monteith method was observed as 5.87, 4.27 and 3.79 mm day^{-1} in the summer, *kharif*, and *rabi* season respectively. The maximum and minimum average reference evapotranspiration (ETo) for the summer season was 15.49 and 4.35 mm day^{-1} for Hargreaves-Samani and Modified Penman method respectively. For *kharif* season the maximum and minimum average reference evapotranspiration was 11.54 and 2.72 mm day^{-1} for the Hargreaves-Samani method and Turc method respectively. Similarly for the *rabi* season, the maximum and minimum average reference evapotranspiration was 14.93 and 2.77 mm day^{-1} for the Hargreaves-Samani method and Modified Penman method respectively. (Table. 4.6).

Thus we found that in the summer season when the temperature and wind speed both are highest so the total reference evapotranspiration (ETo) was maximum, while in *kharif* season temperature is comparatively lower than the summer due to rainfall thereby less reference evapotranspiration (ETo). In the *rabi* season the temperature as well wind speed both are low so total reference evapotranspiration (ETo) was the lowest among all these three seasons (Table 4.6). The similar result was found by Phad *et al.,* (2020) in Parbhani, Maharashtra.

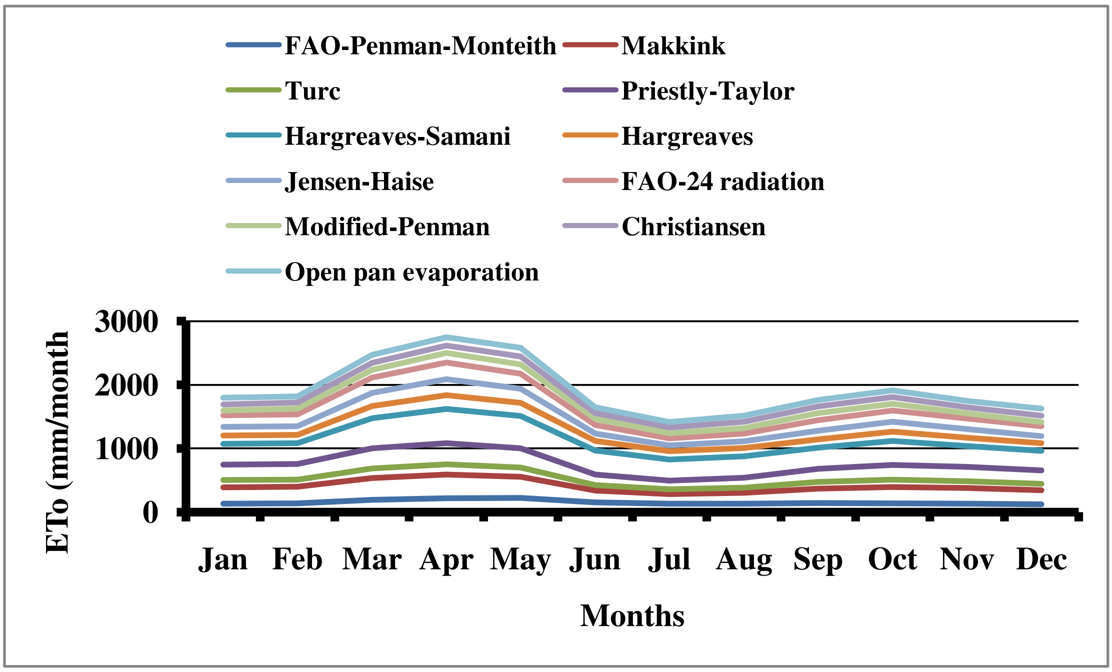

Fig.4.3: Total monthly pattern of reference evapotranspiration (ETo) (mm/month) by different methods at Aurangabad district

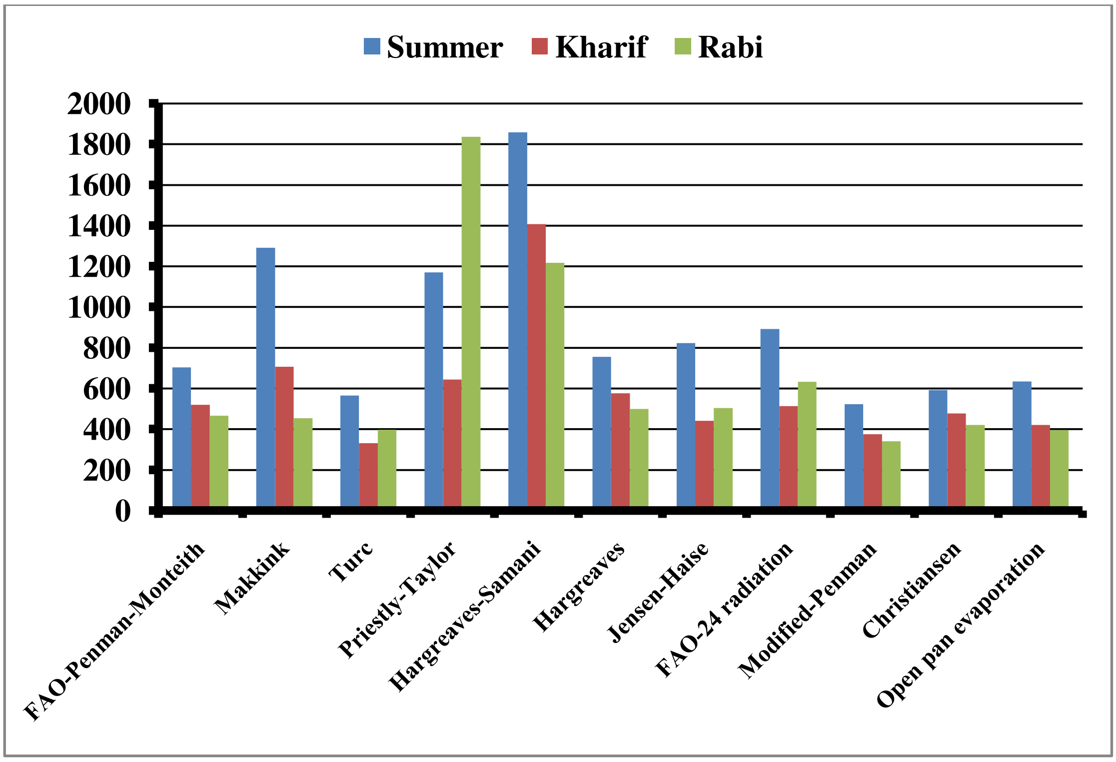

Fig.4.4: Seasonal variation of reference evapotranspiration (ETo) (mm) by different methods at Aurangabad district

Table 4.5: Total seasonal reference evapotranspiration (ETo) (mm) by different methods at Aurangabad

ETo methods	Summer	*Kharif*	*Rabi*	Annual
FAO-Penman-Monteith	704.42	520.34	466.49	1714.33
Makkink	1291.16	707.71	454.58	2453.46
Turc	565.23	331.81	396.88	1293.91
Priestly-Taylor	1170.81	644.00	1218.03	3650.96
Hargreaves-Samani	1858.73	1407.99	1836.16	4484.75
Hargreaves	755.47	577.15	499.49	1832.11
Jensen-Haise	823.36	441.54	503.58	1768.48
FAO-24 radiation	892.76	513.67	633.18	2039.61
Modified-Penman	522.44	374.77	340.70	1237.91
Christiansen	591.70	478.16	421.07	1490.93
Open pan evaporation	635.39	421.08	396.43	1452.90
Maximum	1858.73	1407.99	1836.16	4484.75
Minimum	522.44	331.81	340.70	1237.91
Mean	937.89	627.54	718.73	2241.69

Table 4.6: Average seasonal reference evapotranspiration (ETo) (mm) by different methods at Aurangabad

ETo methods	Summer	*Kharif*	*Rabi*	Annual
FAO-Penman-Monteith	5.87	4.27	3.79	4.70
Makkink	10.76	5.80	3.70	6.72
Turc	4.71	2.72	3.23	3.54
Priestly-Taylor	9.76	5.28	9.90	10.00
Hargreaves-Samani	15.49	11.54	14.93	12.29
Hargreaves	6.30	4.73	4.06	5.02
Jensen-Haise	6.86	3.62	4.09	4.85
FAO-24 radiation	7.44	4.21	5.15	5.59
Modified-Penman	4.35	3.07	2.77	3.39
Christiansen	4.93	3.92	3.42	4.08
Open pan evaporation	5.29	3.45	3.22	3.98
Maximum	15.49	11.54	14.93	12.29
Minimum	4.35	2.72	2.77	3.39
Mean	7.82	5.14	5.84	6.14

4.1.5 Annual variation in reference evapotranspiration (ETo)

The mean annual reference evapotranspiration (ETo) for the FAO-Penman-Monteith method was 1714.33 mm. The maximum and minimum annual reference evapotranspiration were 4484.75 mm and 1237.91 mm for the Hargreaves-Samani method and Modified Penman method, respectively. The Makkink, Priestly-Taylor, Hargreaves-Samani, Hargreaves, Jensen and Haise, FAO-24 Radiation method overestimated the FAO-Penman-Monteith method and Turc, Modified Penman, Christiansen, and Open pan evaporation method underestimated FAO-Penman-Monteith method. The detailed annual reference evapotranspiration (ETo) for different ETo based methods is given in Fig. 4.5 and Table 4.5. The similar result was found by Phad *et al.,* (2020) in Parbhani, Maharashtra.

4.1.7 Comparision between daily calculated reference evapotranspiration and daily reference evapotranspiration by FAO 56.

The reference evapotranspiration under standard conditions, denoted as reference evaoptranspiration (ETo), is the reference evapotranspiration from disease-free, well-fertilized crops, grown in large fields, under optimum soil water conditions, and achieving full production under the given climatic conditions. Aurangabad comes under tropics and subtropics with arid and semi-arid climatic conditions having a moderate temperature range of 20^{o}C. The daily reference evapotranspiration is given by FAO 56 for tropics and subtropics with arid and semi-arid climatic conditions under moderate daily temperature i.e. 20^{0}C ranged between 4 to 6 mm/day.

The daily reference evapotranspiration observed at the Aurangabad region ranged between 2.86 to 7.50 mm/ day. Hence it is found that daily reference evapotranspiration observed at Aurangabad district is more than the daily reference evapotranspiration values given by FAO 56 and it is shown in Fig. 4.6 and Table 4.7.

Table 4.7: Average reference evapotranspiration (ETo) for different agroclimatic regions and Aurangabad district in mm/day.

Regions	**Mean daily temperature (°C)**		
	Cool -10°C	**Moderate 20°C**	**Warm >30°C**
Tropics and subtropics			
i) Humid and sub-humid	2 to 3	3 to 5	5 to 7
ii) Arid and semi-arid	2 to 4	4 to 6	6 to 8
ETo calculated at Aurangabad district		2.86 to 7.50	
Temperate region			
i) Humid and sub-humid	1 to 2	2 to 4	4 to 7
ii) Arid and semi-arid	1 to 3	4 to 7	6 to 9

4.1.8: Statistical analysis for relationship between reference evapotranspiration (ETo) by FAO Penman-Monteith method with other methods

The values of the Root mean square error (RMSE) related to reference evaoptranspiration (ETo) indicate that the estimation of reference evapotranspiration (ETo) by the FAO Penman-Monteith method was less as compared to other methods. However, the higher values of Root mean square error (RMSE) in case of other methods *viz.,* Makkink, Priestly-Taylor, Turc, Hargreaves-Samani, Hargreaves, Jensen and Haise, FAO-24 radiation, Modified Penman, Christiansen, Open pan evaporation indicate their poor performance in estimating reference evapotranspiration (ETo) when compared with FAO Penman-Monteith method. The estimated values of reference evapotranspiration (ETo) by them are consistently overestimated as compared to the FAO Penman-Monteith method. The result of the study reveals that the FAO Penman-Monteith method is the best suitable method for the Aurangabad district for estimation of reference evapotranspiration (ETo) (Table 4.8).

Table 4.8: Statistical analysis of reference evapotranspiration (ETo) by different methods at Aurangabad district

ETo methods	MAE	MBE	RMSE
FAO-Penman-Monteith	1.56	1.56	2.43
Makkink	-1.91	1.91	3.65
Turc	2.45	2.45	5.98
Priestly-Taylor	1.95	1.95	3.80
Hargreaves-Samani	-6.31	6.31	39.78
Hargreaves	2.10	2.10	4.41
Jensen-Haise	2.04	2.04	4.16
FAO-24 radiation	1.80	1.80	3.24
Modified-Penman	2.61	2.61	6.80
Christiansen	1.94	1.94	3.75
Open pan evaporation	2.03	2.03	4.12

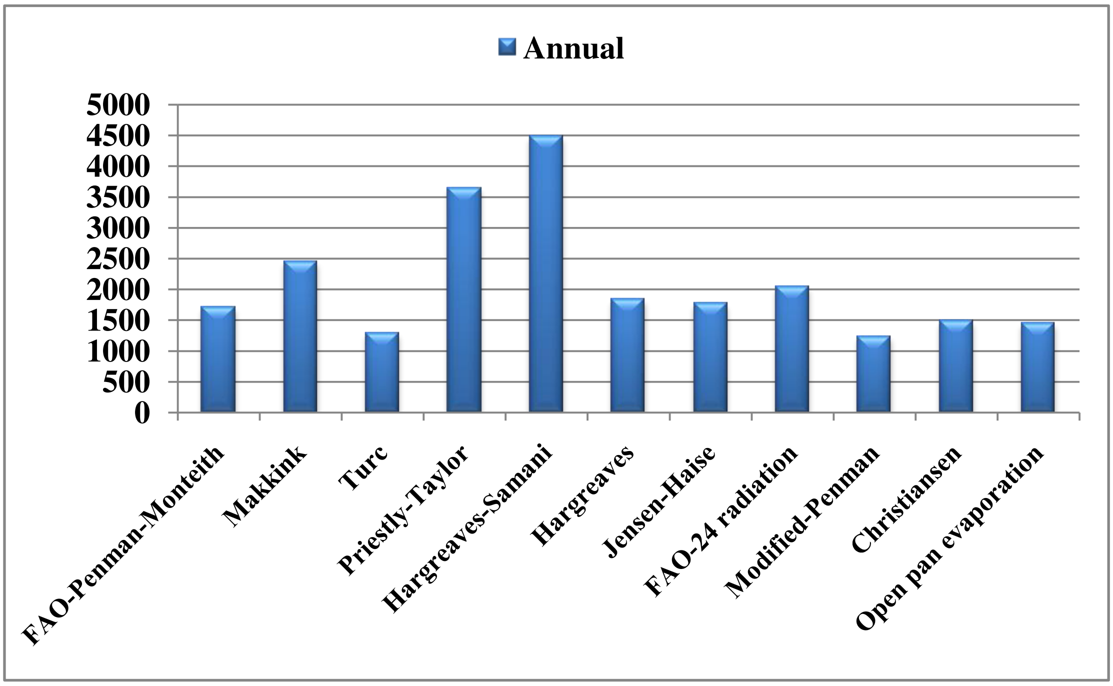

Fig.4.5: Annual variation in reference evapotranspiration (ETo) (mm $year^{-1}$) by different methods at Aurangabad district.

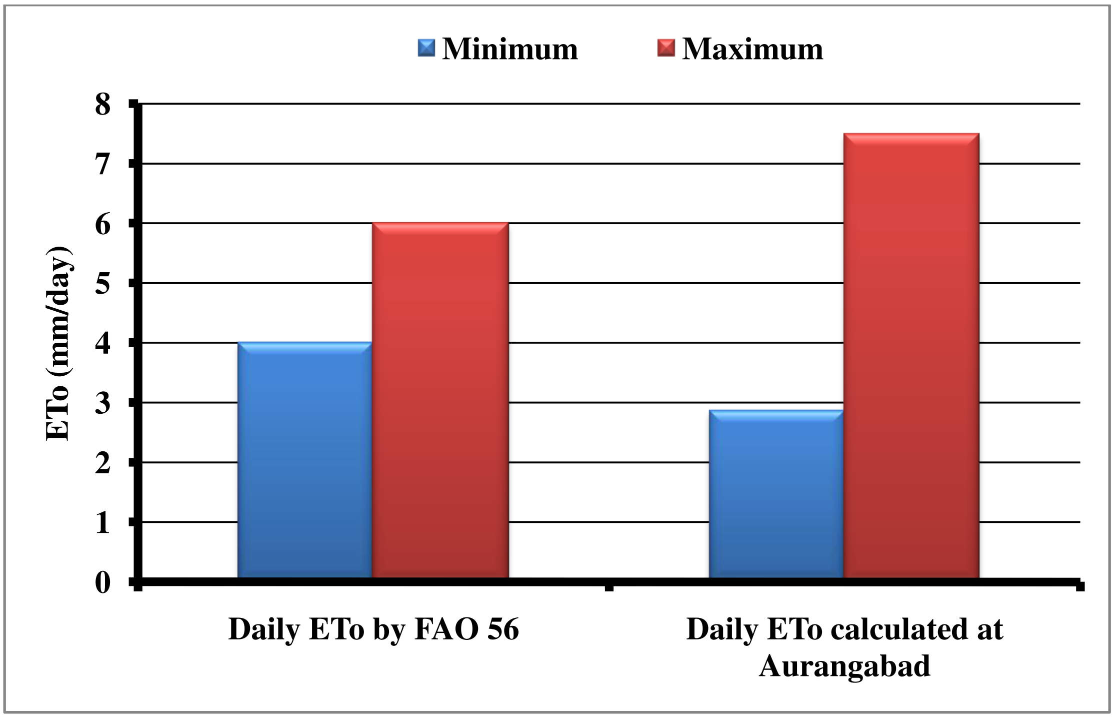

Fig 4.6: Average ETo for different agroclimatic regions by FAO-56 at Aurangabad district in mm/day.

4.2 Crop Water Requirement/ Crop Evapotranspiration (ETc)

The reference evapotranspiration (ETo) was estimated for the Aurangabad district of the Marathwada region. The crop water requirement (ETc) was determined by utilizing FAO-56 Kc values on a daily basis by multiplying the daily ETo with crop coefficient (Kc) values of particular growth stages of eight major *kharif* crops (Cotton, Pigeon pea, Soybean, Maize, Pearl millet, Onion, Tomato, and Brinjal). In this section, stage-wise variation in crop evapotranspiration (ETc) is narrated for each crop.

4.2.1 Crop water requirement (ETc) of Cotton

The data on crop water requirement (ETc) of cotton crop with the mean values for different growth stages are shown in Table 4.9 and Fig. 4.7. As expressed earlier, the crop duration has been divided into four growth stages. During the initial stage of the crop, the total water requirement varies between 27.50 mm to 63.90 mm with mean water requirement differing between 0.92 mm to 2.13 mm day^{-1}. During the developmental stage, the crop water requirement (ETc) increases continuously and total crop water requirement varies between 116.49 mm to 278.92 mm with mean water requirement between 2.33 mm day^{-1} to 5.58 mm day^{-1}. In the course of the mid-stage crop, total water requirement in the region varies between 312.57 mm to 555.24 mm with mean water requirement differing between 5.21 mm day^{-1} to 9.25 mm day^{-1}. In the course of the late-season stage, crop water requirement (ETc) decreases gradually up to the end of the crop season of and total water requirement in the region varies between 65.82 mm to 117.38 mm with mean water requirement varying between 1.20 mm day^{-1} to 2.13 mm day^{-1}. It is established that the difference in crop water requirement (ETc) is more at development and mid-season stages as compared to the initial and maturity stages of the cotton crop across the FAO-Penman-Monteith method.

Among the different years, the highest total annual crop water requirement (ETc) was observed during the year 2019 the value was 970.52 mm while the lowest value was 524.98 mm during the year 1998 and the average crop water requirement of all the year values was 797.24 mm. The similar result was found by Mehta and Pandey, (2015) at Gujrat.

Table 4.9: Stage-wise crop water requirement (ETc) of Cotton estimated by FAO-Penman-Monteith method

Year	Initial stage		Development		Mid-season		Late-season		Total
	Total	Mean	Total	Mean	Total	Mean	Total	Mean	
1991	29.63	0.99	116.49	2.33	364.04	6.07	82.06	1.49	592.22
1992	46.05	1.54	149.89	3.00	399.94	6.67	81.27	1.48	677.15
1993	35.23	1.17	144.28	2.89	375.47	6.26	79.77	1.45	634.76
1994	27.50	0.92	122.37	2.45	350.82	5.85	76.04	1.38	576.72
1995	41.90	1.40	186.01	3.72	430.80	7.18	73.96	1.34	732.67
1996	49.05	1.63	132.02	2.64	340.93	5.68	71.74	1.30	593.73
1997	33.00	1.10	167.69	3.35	399.96	6.67	73.86	1.34	674.50
1998	28.61	0.95	117.97	2.36	312.57	5.21	65.82	1.20	524.98
1999	44.30	1.48	211.69	4.23	507.58	8.46	115.61	2.10	879.18
2000	43.63	1.45	242.25	4.85	555.24	9.25	115.48	2.10	956.60
2001	52.94	1.76	196.72	3.93	508.09	8.47	117.38	2.13	875.14
2002	55.73	1.86	206.45	4.13	547.13	9.12	116.90	2.13	926.22
2003	45.09	1.50	204.84	4.10	525.93	8.77	114.48	2.08	890.34
2004	60.69	2.02	222.68	4.45	531.22	8.85	111.76	2.03	926.36
2005	49.81	1.66	199.40	3.99	483.26	8.05	115.86	2.11	848.34
2006	43.96	1.47	198.19	3.96	480.70	8.01	113.46	2.06	836.31
2007	49.35	1.65	203.71	4.07	491.01	8.18	111.02	2.02	855.09
2008	63.90	2.13	232.94	4.66	495.85	8.26	107.47	1.95	900.16
2009	54.65	1.82	166.33	3.33	454.66	7.58	112.72	2.05	788.35
2010	45.67	1.52	203.10	4.06	470.65	7.84	93.38	1.70	812.80
2011	53.74	1.79	158.95	3.18	409.57	6.83	99.05	1.80	721.32
2012	52.10	1.74	224.43	4.49	453.91	7.57	92.84	1.69	823.28
2013	39.30	1.31	204.06	4.08	438.44	7.31	93.23	1.70	775.02
2014	61.61	2.05	215.08	4.30	481.04	8.02	97.33	1.77	855.05
2015	60.15	2.00	249.39	4.99	540.00	9.00	111.10	2.02	960.64
2016	51.05	1.70	207.93	4.16	472.90	7.88	108.68	1.98	840.56
2017	53.84	1.79	210.23	4.20	481.05	8.02	93.14	1.69	838.26
2018	46.50	1.55	222.14	4.44	552.32	9.21	114.81	2.09	935.77
2019	53.24	1.77	278.92	5.58	545.22	9.09	93.14	1.69	970.52
2020	47.90	1.60	204.20	4.08	438.72	7.31	103.45	1.88	794.26
Maximum	63.90	2.13	278.92	5.58	555.24	9.25	117.38	2.13	970.52
Minimum	27.50	0.92	116.49	2.33	312.57	5.21	65.82	1.20	524.98
Mean	47.23	1.57	193.62	3.87	459.59	7.66	98.13	1.78	797.24

4.2.2 Crop water requirement (ETc) of Soybean

The data on crop water requirement (ETc) of soybean along with the mean values for different growth stages are shown in Table 4.10 and Fig.4.8. In the course of the initial stage of the crop, total water requirements differ between 21.49 mm to 68.17 mm with mean water requirement differing between 1.07 mm day^{-1} to 3.41 mm day^{-1}. In the course of the developmental stage of the crop, total water requirements in the region differ between 45.79 mm to 154.69 mm with mean water requirement varying between 1.83 mm day^{-1} to 6.19 mm day^{-1}. In the course of the mid-stage crop, total water requirements in the region differ between 276.63 mm to 515.45 mm with mean water requirement differing between 3.69 mm day^{-1} to 6.87 mm day^{-1}. In the course of the late-season stage of the crop, total water requirements in the region differ between 37.76 mm to 78.94 mm with mean water requirement differing between 1.26 mm day^{-1} to 2.63 mm day^{-1}. It is established that the variation in crop water requirement (ETc) is more at developmental and mid-season stages as compared to initial and maturity stages of the sorghum crop across the FAO-Penman-Monteith method.

Among the different years, the highest crop water requirement (ETc) was observed during the year 2015 the value is 777.57 mm while the lowest value was 404.42 mm is during the year 1998 and the average total crop water requirement value was 619.62 mm. The similar result was found by Mehta and Pandey, (2015) at Gujrat.

Table 4.10: Stage-wise crop water requirement (ETc) of Soybean estimated by FAO- Penman-Monteith method

	Initial stage		Development		Mid-season		Late-season		Total
Year	Total	Mean	Total	Mean	Total	Mean	Total	Mean	
1991	27.61	1.38	45.79	1.83	292.76	3.90	55.41	1.85	421.58
1992	31.93	1.60	117.65	4.71	386.34	5.15	49.21	1.64	585.14
1993	30.86	1.54	70.31	2.81	330.03	4.40	48.38	1.61	479.59
1994	21.49	1.07	65.56	2.62	308.45	4.11	46.53	1.55	442.02
1995	33.96	1.70	86.54	3.46	391.50	5.22	49.80	1.66	561.79
1996	43.13	2.16	76.44	3.06	304.39	4.06	46.08	1.54	470.03
1997	27.00	1.35	78.96	3.16	356.06	4.75	48.88	1.63	510.89
1998	23.45	1.17	66.59	2.66	276.63	3.69	37.76	1.26	404.42
1999	35.88	1.79	105.48	4.22	438.17	5.84	70.25	2.34	649.80
2000	36.53	1.83	113.23	4.53	490.29	6.54	68.65	2.29	708.70
2001	43.66	2.18	105.25	4.21	442.34	5.90	75.59	2.52	666.84
2002	37.41	1.87	154.69	6.19	503.27	6.71	78.37	2.61	773.73
2003	36.22	1.81	100.80	4.03	448.04	5.97	78.94	2.63	664.00
2004	45.51	2.28	140.10	5.60	488.43	6.51	70.29	2.34	744.32
2005	42.44	2.12	92.59	3.70	425.93	5.68	66.94	2.23	627.90
2006	34.89	1.74	101.71	4.07	414.16	5.52	70.69	2.36	621.45
2007	40.58	2.03	113.99	4.56	424.14	5.66	70.93	2.36	649.64
2008	49.49	2.47	136.35	5.45	458.95	6.12	64.97	2.17	709.75
2009	46.83	2.34	92.65	3.71	395.22	5.27	67.24	2.24	601.94
2010	36.01	1.80	107.68	4.31	429.29	5.72	58.10	1.94	631.08
2011	45.35	2.27	95.75	3.83	358.83	4.78	63.09	2.10	563.03
2012	44.14	2.21	122.87	4.91	413.78	5.52	57.28	1.91	638.06
2013	31.26	1.56	96.63	3.87	393.31	5.24	57.11	1.90	578.30
2014	68.17	3.41	123.66	4.95	430.00	5.73	62.29	2.08	684.12
2015	42.15	2.11	154.34	6.17	515.44	6.87	65.63	2.19	777.57
2016	40.53	2.03	106.23	4.25	421.11	5.61	64.43	2.15	632.31
2017	44.15	2.21	154.35	6.17	515.45	6.87	57.28	1.91	771.23
2018	38.02	1.90	105.26	4.21	480.49	6.41	73.07	2.44	696.84
2019	42.88	2.14	151.34	6.05	512.43	6.83	55.74	1.86	762.38
2020	37.31	1.87	114.05	4.56	410.61	5.47	55.42	1.85	617.38
Maximum	68.17	3.41	154.69	6.19	515.45	6.87	78.94	2.63	777.57
Minimum	21.49	1.07	45.79	1.83	276.63	3.69	37.76	1.26	404.42
Mean	39.01	1.95	106.17	4.25	414.00	5.52	60.97	2.03	619.62

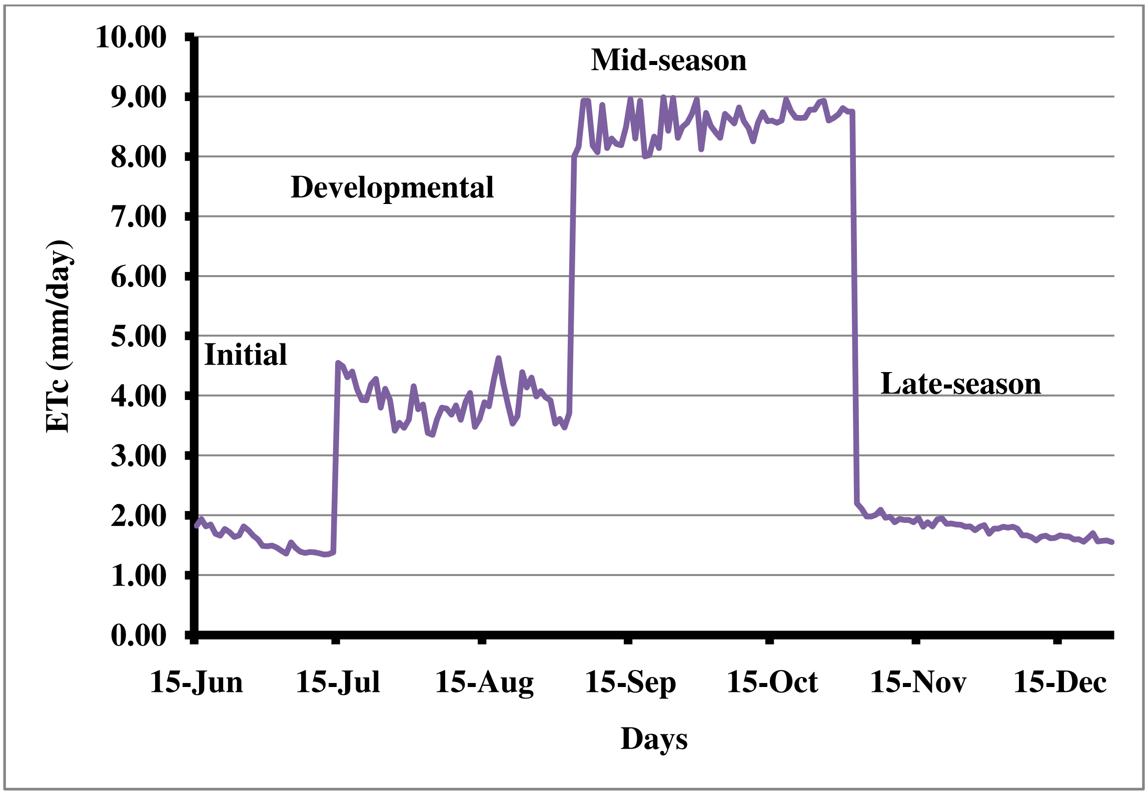

Fig.4.7: Crop water requirement (ETc) (mm day^{-1}) of cotton at different growth stages by FAO Penman-Monteith method

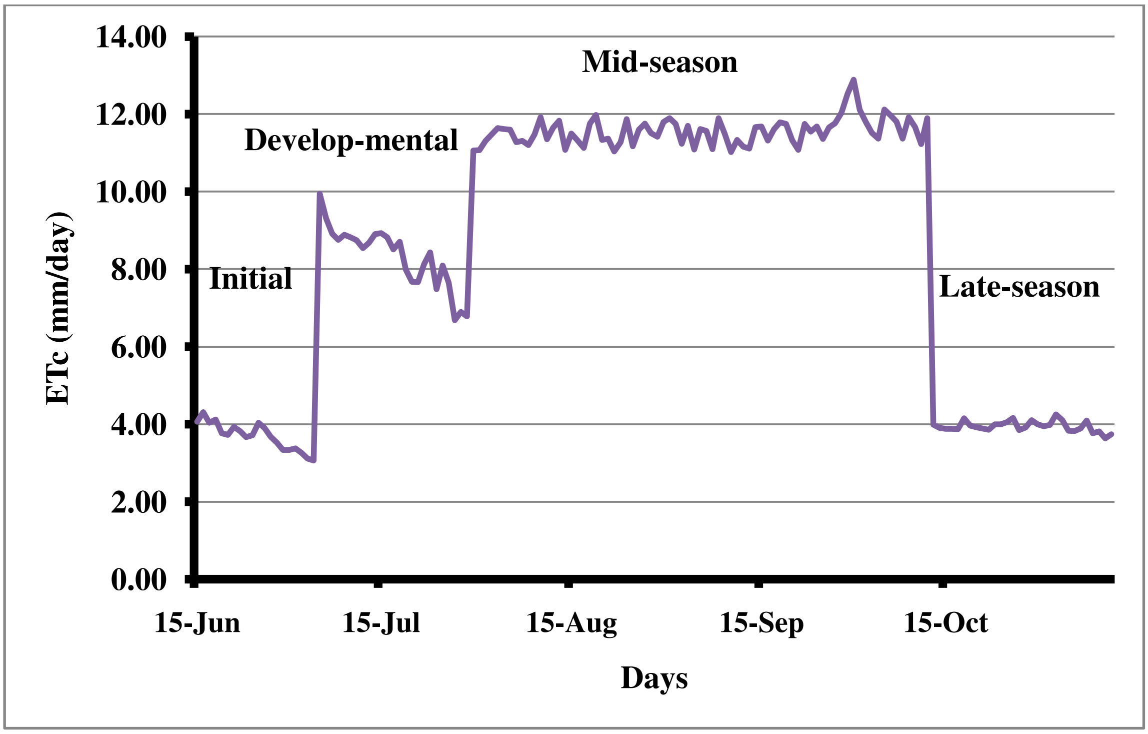

Fig.4.8: Crop water requirement ETc (mm day^{-1}) of soybean at different growth stages by FAO Penman-Monteith method

4.2.3 Crop water requirement (ETc) of Pigeon pea

The data on crop water requirement (ETc) of Pigeon pea along with mean values for different growth stages shown in Table 4.11 and Fig. 4.9. In the course of an initial stage of the crop, total water requirements in the region differ between 64.35 mm to 152.03 mm with mean water requirement differing between 1.17 mm day^{-1} to 2.76 mm day^{-1}. In the course of the developmental stage of the crop, total water requirements differ between 116.61 mm to 239.76 mm with mean water requirement differing between 2.59 mm day^{-1} to 5.33 mm day^{-1}. In the course of the mid-season stage of the crop, total water requirements differ between 312.75 mm to 550.28 mm with mean water requirement differing between 5.21 mm day^{-1} to 9.17 mm day^{-1}. In the course of the late-season stage of the crop, total water requirements differ between 85.44 mm to 167.52 mm with mean water requirement differing between 2.25 mm day^{-1} to 4.41 mm day^{-1}. It is established from the above discussion that the variation in crop water requirement (ETc) is more at developmental and mid-season stages as compared to initial and maturity stages of the Pigeon pea crop across the FAO-Penman-Monteith method.

Among the different years, the highest crop water requirement (ETc) was observed during the year 2004 the value was 1039.79 mm while the lowest value was 596.98 mm is during the year 1998 respectively. The average total crop water requirement value was 885.74 mm. The similar result was established by Phad *et al.,* (2020) in Parbhani, Maharashtra.

Table 4.11: Stage-wise Crop water requirement (ETc) of Pigeon pea estimated by FAO Penman-Monteith method

Year	Initial stage		Development		Mid-season		Late-season		Total
	Total	Mean	Total	Mean	Total	Mean	Total	Mean	
1991	64.35	1.17	150.39	3.34	394.54	6.58	116.31	3.06	725.58
1992	107.53	1.96	145.91	3.24	380.70	6.34	119.89	3.15	754.02
1993	78.20	1.42	163.15	3.63	395.77	6.60	108.82	2.86	745.93
1994	67.89	1.23	129.11	2.87	359.95	6.00	108.87	2.86	665.82
1995	96.49	1.75	193.69	4.30	418.23	6.97	107.62	2.83	816.03
1996	99.20	1.80	133.70	2.97	346.75	5.78	101.53	2.67	681.17
1997	82.18	1.49	165.88	3.69	397.22	6.62	103.62	2.73	748.89
1998	67.06	1.22	116.61	2.59	312.75	5.21	100.55	2.65	596.98
1999	103.82	1.89	205.37	4.56	530.10	8.83	164.35	4.33	1003.63
2000	121.28	2.21	216.65	4.81	534.07	8.90	167.52	4.41	1039.53
2001	113.65	2.07	215.16	4.78	543.62	9.06	161.06	4.24	1033.48
2002	106.66	1.94	211.48	4.70	550.28	9.17	155.92	4.10	1024.34
2003	106.66	1.94	211.48	4.70	550.28	9.17	155.92	4.10	1024.34
2004	134.30	2.44	210.94	4.69	530.08	8.83	164.47	4.33	1039.79
2005	75.31	1.37	195.49	4.34	517.31	8.62	161.45	4.25	949.56
2006	104.56	1.90	194.72	4.33	498.30	8.31	160.80	4.23	958.37
2007	114.99	2.09	184.88	4.11	495.73	8.26	163.65	4.31	959.26
2008	144.01	2.62	182.72	4.06	476.50	7.94	156.51	4.12	959.75
2009	64.41	1.17	166.96	3.71	426.65	7.11	85.44	2.25	743.46
2010	111.99	2.04	182.30	4.05	458.85	7.65	134.93	3.55	888.06
2011	111.84	2.03	156.49	3.48	428.88	7.15	140.06	3.69	837.28
2012	131.77	2.40	152.95	3.40	414.26	6.90	127.76	3.36	826.74
2013	98.75	1.80	191.91	4.26	439.18	7.32	130.42	3.43	860.26
2014	139.13	2.53	180.11	4.00	458.83	7.65	140.50	3.70	918.57
2015	143.16	2.60	212.38	4.72	521.67	8.69	156.04	4.11	1033.24
2016	114.71	2.09	193.00	4.29	482.35	8.04	153.75	4.05	943.80
2017	152.03	2.76	239.76	5.33	510.05	8.50	133.26	3.51	1035.10
2018	114.82	2.09	210.34	4.67	549.98	9.17	160.61	4.23	1035.75
2019	136.41	2.48	229.58	5.10	497.68	8.29	133.26	3.51	996.93
2020	118.99	2.16	169.97	3.78	430.30	7.17	141.86	3.73	861.12
Maximum	152.03	2.76	239.76	5.33	550.28	9.17	167.52	4.41	1039.79
Minimum	64.35	1.17	116.61	2.59	312.75	5.21	85.44	2.25	596.98
Mean	107.58	1.96	183.42	4.08	459.81	7.66	136.55	3.59	885.74

4.2.4 Crop water requirement (ETc) of Maize

The data on crop water requirement (ETc) of Maize along with mean values for different growth stages are shown in Table 4.12 and Fig. 4.10. In the course of an initial stage of the crop, total water requirements differ between 13.34 mm to 33.37 mm with mean water requirement differing between 0.83 mm day^{-1} to 2.09 mm day^{-1}. In the course of the developmental stage of the crop, total water requirements differ between 66.27 mm to 214.26 mm with mean water requirement differing between 2.14 mm day^{-1} to 6.91 mm day^{-1}. In the course of the mid-stage crop, total water requirements differ between 180.41 mm to 423.54 mm with mean water requirement differing between 4.75 mm day^{-1} to 11.15 mm day^{-1}. In the course of the late-season stage of the crop, total water requirements differ between 16.06 mm to 29.41 mm with mean water requirement differing between 0.94 mm day^{-1} to 2.94 mm day^{-1}. It is established from the above discussion that the variation in crop water requirement (ETc) is more at developmental and mid-season stages as compared to initial and maturity stages of the maize crop across the FAO-Penman-Monteith method.

Among the different years, the highest crop water requirement (ETc) was 627.63 mm observed during the year 2019 and the values are while the lowest value was 292.51 mm in the year 1991 and the average crop water requirement value was 458.78 mm. The similar result was established by Phad *et al.,* (2020) in Parbhani, Maharashtra.

Table 4.12: Stage-wise crop water requirement (ETc) of Maize estimated by FAO Penman-Monteith method

Year	Initial stage		Development		Mid-season		Late-season		Total
	Total	Mean	Total	Mean	Total	Mean	Total	Mean	
1991	17.85	1.12	66.27	2.14	191.18	5.03	17.20	1.01	292.51
1992	17.69	1.11	164.09	5.29	275.24	7.24	24.61	1.45	481.63
1993	19.32	1.21	94.17	3.04	229.48	6.04	19.06	1.12	362.03
1994	13.34	0.83	85.72	2.77	193.53	5.09	19.94	1.17	312.52
1995	19.66	1.23	124.92	4.03	294.17	7.74	21.96	1.29	460.72
1996	27.28	1.70	108.77	3.51	219.97	5.79	18.59	1.09	374.61
1997	17.80	1.11	98.25	3.17	248.71	6.55	17.70	1.04	382.46
1998	15.38	0.96	85.83	2.77	180.41	4.75	16.06	0.94	297.69
1999	19.88	1.24	148.95	4.80	327.77	8.63	21.14	1.24	517.75
2000	23.18	1.45	154.15	4.97	346.81	9.13	29.41	1.73	553.56
2001	28.14	1.76	141.13	4.55	315.51	8.30	25.86	1.52	510.64
2002	22.46	1.40	196.87	6.35	359.11	9.45	28.41	1.67	606.85
2003	22.23	1.39	144.28	4.65	320.10	8.42	21.67	1.27	508.28
2004	29.77	1.86	175.06	5.65	352.57	9.28	28.24	1.66	585.64
2005	27.25	1.70	124.86	4.03	299.89	7.89	22.24	1.31	474.24
2006	22.16	1.38	135.70	4.38	305.55	8.04	22.42	1.32	485.83
2007	25.58	1.60	150.59	4.86	313.53	8.25	21.84	1.28	511.54
2008	30.54	1.91	186.60	6.02	350.00	9.21	19.44	1.14	586.58
2009	29.01	1.81	125.85	4.06	298.00	7.84	24.10	1.42	476.97
2010	22.53	1.41	144.23	4.65	300.00	7.89	24.33	1.43	491.09
2011	28.10	1.76	135.14	4.36	320.22	8.43	20.64	1.21	504.10
2012	28.18	1.76	162.22	5.23	299.99	7.89	17.08	1.00	507.46
2013	18.93	1.18	134.66	4.34	289.90	7.63	20.26	1.19	463.74
2014	33.37	2.09	170.61	5.50	315.17	8.29	21.44	1.26	540.59
2015	22.96	1.43	214.26	6.91	317.89	8.37	24.09	1.42	579.20
2016	25.90	1.62	140.47	4.53	296.77	7.81	19.65	1.16	482.80
2017	31.36	1.96	207.90	6.71	423.54	11.15	24.94	2.94	624.94
2018	21.65	1.35	151.03	4.87	299.13	7.87	24.96	1.47	496.78
2019	28.46	1.78	184.68	5.96	390.64	10.28	23.86	1.40	627.63
2020	22.34	1.40	159.28	5.14	329.18	8.66	17.17	1.01	527.96
Maximum	33.37	2.09	214.26	6.91	423.54	11.15	29.41	2.94	627.63
Minimum	13.34	0.83	66.27	2.14	180.41	4.75	16.06	0.94	292.51
Mean	23.72	1.48	143.66	4.63	300.25	7.90	21.99	2.75	458.78

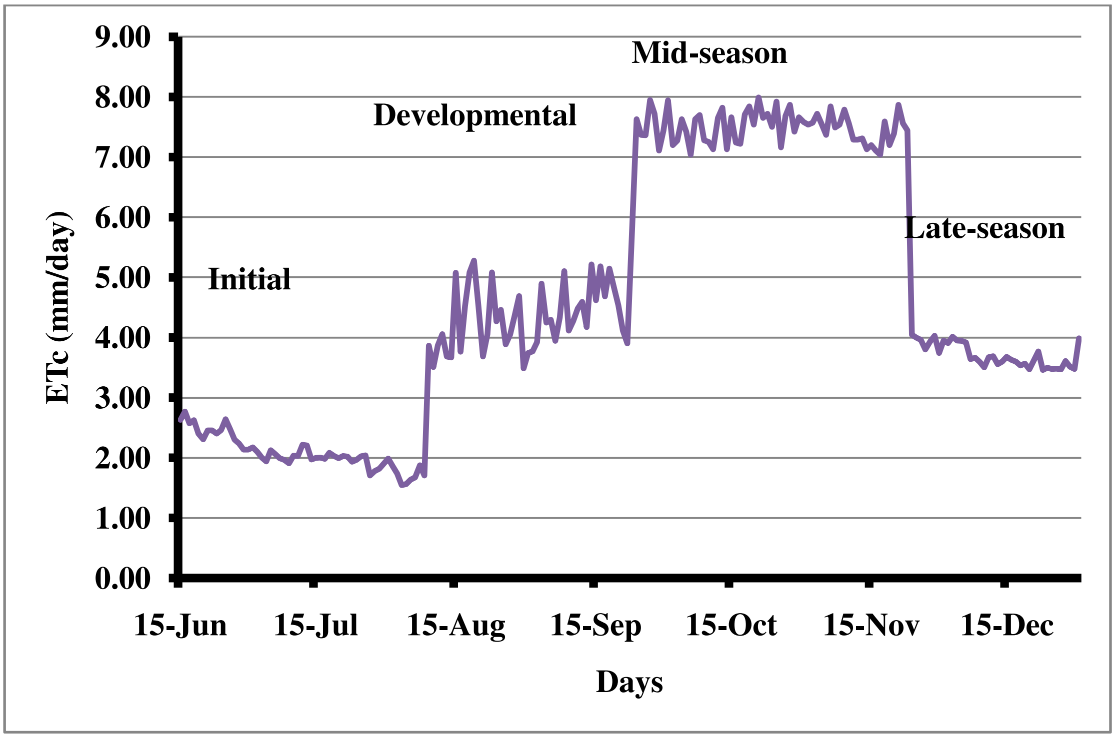

Fig .4.9: Crop water requirement (ETc) (mm day^{-1}) of Pigeon pea at different growth stages by FAO Penman-Monteith method

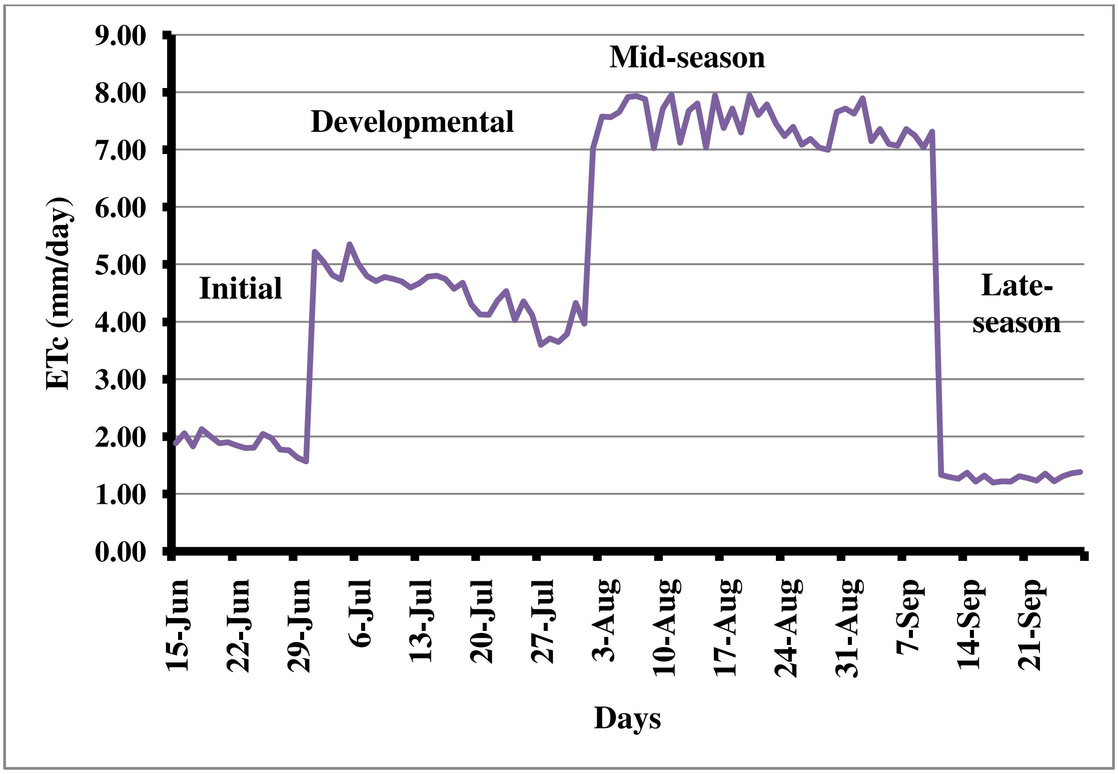

Fig.4.10: Crop water requirement (ETc) (mm day^{-1}) of Maize at different growth stages by FAO Penman-Monteith method

4.2.5 Crop water requirement (ETc) of Pearl millet

The data on crop water requirement (ETc) of Pearl millet along with mean values for different growth stages are shown in Table 4.13 and Fig 4.11. In the course of an initial stage of the crop, total water requirements differ between 12.06 mm to 31.01 mm with mean water requirement differing between 0.80 mm day^{-1} to 2.07 mm day^{-1}. In the course of the developmental stage of the crop, total water requirements differ between 48.17 mm to 158.85 mm with mean water requirement differing between 1.72 mm day^{-1} to 5.67 mm day^{-1}. In the course of the mid-stage of the crop, total water requirements differ between 124.12 mm to 309.18 mm with mean water requirement differing between 3.55 mm day^{-1} to 8.83 mm day^{-1}. In the course of the late-season stage of the crop, total water requirements differ between 11.68 mm to 26.19 mm with mean water requirement differing between 0.69 mm day^{-1} to 1.54 mm day^{-1}. It is established that the variation in crop water requirement (ETc) is more at developmental and mid-season stages as compared to the initial and maturity stages of the pearl millet crop across the FAO-Penman-Monteith method.

Among the different years, the highest crop water requirement (ETc) was 508.02 mm observed during at the year 2015 and the values are while the lowest value was 208.47 mm during the year 1991 and the average crop water requirement value was 371.57 mm. The similar result was established by Phad *et al.,* (2020) in Parbhani, Maharashtra.

Table 4.13: Stage-wise crop water requirement (ETc) of Pearl millet estimated by FAO Penman-Monteith method

Year	Initial stage		Development		Mid-season		Late-season		Total
	Total	Mean	Total	Mean	Total	Mean	Total	Mean	
1991	17.05	1.14	48.17	1.72	124.12	3.55	19.12	1.12	208.47
1992	16.33	1.09	122.68	4.38	205.16	5.86	16.97	1.00	361.15
1993	17.51	1.17	77.72	2.78	166.28	4.75	16.42	0.97	277.93
1994	12.06	0.80	66.02	2.36	141.92	4.05	13.38	0.79	233.39
1995	18.51	1.23	91.46	3.27	213.37	6.10	17.60	1.04	340.94
1996	26.23	1.75	82.36	2.94	161.92	4.63	12.40	0.73	282.91
1997	16.68	1.11	75.12	2.68	177.69	5.08	18.17	1.07	287.65
1998	14.29	0.95	67.23	2.40	133.51	3.81	11.68	0.69	226.71
1999	17.93	1.20	115.51	4.13	239.44	6.84	19.11	1.12	391.99
2000	22.55	1.50	102.90	3.67	251.32	7.18	21.97	1.29	398.73
2001	26.26	1.75	105.33	3.76	225.43	6.44	21.89	1.29	378.90
2002	21.71	1.45	147.33	5.26	262.73	7.51	23.09	1.36	454.85
2003	20.37	1.36	104.95	3.75	232.99	6.66	21.75	1.28	380.06
2004	28.20	1.88	136.72	4.88	264.26	7.55	20.31	1.19	449.48
2005	26.07	1.74	92.68	3.31	217.51	6.21	18.58	1.09	354.83
2006	21.10	1.41	98.62	3.52	219.50	6.27	19.47	1.15	358.69
2007	24.49	1.63	112.85	4.03	232.52	6.64	18.44	1.08	388.29
2008	29.15	1.94	138.22	4.94	279.44	7.98	26.19	1.54	472.99
2009	28.07	1.87	101.14	3.61	199.86	5.71	18.85	1.11	347.92
2010	21.27	1.42	106.86	3.82	231.29	6.61	16.73	0.98	376.14
2011	26.65	1.78	103.94	3.71	199.96	5.71	18.13	1.07	348.69
2012	27.03	1.80	118.79	4.24	247.52	7.07	15.14	0.89	408.48
2013	18.06	1.20	94.17	3.36	222.06	6.34	17.97	1.06	352.27
2014	31.01	2.07	134.09	4.79	255.94	7.31	16.31	0.96	437.34
2015	21.38	1.43	158.84	5.67	309.18	8.83	18.62	1.10	508.02
2016	25.10	1.67	103.38	3.69	238.57	6.82	17.57	1.03	384.61
2017	27.02	1.80	158.85	5.67	279.98	8.00	18.15	1.07	484.00
2018	20.38	1.36	111.29	3.97	248.71	7.11	22.63	1.33	403.02
2019	27.69	1.85	139.11	4.97	296.40	8.47	18.41	1.08	481.61
2020	20.70	1.38	115.91	4.14	238.33	6.81	18.82	1.11	393.77
Maximum	31.01	2.07	158.85	5.67	309.18	8.83	26.19	1.54	508.02
Minimum	12.06	0.80	48.17	1.72	124.12	3.55	11.68	0.69	208.47
Mean	22.31	1.49	107.48	3.84	223.44	6.38	18.49	1.09	371.57

4.2.6 Crop water requirement (ETc) of Onion

The data on crop water requirement (ETc) of Onion determined along with mean values for different growth stages are shown in Table 4.14 and Fig. 4.12. In the course of an initial stage of the crop, total water requirements differ between 42.23 mm to 108.53 mm with mean water requirement differing between 2.82 mm day^{-1} to 7.24 mm day^{-1}. In the course of the developmental stage of the crop, total water requirements differ between 32.44 mm to 110.02 mm with mean water requirement differing between 1.30 mm day^{-1} to 4.40 mm day^{-1}. In the course of the mid-stage of the crop, total water requirements differ between 169.68 mm to 341.26 mm with mean water requirement differing between 2.42 mm day^{-1} to 4.88 mm day^{-1}. In the course of the late-season stage of the crop, total water requirements differ between 44.56 mm to 85.46 mm with mean water requirement differing between 1.11 mm day^{-1} to 2.14 mm day^{-1}. It is established from the above discussion that the variation in crop water requirement (ETc) is more at developmental and mid-season stages as compared to the initial and maturity stages of the onion crop across the FAO-Penman-Monteith method.

Among the different years, the highest crop water requirement (ETc) was 596.72 mm observed during the year 2015 while the lowest value was 309.36 mm during the year 1998 and the average crop water requirement value was 481.64 mm. The similar result was reported by Mehta and Pandey, (2015) at Gujrat.

Table 4.14: Stage-wise crop water requirement (ETc) of Onion estimated by FAO-Penman-Monteith method

Year	Initial stage		Development		Mid-season		Late-season		Total
	Total	**Mean**	**Total**	**Mean**	**Total**	**Mean**	**Total**	**Mean**	
1991	59.68	3.98	32.44	1.30	180.16	2.57	60.65	1.52	332.93
1992	57.16	3.81	86.22	3.45	254.92	3.64	52.83	1.32	451.13
1993	61.30	4.09	53.71	2.15	210.71	3.01	54.34	1.36	380.06
1994	42.23	2.82	43.80	1.75	190.54	2.72	53.07	1.33	329.64
1995	64.80	4.32	76.42	3.06	322.58	4.61	54.01	1.35	517.81
1996	91.80	6.12	57.58	2.30	196.13	2.80	51.22	1.28	396.73
1997	58.36	3.89	51.80	2.07	219.82	3.14	54.74	1.37	384.72
1998	50.02	3.33	45.10	1.80	169.68	2.42	44.56	1.11	309.36
1999	62.74	4.18	79.37	3.17	283.16	4.05	76.75	1.92	502.03
2000	78.91	5.26	67.50	2.70	313.14	4.47	72.61	1.82	532.16
2001	91.89	6.13	71.39	2.86	281.66	4.02	80.45	2.01	525.39
2002	75.97	5.06	98.92	3.96	317.72	4.54	84.05	2.10	576.67
2003	71.31	4.75	72.04	2.88	282.45	4.03	85.46	2.14	511.25
2004	98.69	6.58	97.22	3.89	311.37	4.45	74.46	1.86	581.75
2005	91.23	6.08	63.57	2.54	263.10	3.76	75.67	1.89	493.57
2006	73.85	4.92	66.27	2.65	264.84	3.78	74.17	1.85	479.12
2007	85.70	5.71	74.57	2.98	269.52	3.85	75.12	1.88	504.91
2008	102.01	6.80	96.85	3.87	298.19	4.26	68.83	1.72	565.89
2009	98.24	6.55	69.12	2.76	254.49	3.64	69.70	1.74	491.55
2010	74.44	4.96	71.05	2.84	273.64	3.91	62.85	1.57	481.98
2011	93.29	6.22	72.49	2.90	231.49	3.31	68.00	1.70	465.27
2012	94.61	6.31	79.38	3.18	263.56	3.77	62.39	1.56	499.94
2013	63.22	4.21	62.91	2.52	256.45	3.66	58.80	1.47	441.39
2014	108.53	7.24	90.22	3.61	286.50	4.09	66.32	1.66	551.57
2015	74.83	4.99	109.83	4.39	341.26	4.88	70.80	1.77	596.72
2016	87.83	5.86	71.64	2.87	267.72	3.82	69.60	1.74	496.80
2017	105.83	7.06	110.02	4.40	238.31	3.40	62.59	1.56	516.75
2018	71.35	4.76	75.49	3.02	306.94	4.38	78.80	1.97	532.57
2019	96.92	6.46	92.75	3.71	324.51	4.64	61.89	1.55	576.07
2020	72.45	4.83	77.55	3.10	271.09	3.87	59.42	1.49	480.50
Maximum	108.53	7.24	110.02	4.40	341.26	4.88	85.46	2.14	596.72
Minimum	42.23	2.82	32.44	1.30	169.68	2.42	44.56	1.11	309.36
Mean	78.44	5.23	73.74	2.95	264.27	3.78	66.07	1.65	481.64

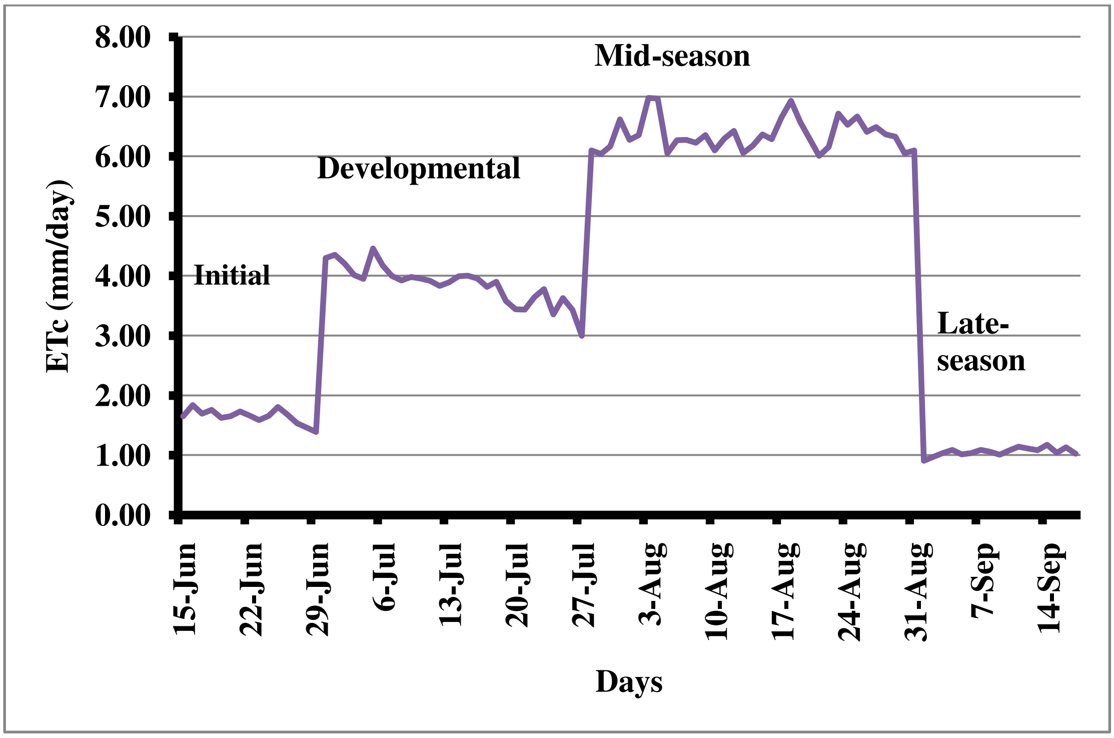

Fig. 4.11: Crop water requirement (ETc) (mm day^{-1}) Pearl millet at different growth stages by FAO Penman-Monteith method

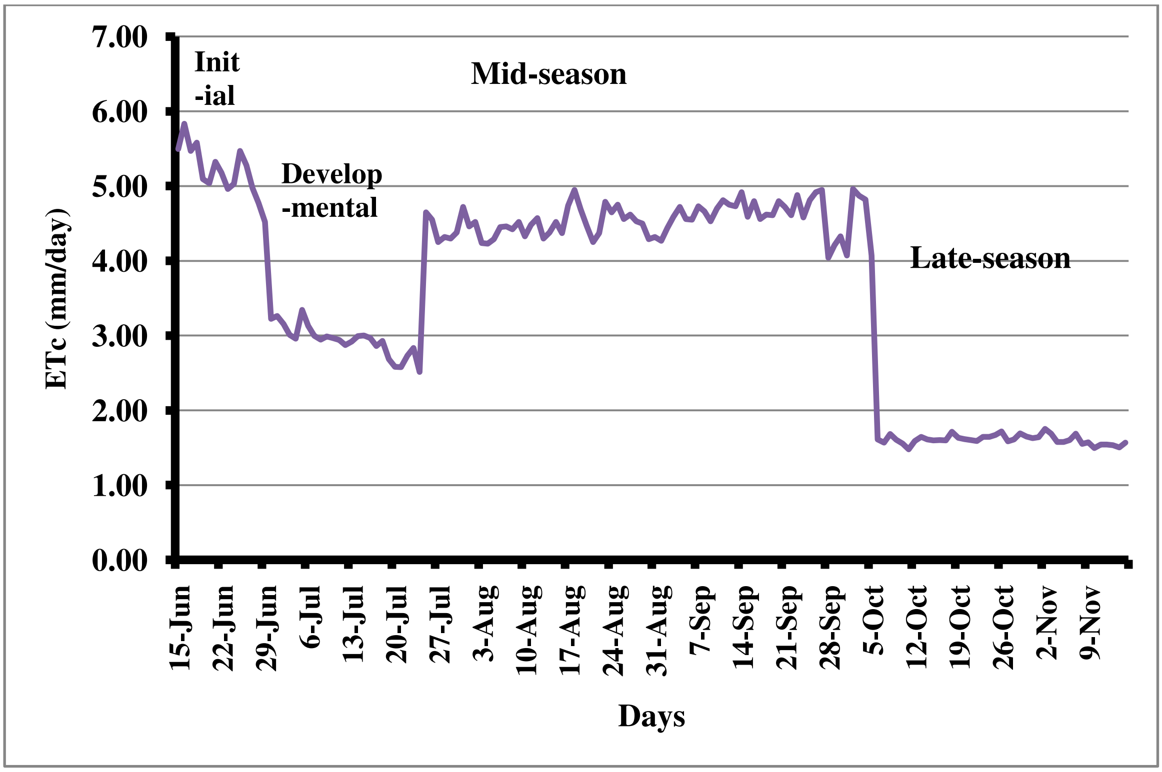

Fig. 4.12: Crop water requirement (ETc) (mm day^{-1}) of Onion at different growth stages by FAO Penman-Monteith method

4.2.7 Crop water requirement (ETc) of Tomato

The data on crop water requirement (ETc) of tomato along with mean values for different growth stages are shown in Table 4.15 and Fig 4.13. During the initial stage of the crop, total water requirements differ between 54.46 mm to 124.59 mm with mean water requirement differing between 1.56 mm day^{-1} to 3.56 mm day^{-1}. In the course of the developmental stage of the crop, total water requirements differ between 93.32 mm to 214.23 mm with mean water requirement differing between 2.33 mm day^{-1} to 5.36 mm day^{-1}. In the course of the mid-stage of the crop, total water requirements differ between 251.93 mm to 454.46 mm with mean water requirement differing between 5.04 mm day^{-1} to 9.09 mm day^{-1}. In the course of the late-season stage of the crop, total water requirements differ between 53.90 mm to 108.67 mm with mean water requirement differing between 1.80 mm day^{-1} to 3.62 mm day^{-1}. It is established from the above discussion that the variation in crop water requirement (ETc) is more at developmental and mid-season stages as compared to initial and maturity stages of the tomato crop across the FAO-Penman-Monteith method.

Among the different years, the highest crop water requirement (ETc) was 848.32 mm observed during the year 2019 while the lowest value was 457.60 mm during the year 1998 and the average crop water requirement value was 692.58 mm. The similar result was found by Mehta and Pandey, (2015) at Gujrat.

Table 4.15: Stage-wise crop water requirement (ETc) of Tomato estimated by FAO-Penman-Monteith method

Year	Initial stage		Development		Mid-season		Late-season		Total
	Total	**Mean**	**Total**	**Mean**	**Total**	**Mean**	**Total**	**Mean**	
1991	55.90	1.60	93.32	2.33	286.03	5.72	76.99	2.57	512.23
1992	89.66	2.56	120.49	3.01	323.69	6.47	68.64	2.29	602.48
1993	67.54	1.93	119.88	3.00	308.47	6.17	68.04	2.27	563.92
1994	54.46	1.56	99.80	2.49	283.33	5.67	64.59	2.15	502.18
1995	78.78	2.25	158.18	3.95	354.29	7.09	69.78	2.33	661.04
1996	93.20	2.66	102.69	2.57	270.82	5.42	62.35	2.08	529.06
1997	63.86	1.82	136.10	3.40	329.52	6.59	66.53	2.22	596.01
1998	55.27	1.58	96.50	2.41	251.93	5.04	53.90	1.80	457.60
1999	84.48	2.41	166.35	4.16	409.50	8.19	95.96	3.20	756.28
2000	84.46	2.41	200.05	5.00	454.46	9.09	99.52	3.32	838.48
2001	101.28	2.89	146.10	3.65	403.61	8.07	104.28	3.48	755.28
2002	111.08	3.17	164.81	4.12	429.55	8.59	106.23	3.54	811.67
2003	88.47	2.53	166.05	4.15	413.66	8.27	108.67	3.62	776.85
2004	118.79	3.39	165.15	4.13	418.84	8.38	96.16	3.21	798.94
2005	96.66	2.76	152.08	3.80	385.08	7.70	94.34	3.14	728.16
2006	86.05	2.46	155.80	3.89	377.35	7.55	99.59	3.32	718.78
2007	96.75	2.76	163.34	4.08	382.64	7.65	97.24	3.24	739.96
2008	124.59	3.56	181.05	4.53	388.18	7.76	88.67	2.96	782.49
2009	102.49	2.93	127.57	3.19	357.46	7.15	89.75	2.99	677.27
2010	89.12	2.55	166.73	4.17	379.65	7.59	81.67	2.72	717.16
2011	100.46	2.87	133.83	3.35	315.79	6.32	90.39	3.01	640.48
2012	104.63	2.99	181.10	4.53	359.51	7.19	79.42	2.65	724.67
2013	77.52	2.21	162.40	4.06	351.23	7.02	83.08	2.77	674.23
2014	119.23	3.41	179.45	4.49	383.25	7.66	84.92	2.83	766.85
2015	121.02	3.46	193.33	4.83	433.50	8.67	90.83	3.03	838.68
2016	99.59	2.85	168.57	4.21	373.13	7.46	90.15	3.00	731.43
2017	120.18	3.43	180.91	4.52	380.19	7.60	91.99	3.07	773.27
2018	90.13	2.58	178.41	4.46	269.76	5.40	96.79	3.23	635.08
2019	111.60	3.19	214.23	5.36	446.20	8.92	76.28	2.54	848.32
2020	92.92	2.65	165.01	4.13	358.12	7.16	81.90	2.73	697.95
Maximum	124.59	3.56	214.23	5.36	454.46	9.09	108.67	3.62	848.32
Minimum	54.46	1.56	93.32	2.33	251.93	5.04	53.90	1.80	457.60
Mean	92.47	2.64	154.59	3.86	362.04	7.24	85.04	2.83	692.58

4.2.8 Crop water requirement (ETc) of Brinjal

The data on crop water requirement (ETc) of Brinjal determined for Aurangabad district along with mean values for different growth stages are shown in Table 4.16 and Fig.4.14. During the initial stage of the crop, total water requirements differ between 47.15 mm to 109.54 mm with mean water requirements differing between 1.57 mm day^{-1} to 3.65 mm day^{-1}. In the course of the developmental stage of the crop, total water requirements differ between 94.13 mm to 237.65 mm with mean water requirement differing between 2.09 mm day^{-1} to 5.28 mm day^{-1}. In the course of the mid-stage of the crop, total water requirements differ between 208.83 mm to 409.73 mm with mean water requirement differing between 5.22 mm day^{-1} to 10.24 mm day^{-1}. In the course of the late-season stage of the crop, total water requirements differ between 65.63 mm to 117.97 mm with mean water requirement differing between 2.63 mm day^{-1} to 4.72 mm day^{-1}. It is established from the above discussion that the variation in crop water requirement (ETc) is more at developmental and mid-season stages as compared to initial and maturity stages of the brinjal crop across the FAO-Penman-Monteith method.

Among the different years, the highest crop water requirement (ETc) was 842.84 mm observed during 2017. While the lowest value was 422.49 mm during the year 1998 and the average crop water requirement value was 650.94 mm. The similar result was found by Mehta and Pandey (2015) at Gujrat.

Table 4.16: Stage-wise crop water requirement (ETc) of Brinjal estimated by FAO- Penman-Monteith method

Year	Initial stage		Development		Mid-season		Late-season		Total
	Total	Mean	Total	Mean	Total	Mean	Total	Mean	
1991	50.80	1.69	94.13	2.09	230.99	5.77	86.91	3.48	462.83
1992	78.95	2.63	128.77	2.86	283.38	7.08	70.10	2.80	561.19
1993	60.39	2.01	121.96	2.71	260.20	6.50	70.82	2.83	513.37
1994	47.15	1.57	103.92	2.31	235.54	5.89	72.66	2.91	459.27
1995	71.83	2.39	156.60	3.48	303.11	7.58	77.34	3.09	608.88
1996	84.09	2.80	109.70	2.44	224.70	5.62	74.21	2.97	492.70
1997	56.57	1.89	137.03	3.05	275.45	6.89	76.91	3.08	545.95
1998	49.04	1.63	98.99	2.20	208.83	5.22	65.63	2.63	422.49
1999	75.95	2.53	166.81	3.71	336.72	8.42	108.62	4.34	688.09
2000	74.80	2.49	199.56	4.43	396.76	9.92	94.45	3.78	765.57
2001	90.76	3.03	151.81	3.37	335.34	8.38	110.20	4.41	688.11
2002	95.55	3.18	177.66	3.95	365.94	9.15	114.53	4.58	753.67
2003	77.30	2.58	171.16	3.80	342.56	8.56	117.97	4.72	708.99
2004	104.05	3.47	176.59	3.92	361.79	9.04	105.63	4.23	748.06
2005	85.39	2.85	158.57	3.52	319.98	8.00	103.94	4.16	667.89
2006	75.36	2.51	160.95	3.58	316.89	7.92	104.58	4.18	657.78
2007	84.60	2.82	170.38	3.79	323.20	8.08	107.24	4.29	685.43
2008	109.54	3.65	191.64	4.26	334.51	8.36	101.33	4.05	737.02
2009	93.69	3.12	131.88	2.93	297.02	7.43	101.23	4.05	623.82
2010	78.29	2.61	171.19	3.80	330.86	8.27	84.74	3.39	665.08
2011	92.13	3.07	136.77	3.04	263.52	6.59	94.66	3.79	587.08
2012	89.31	2.98	192.17	4.27	316.52	7.91	83.93	3.36	681.93
2013	67.37	2.25	166.05	3.69	312.11	7.80	75.60	3.02	621.13
2014	105.61	3.52	187.69	4.17	331.98	8.30	91.91	3.68	717.19
2015	103.11	3.44	207.86	4.62	381.56	9.54	95.56	3.82	788.09
2016	87.51	2.92	175.05	3.89	316.38	7.91	98.92	3.96	677.85
2017	109.44	3.65	237.65	5.28	409.73	10.24	86.03	3.44	842.84
2018	79.71	2.66	181.13	4.03	372.022	9.30	113.37	4.53	746.23
2019	91.26	3.04	231.19	5.14	399.15	9.98	84.57	3.38	806.17
2020	82.11	2.74	169.58	3.77	315.66	7.89	72.77	2.91	640.12
Maximum	109.54	3.65	237.65	5.28	409.73	10.24	117.97	4.72	842.84
Minimum	47.15	1.57	94.13	2.09	208.83	5.22	65.63	2.63	422.49
Mean	81.51	2.72	162.38	3.61	316.28	7.91	91.56	3.66	650.94

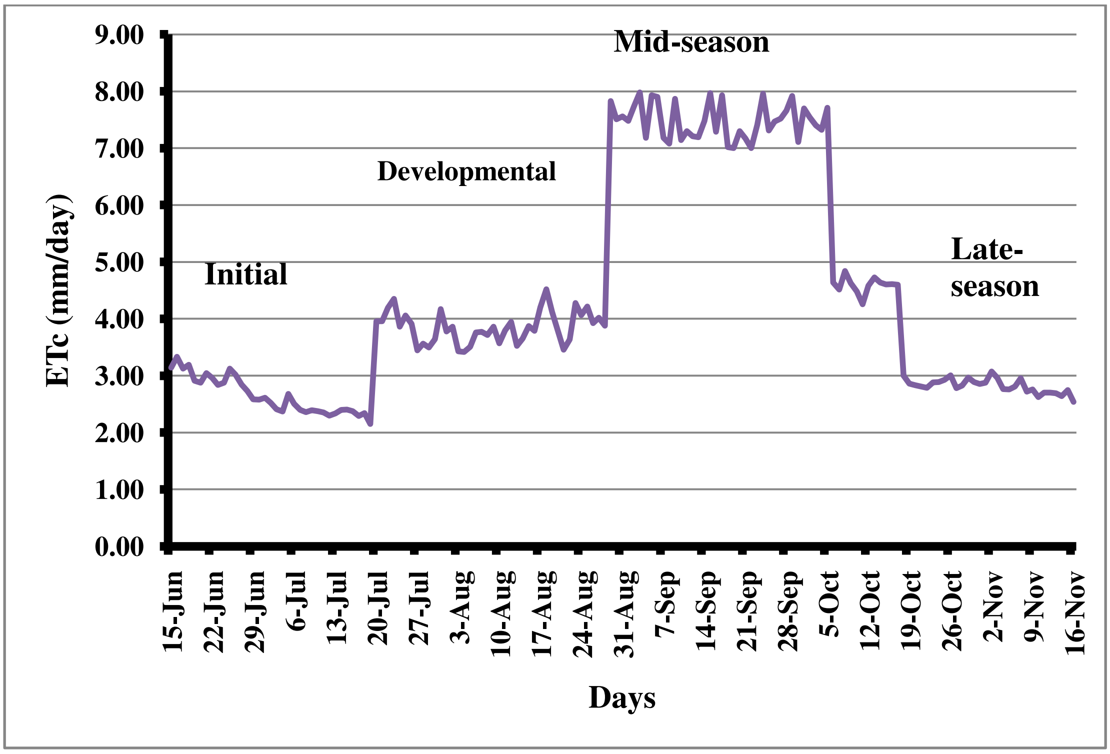

Fig. 4.13: Crop water requirement (ETc) (mm day^{-1}) of Tomato at different growth stages by FAO Penman-Monteith method

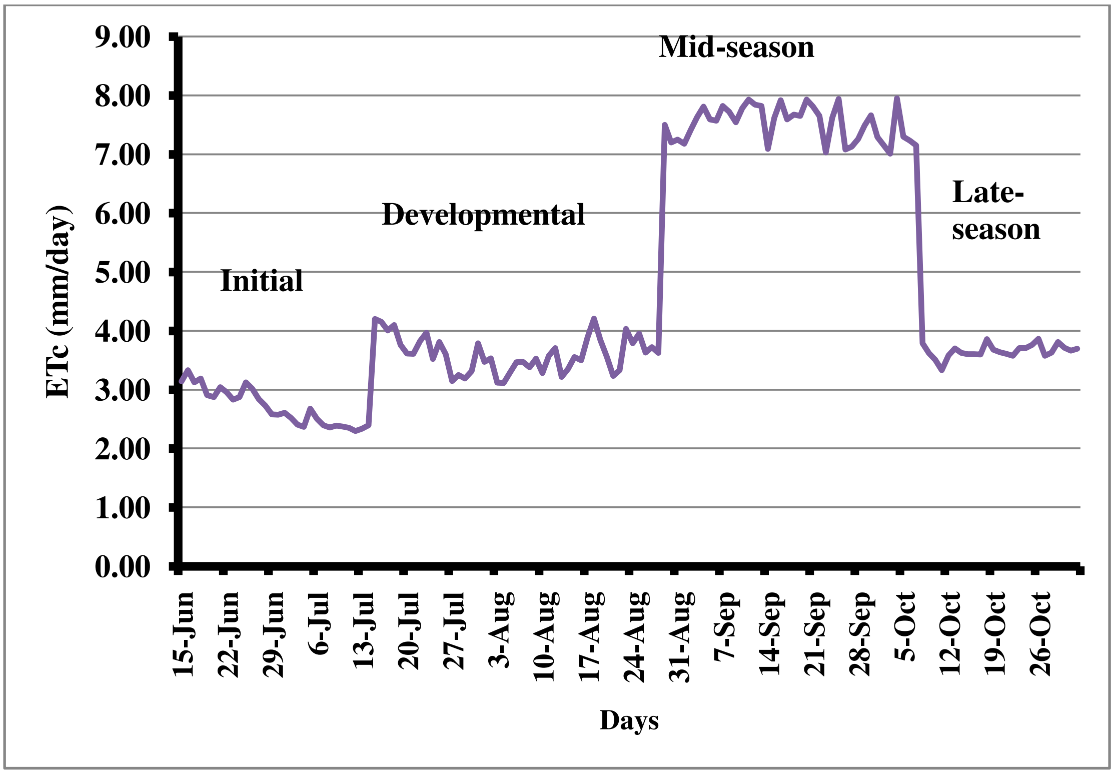

Fig. 4.14: Crop water requirement (ETc) (mm day^{-1}) of Brinjal at different growth stages by FAO Penman-Monteith method

CHAPTER -V

SUMMARY AND CONCLUSION

CHAPTER-V

SUMMARY AND CONCLUSIONS

The result acquired from the present study entitled **"Estimation of crop water requirement of major *kharif* crops in Aurangabad district"** presented and discussed in the foregoing chapters are summarized here one by one. In the present investigation, the Aurangabad district of the Marathwada region was chosen for estimating long-term average reference evapotranspiration (ETo) by all the methods. Crop coefficient (Kc) values of different crops were taken from FAO-56 paper for estimating crop water requirement, according to the climatic conditions of Aurangabad district. The present investigation was carried with the succeeding objectives.

1. To estimate reference evapotranspiration(ETo) on a daily, weekly, and monthly basis for major *kharif* crops (by FAO Penman-Monteith method)

2. To estimate crop water requirement (using FAO-56 Kc values) for major *kharif* crops

5.1. To estimate reference evapotranspiration (ETo) on a daily, weekly, and monthly basis for major *kharif* crops (by FAO Penman-Monteith method).

5.1.1 Mean daily variation in reference evapotranspiration (ETo)

Among the different methods, Pan evaporation based methods, Radiation based methods, Temperature based methods, and Energy balance based methods the estimated reference evapotranspiration (ETo) ranged from 0.12 to 19.88 mm day^{-1}. The mean maximum daily reference evapotranspiration (ETo) was 12.31 mm day^{-1} (Hargreaves-Samani method) and the mean minimum daily reference evapotranspiration (ETo) was 3.39 mm day^{-1} (Modified Penman method). By the Hargreaves-Samani method, the reference evapotranspiration (ETo) was highest and by the Modified Penman method, the reference evapotranspiration (ETo) was lowest at Aurangabad district.

5.1.2 Mean weekly variation in reference evapotranspiration (ETo)

Among the different methods, pan evaporation-based methods, radiation-based methods, temperature-based methods, energy balance-based methods are estimated reference evapotranspiration (ETo) ranging from 0.94 to 18.66 mm day^{-1}. The mean maximum weekly reference evapotranspiration (ETo) was 12.35 mm day^{-1} (Hargreaves-Samani method) and the mean minimum weekly reference evapotranspiration (ETo) was 3.39 mm day^{-1} (Modified Penman method). By the Hargreaves-Samani method, the reference evapotranspiration (ETo) is highest and by the Modified Penman method, the reference evapotranspiration (ETo) is lowest at Aurangabad district.

5.1.3 Mean monthly variation in reference evapotranspiration (ETo)

Among the different methods, pan evaporation based methods, radiation-based methods, temperature-based methods, energy balance based methods the estimated reference evapotranspiration (ETo) ranged from total mean maximum reference evapotranspiration (ETo) was 420.82 mm with mean 13.80 mm $month^{-1}$ (Hargreaves-Samani method) and total mean minimum reference evapotranspiration (ETo) was 122.29 mm with 4.30 mm $month^{-1}$ (Modified Penman method). By the Hargreaves-Samani method, the reference evapotranspiration (ETo) is highest and by the Modified Penman method, the reference evapotranspiration (ETo) is lowest at Aurangabad district.

5.1.3.4 Seasonal variation in reference evapotranspiration (ETo)

During the summer season, the maximum total seasonal reference evapotranspiration (ETo) was predicted by the Hargreaves-Samani method (1858.73 mm) and the minimum by the Modified Penman method (522.44 mm) with a mean of 937.89 mm. During the *kharif* season, the maximum total seasonal reference evapotranspiration (ETo) was predicted by the Hargreaves-Samani method (1407.99 mm) and the minimum by the Turc method (331.81 mm) with a mean of 627.54 mm. During the *rabi* season, the maximum total seasonal reference evapotranspiration (ETo) was predicted by the Hargreaves-Samani method (1836.16 mm) and the minimum by the Modified Penman method (340.70 mm) with a mean of 718.73 mm.

By the Hargreaves-Samani method, the reference evapotranspiration (ETo) is highest at Aurangabad district.

5.1.5 Annual variation in reference evapotranspiration (ETo)

The average annual reference evapotranspiration (ETo) for the FAO-Penman-Monteith method was 1714.33 mm. The maximum and minimum total reference evapotranspiration were 4484.75 mm and 1237.91 mm for the Hargreaves-Samani method and Modified Penman method respectively.

5.2 To estimate crop water requirement (using FAO-56 Kc values) for major *kharif* crops.

5.2.1 Crop water requirement (ETc) of Cotton

In the case of the cotton crop, variation in mean crop water requirement during the initial stage differs between 0.92 mm to 2.13 mm day^{-1}, during developmental stage 2.33 mm day^{-1} to 5.58 mm day^{-1}, during mid-season stage 5.21 mm day^{-1} to 9.25 mm day^{-1} and late-season stage crop water requirement (ETc) decreases gradually up to end of the crop season and differs between 1.20 mm day^{-1} to 2.13 mm day^{-1}.

5.2.2 Crop water requirement (ETc) of Soybean

The mean crop water requirement of soybean during the initial stage varies between 1.07 mm day^{-1} to 3.41 mm day^{-1}. During the developmental stage, the water requirement (ETc) of soybean increases continuously and it differs between 1.83 mm day^{-1} to 6.19 mm day^{-1}, during the mid-season stage, it further rises continuously and differs between 3.69 mm day^{-1} to 6.87 mm day^{-1} and during the late-season stage, crop water requirement (ETc) decreases gradually up to end of the crop season and differs between 1.26 mm day^{-1} to 2.63 mm day^{-1}.

5.2.3 Crop water requirement (ETc) of Pigeon pea

The mean crop water requirement of pigeon pea during the initial stage varies between 1.17 mm day^{-1} to 2.76 mm day^{-1}. During the developmental stage, the water requirement (ETc) of pigeon pea rises continuously and it differs between 2.59 mm day^{-1} to 5.33 mm day^{-1}, during the mid-season stage, it further rises continuously and differs between 5.21 mm day^{-1} to 9.17 mm day^{-1} and during the late-season stage, crop water requirement (ETc) decreases gradually up to end of the crop season and differs between 2.25 mm day^{-1} to 4.41 mm day^{-1}.

5.2.4 Crop water requirement (ETc) of Maize

The mean crop water requirement of maize during the initial stage varies between 0.83 mm day^{-1} to 2.09 mm day^{-1}. During the developmental stage, the water requirement (ETc) of maize rises continuously and it differs between 2.14 mm day^{-1} to 6.91 mm day^{-1}, during the mid-season stage, it further rises continuously and differs between 4.75 mm day^{-1} to 11.15 mm day^{-1} and during the late-season stage, crop water requirement (ETc) decreases gradually up to end of the crop season and differs between 0.94 mm day^{-1} to 2.94 mm $day^{-1.}$

5.2.5 Crop water requirement (ETc) of Pearl millet

The mean crop water requirement of pearl millet during the initial stage varies between 0.80 mm day^{-1} to 2.07 mm day^{-1}. During the developmental stage, the water requirement (ETc) of pearl millet increases continuously and it differs between 1.72 mm day^{-1} to 5.67 mm day^{-1}, during the mid-season stage, it further rises continuously and differs between 3.55 mm day^{-1} to 8.83 mm day^{-1} and during the late-season stage, crop water requirement (ETc) decreases progressively up to end of the crop season and differs between 0.69 mm day^{-1} to 1.54 mm day^{-1}.

5.2.6 Crop water requirement (ETc) of Onion

The mean crop water requirement of onion during the initial stage varies between 2.82 mm day^{-1} to 7.24 mm day^{-1}. During the developmental stage, the water requirement (ETc) of onion increases continuously and it varies between 1.30 mm day^{-1} to 4.40 mm day^{-1}, during the mid-season stage, it further increases continuously and differs between 2.42 mm day^{-1} to 4.88 mm day^{-1} and during the late-season stage, crop water requirement (ETc) decreases progressively up to end of the crop season and differs between 1.11 mm day^{-1} to 2.14 mm day^{-1}.

5.2.7 Crop water requirement (ETc) of Tomato

The mean crop water requirement of tomato during the initial stage varie between 1.56 mm day^{-1} to 3.56 mm day^{-1}. During the developmental stage, the water requirement (ETc) of tomato rises continuously and it differs between 2.33 mm day^{-1}

to 5.36 mm day^{-1}, during the mid-season stage, it further rises continuously and varies between 5.04 mm day^{-1} to 9.09 mm day^{-1} and during the late-season stage, crop water requirement (ETc) decreases gradually up to end of the crop season and differs between 1.80 mm day^{-1} to 3.62 mm day^{-1}.

5.2.8 Crop water requirement (ETc) of Brinjal

The mean crop water requirement of brinjal during the initial stage varies between 1.57 mm day^{-1} to 3.65 mm day^{-1}. During the developmental stage, the water requirement (ETc) of brinjal rises continuously and it differs between 2.09 mm day^{-1} to 5.28 mm day^{-1}, during the mid-season stage, it further rises continuously and differs between 5.22 mm day^{-1} to 10.24 mm day^{-1} and during the late-season stage, crop water requirement (ETc) decreases gradually up to end of the crop season and differs between 2.63 mm day^{-1} to 4.72 mm day^{-1}.

5.3 Conclusions

The reference evapotranspiration (ETo) was found to vary with time. The peak reference evapotranspiration (ETo) is observed during May and the lowest during December, Jensen and Haise method (1963) and Hargreaves method (1985) values were found to be closer with the FAO Penman-Monteith method for estimating reference evapotranspiration (ETo). reference evapotranspiration (ETo) estimated by Hargreaves method (1985) was highest. The result indicated that highest daily reference evapotranspiration (ETo) was 12.31 mm day^{-1} Hargreaves-Samani method (H-S method) and the lowest was 3.39 mm day^{-1} (Modified Penman method). The highest weekly reference evapotranspiration (ETo) was 12.35 mm day^{-1} (H-S method) and the lowest was 3.39 mm day^{-1} (Modified Penman method). The highest monthly reference evapotranspiration (ETo) was 420.82 mm (H-S method) and the lowest was 122.29 mm (Modified Penman method). During the summer season reference evapotranspiration (ETo) was found to vary between Modified Penman method (522.44 mm) to H-S method (1858.73 mm) while during *kharif* season it varied between Turc method (331.81 mm) to H-S method (1407.99 mm) and in *rabi* season it was between Modified Penman method (340.70 mm) to H-S method (1836.16 mm). The highest annual reference evapotranspiration (ETo) was 4484.75 mm (H-S method) and the lowest was 1237.91 mm (Modified Penman method).

The crop water requirement was found to be different from the stage of the crop. The maximum water requirement is found during the developmental and mid-season stages of the crop. It is minimum during the initial and maturity stages of the crop. For the Cotton crop the highest crop water requirement (ETc) has been observed in the year 2019 the value was 970.52 mm while the lowest value was 524.98 mm in the year 1998 and the average crop water requirement of all the year value was 797.24 mm. For the Soybean crop the highest crop water requirement (ETc) was observed in 2015 the value was 777.57 mm while the lowest value was 404.42 mm is observed in the year 1998 and the average total crop water requirement value was 619.62 mm.

For the Pigeon pea crop the highest crop water requirement (ETc) was observed in 2004 the value was 1039.79 mm while the lowest value was 596.98 mm was observed in the year 1998 and the average total crop water requirement value is 885.74 mm. For Maize crop among the different years, the highest crop water requirement (ETc) was 627.63 mm observed at 2019 and the values are while the lowest value was 292.51 mm at the year 1991 and the average crop water requirement value was 458.78 mm.

For Pearl millet crop the highest crop water requirement (ETc) was 508.02 mm observed in 2015 and the values are while the lowest value was 208.47 mm at the year 1991 and the average crop water requirement value was 371.57 mm. For the Onion crop among the different years, the highest crop water requirement (ETc) was 596.72 mm observed in 2015 while the lowest value was 309.36 mm at the year 1998 and the average crop water requirement value was 481.64 mm.

For Tomato crop, the highest crop water requirement (ETc) was 848.32 mm observed in 2019 while the lowest value was 457.60 mm at the year 1998 and the average crop water requirement value was 692.58 mm. For the Brinjal crop among the different years, the highest crop water requirement (ETc) was 842.84 mm observed in 2017. While the lowest value was 422.49 mm in the year 1998 and the average crop water requirement value was 650.94 mm.

LITERATURE CITED

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Abdelhadi, A. W., Hata, T., Tanakamaru, H., Tada, A., and Tariq, M.A. (2000). Estimation of crop water requirements in arid region using Penman-Monteith equation with derived crop coefficients : a case study on Acala cotton in Sudan Gezira irrigated scheme. *Agricultural Water Management.* 45(2), 203-214.

Ai, Z., Yang, Y., Wang, Q., Manevski, K., Wang, Q., Hu, Q., & Wang, J. (2018). Characteristics and influencing factors of crop coefficient for drip-irrigated cotton under plastic-mulched condition in arid environment. *Journal of Agricultural Meteorology*, 74(1), 1-8.

Al-Ghobari, H. M. (2000). Estimation of reference evapotranspiration for southern region of Saudi Arabia. *Irrigation science.* 19(2), 81-86.

Allen, R. G., Pereira, L. S., Raes, D. and Smith, M. (1998). Crop Evapotranspiration: Guidelines for computing crop water requirements. *Irrigation and Drainage Paper 56, Food and Agriculture Organization of the United Nations, Rome.* Pp. 300.

Allen, R. G., Pruitt, W. O., Raes, D., Smith, M., & Pereira, L. S. (2005). Estimating evaporation from bare soil and the crop coefficient for the initial period using common soils information. *Journal of Irrigation and Drainage Engineering*, 131(1), 14-23.

Alves, M. D. C., Sá Júnior, A. D., & Miranda, W. L. (2013). FAO Penman-Monteith equation for reference evapotranspiration from missing data.

Ayars, J. E. (2008). Water Requirement of Irrigated Garlic. *Transactions of the ASABE.* 51(5), 1683-1688.

Basanagouda R. F. and Suresh J. H., (2016). Identification of suitable method for crop assessment by estimating evapotranspiration-a case study. *International Journal of Agricultural Sciences.* 8(48): 2020-2023.

Bergamaschi, H., Radin, B., Rosa, L. M. G., Bergonci, J. I., Aragones, R., Santos, A. O.,and Langensiepen, M. (2001). Estimating maize water requirements using agrometeorological data.*Revista Argentina de Agrometeorologia.* 1(1), 23-7.

Bhagat, A. D., & Patil, M. A. (2014). Probability distribution functions of weekly reference crop evapotranspiration for Solapur district of Maharashtra. *In Journal of Agricultural Enggineering*. 7(2), 399-401.

Bhakar, S. R., and Singh, R. V. (2003). Estimation of reference evapotranspiration under sub-humid climatic condition of Rajasthan. Proceedings 37th *ISAE Annual Convention and Symposium held at CTAE, MPUAT, Udaipur* from Jan 29-30.

Boonwichai, S., Shrestha, S., Babel, M. S., Weesakul, S., & Datta, A. (2018). Climate change impacts on irrigation water requirement, crop water productivity and rice yield in the Songkhram River Basin, Thailand. *Journal of Cleaner Production*. 198, 1157-1164.

Carvalho, L. G. D., Evangelista, A. W. P., Oliveira, K. M. G., Silva, B. M., Alves, M.D.C., Sajunior, A. D., and Miranda, W. L. (2013). FAO Penman-Monteith equation for reference evapotranspiration from missing data. *Chile.* (2013)

Chavan, M. L., Khodke, U. M., & Patil, A. (2009). Comparison of several reference evapotranspiration methods for hot and humid regions in Maharashtra. *International Journal of Agricultural Engineering*. 2(2), 259-265.

Chowdhury, A., Gupta, D., Das, D. P., and Bhowmick, A. (2017). Estimation of reference evapotranspiration using artificial neural network for Mohanpur, Nadia District, West Bengal: a case study. *Int J Res Eng Technol,* 6, 125-130.

Christiansen, J.E. (1968). Pan evaporation and evapotranspiration from climatic data. *J. Irrig. And Drain. Div.,ASCE.* 94: 243-265.

Dauda, K.A., and Olayaki-Luqman, M. (2020). Comparision of reference evapotranspiration models for the agro-ecological zones of Nigeria. In *IOP conference series : Earth and Environmental Science.* (Vol. 445. No.1, p. 012015). IOP Publishingss

Debnath, S., Adamala, S., and Raghuwanshi, N. S. (2015). Sensitivity analysis of FAO-56 Penman-Monteith method for different agro-ecological regions of India. *Environmental Processes*. 2(4), 689-704.

Djaman, K., Irmak, S., and Futakuchi, K. (2017). Daily reference evapotranspiration estim,ation under limited data in Eastern Africa. *Journal of Irrigation and Drainage Engineering*. 143(4),06016015.

Donald, B. A. (1968). Water – Our second most important natural resource, 9 B.C.L. revised. (*http://lauxdigitalcommons.bc.edu./bclr*). 19(3): 535-552.

Doorenbos, J. and Pruitt, W. O. (1975). Guidelines for predicting crop water requirements, Irrigation and Drainage Paper 24, FAO of the United Nations, Rome. 179 pp.

Doorenbos, J. and Priutt, W. o. (1977). Crop water requirements. Irrigation and Drainage Paper 24, *Food and Agriculture Organization of United Nations, Rome*. 144 pp.

Gadge, S. B., Gorantiwar, S. D., Kumar, V., and Kothari, M. (2011). Estimation of crop water requirement based on Penman-Monteith approach under micro-irrigation system. *Journal of Agrometeorol.* 13 (1), 58-61.

Garg, T., Kumar, N., Chauhan, T., & Kango, R. (2016). Estimation of Reference Evapotranspiration using the FAO Penman-Monteith Method for Climatic Conditions of Himachal Pradesh, India. In Proceedings of National Conference: *Civil Engineering Conference–Innovation for Sustainability (*CEC–2016). (Vol. 9, p. 10th).

Guerra, E., Ventura, F., & Snyder, R. L. (2016). Crop coefficients: A literature review. *Journal of Irrigation and Drainage Engineering*. 142(3), 06015006.

Hajare, H. V., Raman, N. S., &Dharkar, E. J. (2008). New technique for evaluation of crop water requirement. *WSEAS Transactions on Environment and Development*. 5(4), 436-446.

Hargreaves G. H. and Samani, Z. A. (1985). Applied engineering in agriculture. 1: 96-99

Jadhav, P. B., Kadam, S. A., and Dahiwalkar, S. D. (2017). Trends and Variability of reference evapotranspiration (ETo) at Rahuri, Maharashtra. *Journal of Agriculture Research and* Technology. 42(3),75.

Jensen and Haise (1963). Fundamentals of Agro-Meteorology book. Mahi G. S. and Kingra P. K. pp. 118.

Kumar, S.(2017). Reference evapotranspiration (ETo) and irrigation water requirement of different crops in Bihar. *Journal of Agrometeorology*. 19(3), 238-241.

Kumari, M., Patel, N.R. and Khayruloevich, P. Y. (2013). Estimation of crop water requirement in rice-wheat system from multi-temporal AWIFS satellite data. *International Journal of Geomatics and Geosciences.* 4(1), 61-74.

Lang, D., Zheng, J., Shi, J., Liao, F., Ma, X., Wang, W., and Zhang, M.(2017). A comparative study of potential evapotranspiration estimation by eight methods with FAO-Penman-Monteith method in southwestern China. *Water*. 9(10),734.

Makkink, G. F.(1957). Testing the Penman formula by means of lysimeter. *J. Inst. Water Engg.* 11(3): 277-288.

Mane, M.E.(2013), Impact of Climate Change on Water Requirement and Crop Yeild in Central Vidarbha Agro-Climatic Region of Maharashtra (Doctoral dissertation, IARI, Division of Water Science and Technology, New Delhi).

Mehta, R., and Pandey, V. (2015). Reference evapotranspiration (ETo) and crop water requirement (ETc) of wheat and maize in Gujarat. *Journal of Agrometeorology*. 17(1), 107.

Memon, A.V., and Jamsa, S. (2018). Crop water requirement and irrigation scheduling of soybean and tomato crop using CROPWAT 8.0. *International Research Journal of Engineering and Technology,* 5(9), 669-671.

Meshram, D. T., Gorantiwar, S. D., Mittal, H. K., & Purohit, R. C. (2010). Comparison of reference crop evapotranspiration methods in western part of Maharashtra state. *Journal of Agrometeorology*. 12(1), 44-46.

Monteith, J. L. (1965). Evaporation and environment. *Symposia Society Experimental Biology.* 19: 205-224.

Naheed, G., and Rasul, G. (2010). Recent water requirement of cotton crop in Pakistan. *Pakistan Journal of Meteorology.* 6(12), 75-84.

Nandagiri, L., & Kovoor, G. M. (2006). Performance evaluation of reference evapotranspiration equations across a range of Indian climates. *Journal of irrigation and drainage engineering*. 132(3), 238-249.

Panchal, K. D., Sharma, P. J., Loliyana, V. D., and Timbadiya, P. V. (2016). Assessment of reference evapotranspiration estimation methods for Purna river basin, India. *National Conference on Water Resources and Flood Management with special reference to Flood Modelling.* October 14-15, 2016 SVNIT Surat.

Pakhale G., Gupta Prasun & Nale, Jyoti (2010) Crop and Irrigation Water Requirement Estimation By Remote Sensing and GIS: A case study of Karnal district, Haryana, India *International Journal of Engineering and Technology*, **2**(4), 207-211.

Paredes, P., Pereira, L. S., Almorox, J., and Darouich, H. (2013). Reference grass evapotranspiration with reduced data sets: Parameterization of the FAO Penman-Monteith temperature approach and the Hargeaves-Samani equation using local climatic variables. *Agricultural Water Management*. 240, 106210.

Phad, S., Dakhore, K. K., & Sayyad, R. S. (2020). Estimation of reference evapotranspiration (ETo) at Parbhani, Maharashtra. *MAUSAM*. 71(1), 145-148.

Priestly, C. H. B. and Taylor, R. J. (1972). On the assessment of surface heat flux and evaporation using large scale parameters. *Mon. Weath. Rev.* 100: 81-92.

Ragab, R., Evans, J. G., Battilani, A., and Solimando, D. (2017). Towards accurate estimation of crop water requirement without the crop coefficient Kc : New approach using modern technologies. *Irrigation and Drainage.* 66(4), 469-477.

Rao, A. S., and Poonia, S. (2011). Climate change impact on crop water requirements in arid Rajasthan.

Rao, B. B., Sandeep, V. M., Chowdary, P. S., Pramod, V. P., & Rao, V. U. M. (2013). Reference crop evapotranspiration over India: A comparison of estimates from open pan with Penman-Monteith method. *Journal of Agrometeorology*. 15(2), 108-114.

Sabziparvar, A. A., and Tabari, H. (2010). Regional estimation of reference evapotranspiration in arid and semiarid regions. *Journal of Irrigation and Drainage Engineering*. 136(10), 724-731.

Sachan, S., Lohani, A., and Chandola, V. (2016). Assessment of adequacy in canal irrigated system for an existing cropping pattern in upper Bhima basin of Maharashtra. *Current Advances in Agricultural Sciences (An International Journal)*, 8(2), 156-162.

Sharghi, T., Bari, A. H., Asadi, M. A., & Kousari, M. (2010). Estimation of Reference Evapotranspiration by FAO-Penman-Monteith method and its Zonation in YAZD, Province. *Arid Biom Scientific and Research Journal.* 1(1), 25-33,2010

Singh, R., Singh, K., and Bhandarkar, D.M. (2014). Estimation of water requirement for soybean (*Glycine max*) and wheat (*Triticum aestivum*) under vertisols of Madhya Pradesh. *Indian Journal of Agriculture Science.* 84, 190-197.

Soundarrajan, D., Vijayalakshmi, M. M., Partheeban, P., and Poongothai, S. (2014). A procedure for estimating evapotranspiration and comparision of various models for crop water requirement at Kancheepuram district. *National Journal on Chembiosis.*5(1).

Tarate, B. S., and Awari, H. W. (2017). Estimation of reference evapotranspiration for Parbhani district. *International Journal of Agricultural Engineering*. 10(1), 51-54.

Turc, L., (1961). Evaluation des besoins en eau d'irrigation, evapotranspiration potentielle, formule climatique simplifiee ET mise a jour, (in French). *Ann. Agron.* 12:13-49.

Varija, K. (2015). Comparision of different RET methods at different climatic conditions. *I-Manager's Journal on Civil Engineering,* 5(3), 16.

Xu, C., Zhang, X., Zhang, J., Chen, Y., Yami, T. L., and Hong, Y. (2021). Estimation of Crop Water Requirement Based on Planting Structure Extraction from Multi-Temporal MODIS EVI. *Water Resources Management.* 35(7), 2231-2247.

Yoder, R.E., Odhiambo, L.O. and Wright, W.C (2005). Evaluation of methods for estimating daily reference crop evapotranspiration at sites in the humid Southern United States. *Applied Engineering in Agriculture,* 21(2), 197-202.

Zhou, T., Wu, P., Sun, S., Li, X., Wang, Y., & Luan, X. (2017). Impact of future climate change on regional crop water requirement—a case study of hetao irrigation District, China. *Water*, 9(6), 429.

APPENDICES

Appendix I

Step wise procedure for computation of reference evapotranspiration in MS Excel

Date	Lat	Lat	Alt.	JD	Tmax	Tmin	RH	RH	BSS	WS	T	u2	e	e	es	Ea	es-ea	Term	Term	Term	Ra	Rs	Rso	Rns	Rnl	Rn	ETo
	(°)	(Min.)	(Z)				max	min	n	uz	mean		Tmax	Tmin	SVP	AVP	VPD	sin	cos	sinws							
1-Jan	19	51	587	1	31.0	12.5	72	25	7.2	3.7	21.8	1.0	4.5	1.4	3.0	1.1	2.7	-0.2	0.9	0.99	26.0	12.9	19.5	10.0	4.0	6.0	3.6
2-Jan	19	51	587	2	30.0	12.0	79	28	9.0	4.1	21.0	1.1	4.2	1.4	2.8	1.1	2.4	-0.2	0.9	0.99	26.0	16.2	19.5	12.5	5.4	7.1	3.9
3-Jan	19	51	587	3	29.0	13.0	71	42	6.8	3.8	21.0	1.0	4.0	1.5	2.8	1.4	2.3	-0.2	0.9	0.99	26.0	12.3	19.5	9.4	3.2	6.2	3.5
4-Jan	19	51	587	4	30.0	13.0	81	43	8.9	4.4	21.5	1.1	4.2	1.5	2.9	1.5	2.3	-0.2	0.9	0.99	26.1	16.1	19.6	12.4	4.7	7.7	4.1
5-Jan	19	51	587	5	31.0	14.0	71	55	9.0	5.1	22.5	1.3	4.5	1.6	3.0	1.8	2.8	-0.2	0.9	0.99	26.2	16.3	19.6	12.5	4.4	8.1	4.9
6-Jan	19	51	587	6	29.5	13.0	66	21	9.6	4.8	21.3	1.2	4.1	1.5	2.8	0.9	2.4	-0.2	0.9	0.99	26.2	17.4	19.7	13.4	6.4	7.0	4.1
7-Jan	19	51	587	7	28.0	13.5	67	46	8.9	4.5	20.8	1.2	3.8	1.5	2.7	1.4	2.2	-0.2	0.9	0.99	26.3	16.1	19.7	12.4	4.9	7.6	4.0
8-Jan	19	51	587	8	27.0	14.0	65	48	6.2	4.6	20.5	1.2	3.6	1.6	2.6	1.4	2.2	-0.2	0.9	0.99	26.3	11.3	19.8	8.7	2.7	6.0	3.6
9-Jan	19	51	587	9	29.0	12.0	70	42	9.0	4.2	20.5	1.1	4.0	1.4	2.7	1.3	2.5	-0.2	0.9	0.99	26.4	16.4	19.8	12.6	5.0	7.6	4.1
10-Jan	19	51	587	10	30.5	11.5	80	25	9.0	3.6	21.0	0.9	4.4	1.4	2.9	1.1	2.5	-0.2	0.9	0.99	26.5	16.4	19.9	12.6	5.5	7.2	3.8
11-Jan	19	51	587	11	30.0	13.0	73	39	9.0	4.5	21.5	1.2	4.2	1.5	2.9	1.4	2.5	-0.2	0.9	0.99	26.5	16.4	19.9	12.7	5.0	7.7	4.3
12-Jan	19	51	587	12	31.0	12.0	80	39	9.9	3.1	21.5	0.8	4.5	1.4	2.9	1.4	2.5	-0.2	0.9	0.99	26.6	18.1	20.0	14.0	5.6	8.4	3.9
13-Jan	19	51	587	13	31.0	14.0	71	44	9.5	5.0	22.5	1.3	4.5	1.6	3.0	1.6	2.6	-0.2	0.9	0.99	26.7	17.4	20.0	13.4	5.1	8.3	4.7
14-Jan	19	51	587	14	30.5	14.0	66	44	9.1	3.9	22.3	1.0	4.4	1.6	3.0	1.5	2.6	-0.2	0.9	0.99	26.8	16.7	20.1	12.9	4.9	8.0	4.2
15-Jan	19	51	587	15	31.5	15.0	81	38	9.8	5.0	23.3	1.3	4.6	1.7	3.2	1.6	2.8	-0.2	0.9	0.99	26.9	18.1	20.2	13.9	5.4	8.5	4.9
16-Jan	19	51	587	16	31.0	15.0	64	34	9.4	2.8	23.0	0.7	4.5	1.7	3.1	1.3	2.7	-0.2	0.9	0.99	27.0	17.4	20.2	13.4	5.5	7.9	3.7
17-Jan	19	51	587	17	32.0	13.0	79	35	9.5	2.2	22.5	0.6	4.8	1.5	3.1	1.4	2.9	-0.2	0.9	0.99	27.1	18.5	20.3	14.3	5.8	8.5	3.7
18-Jan	19	51	587	18	30.0	12.0	70	18	9.3	2.6	21.0	0.7	4.2	1.4	2.8	0.9	2.4	-0.2	0.9	0.99	27.2	18.6	20.4	14.3	6.8	7.5	3.4
19-Jan	19	51	587	19	29.0	11.5	69	41	9.1	4.0	20.3	1.0	4.0	1.4	2.7	1.3	2.3	-0.2	0.9	0.99	27.3	18.6	20.4	14.3	5.8	8.5	4.1
20-Jan	19	51	587	20	29.0	12.0	63	42	9.0	3.9	20.5	1.0	4.0	1.4	2.7	1.3	2.3	-0.2	0.9	0.99	27.4	18.7	20.5	14.4	5.8	8.5	4.2
21-Jan	19	51	587	21	29.5	12.0	70	37	9.9	3.3	20.8	0.9	4.1	1.4	2.8	1.3	2.2	-0.2	0.9	0.99	27.5	18.7	20.6	14.4	5.9	8.5	3.8
22-Jan	19	51	587	22	28.0	11.5	79	55	9.1	2.7	19.8	0.7	3.8	1.4	2.6	1.6	2.4	-0.2	0.9	0.99	27.6	18.8	20.7	14.5	5.2	9.2	3.9
23-Jan	19	51	587	23	27.5	10.5	77	18	9.2	4.3	19.0	1.1	3.7	1.3	2.5	0.8	2.2	-0.2	0.9	0.99	27.7	18.8	20.8	14.5	6.7	7.8	4.1
24-Jan	19	51	587	24	25.0	9.0	88	27	9.6	3.7	17.0	1.0	3.2	1.1	2.2	0.9	2.0	-0.2	0.9	0.99	27.8	18.1	20.8	14.0	5.9	8.1	3.7
25-Jan	19	51	587	25	25.0	8.0	66	19	9.3	3.7	16.5	1.0	3.2	1.1	2.1	0.7	1.9	-0.2	0.9	0.99	27.9	17.6	20.9	13.6	6.2	7.4	3.6
26-Jan	19	51	587	26	27.5	9.0	63	18	9.2	5.3	18.3	1.4	3.7	1.1	2.4	0.7	2.2	-0.2	0.9	0.99	28.0	19.0	21.0	14.6	6.9	7.7	4.5
27-Jan	19	51	587	27	25.0	9.5	68	20	9.1	4.5	17.3	1.2	3.2	1.2	2.2	0.7	1.7	-0.2	0.9	0.99	28.1	19.1	21.1	14.7	6.7	7.9	3.8
28-Jan	19	51	587	28	26.8	9.0	59	44	9.0	2.7	17.9	0.7	3.5	1.1	2.3	1.1	1.9	-0.2	0.9	0.99	28.2	19.1	21.2	14.7	5.9	8.8	3.5
29-Jan	19	51	587	29	28.0	8.0	77	46	9.3	3.0	18.0	0.8	3.8	1.1	2.4	1.3	2.1	-0.2	0.9	0.99	28.4	19.2	21.3	14.8	5.6	9.2	3.9
30-Jan	19	51	587	30	27.0	10.0	61	29	9.1	4.9	18.5	1.3	3.6	1.2	2.4	0.9	2.2	-0.2	1.0	0.99	28.5	19.2	21.4	14.8	6.4	8.4	4.5
31-Jan	19	51	587	31	25.0	10.0	51	20	9.0	5.0	17.5	1.3	3.2	1.2	2.2	0.6	2.0	-0.2	1.0	0.99	28.6	19.3	21.5	14.9	6.9	7.9	4.2

Appendix II

Step wise procedure for computation of crop water requirement of cotton crop in MS Excel

Date	Lat	Lat	Alt.	JD	Tmax	Tmin	RH	RH	BSS	WS	T	e	e	es	ea	es-ea	Ra	Rs	Rso	Rns	Rnl	Rn	ETo	Cotton			Crop water req.		
	(°)	(Min.)	(Z)				max	min	n	uz	mean	Tmax	Tmin	SVP	AVP	VPD								Kcini	Kcmid	Kcend	ini	mid	end
1-Jan	19	51	587	1	31.0	12.5	72	25	7.2	3.7	21.8	4.5	1.4	3.0	1.1	2.7	26.0	12.9	19.5	10.0	4.0	6.0	3.6	0.35	1.15	0.50	1.3	4.43	1.92
2-Jan	19	51	587	2	30.0	12.0	79	28	9.0	4.1	21.0	4.2	1.4	2.8	1.1	2.4	26.0	16.2	19.5	12.5	5.4	7.1	3.9	0.35	1.15	0.50	1.0	3.20	1.39
3-Jan	19	51	587	3	29.0	13.0	71	42	6.8	3.8	21.0	4.0	1.5	2.8	1.4	2.3	26.0	12.3	19.5	9.4	3.2	6.2	3.5	0.35	1.15	0.50	1.8	5.78	2.51
4-Jan	19	51	587	4	30.0	13.0	81	43	8.9	4.4	21.5	4.2	1.5	2.9	1.5	2.3	26.1	16.1	19.6	12.4	4.7	7.7	4.1	0.35	1.15	0.50	1.8	5.87	2.55
5-Jan	19	51	587	5	31.0	14.0	71	55	9.0	5.1	22.5	4.5	1.6	3.0	1.8	2.8	26.2	16.3	19.6	12.5	4.4	8.1	4.9	0.35	1.15	0.50	1.2	4.05	1.76
6-Jan	19	51	587	6	29.5	13.0	66	21	9.6	4.8	21.3	4.1	1.5	2.8	0.9	2.4	26.2	17.4	19.7	13.4	6.4	7.0	4.1	0.35	1.15	0.50	1.2	3.99	1.74
7-Jan	19	51	587	7	28.0	13.5	67	46	8.9	4.5	20.8	3.8	1.5	2.7	1.4	2.2	26.3	16.1	19.7	12.4	4.9	7.6	4.0	0.35	1.15	0.50	1.6	5.24	2.28
8-Jan	19	51	587	8	27.0	14.0	65	48	6.2	4.6	20.5	3.6	1.6	2.6	1.4	2.2	26.3	11.3	19.8	8.7	2.7	6.0	3.6	0.35	1.15	0.50	1.5	4.79	2.08
9-Jan	19	51	587	9	29.0	12.0	70	42	9.0	4.2	20.5	4.0	1.4	2.7	1.3	2.5	26.4	16.4	19.8	12.6	5.0	7.6	4.1	0.35	1.15	0.50	1.3	4.14	1.80
10-Jan	19	51	587	10	30.5	11.5	80	25	9.0	3.6	21.0	4.4	1.4	2.9	1.1	2.5	26.5	16.4	19.9	12.6	5.5	7.2	3.8	0.35	1.15	0.50	1.4	4.74	2.06
11-Jan	19	51	587	11	30.0	13.0	73	39	9.0	4.5	21.5	4.2	1.5	2.9	1.4	2.5	26.5	16.4	19.9	12.7	5.0	7.7	4.3	0.35	1.15	0.50	1.3	4.36	1.90
12-Jan	19	51	587	12	31.0	12.0	80	39	9.9	3.1	21.5	4.5	1.4	2.9	1.4	2.5	26.6	18.1	20.0	14.0	5.6	8.4	3.9	0.35	1.15	0.50	1.4	4.66	2.03
13-Jan	19	51	587	13	31.0	14.0	71	44	9.5	5.0	22.5	4.5	1.6	3.0	1.6	2.6	26.7	17.4	20.0	13.4	5.1	8.3	4.7	0.35	1.15	0.50	1.2	4.08	1.77
14-Jan	19	51	587	14	30.5	14.0	66	44	9.1	3.9	22.3	4.4	1.6	3.0	1.5	2.6	26.8	16.7	20.1	12.9	4.9	8.0	4.2	0.35	1.15	0.50	1.4	4.62	2.01
15-Jan	19	51	587	15	31.5	15.0	81	38	9.8	5.0	23.3	4.6	1.7	3.2	1.6	2.8	26.9	18.1	20.2	13.9	5.4	8.5	4.9	0.35	1.15	0.50	1.5	4.85	2.11
16-Jan	19	51	587	16	31.0	15.0	64	34	9.4	2.8	23.0	4.5	1.7	3.1	1.3	2.7	27.0	17.4	20.2	13.4	5.5	7.9	3.7	0.35	1.15	0.50	1.3	4.42	1.92
17-Jan	19	51	587	17	32.0	13.0	79	35	9.5	2.2	22.5	4.8	1.5	3.1	1.4	2.9	27.1	18.5	20.3	14.3	5.8	8.5	3.7	0.35	1.15	0.50	1.4	4.68	2.04
18-Jan	19	51	587	18	30.0	12.0	70	18	9.3	2.6	21.0	4.2	1.4	2.8	0.9	2.4	27.2	18.6	20.4	14.3	6.8	7.5	3.4	0.35	1.15	0.50	1.0	3.16	1.37
19-Jan	19	51	587	19	29.0	11.5	69	41	9.1	4.0	20.3	4.0	1.4	2.7	1.3	2.3	27.3	18.6	20.4	14.3	5.8	8.5	4.1	0.35	1.15	0.50	1.6	5.37	2.33
20-Jan	19	51	587	20	29.0	12.0	63	42	9.0	3.9	20.5	4.0	1.4	2.7	1.3	2.3	27.4	18.7	20.5	14.4	5.8	8.5	4.2	0.35	1.15	0.50	1.8	5.93	2.58
21-Jan	19	51	587	21	29.5	12.0	70	37	9.9	3.3	20.8	4.1	1.4	2.8	1.3	2.2	27.5	18.7	20.6	14.4	5.9	8.5	3.8	0.35	1.15	0.50	1.4	4.59	1.99
22-Jan	19	51	587	22	28.0	11.5	79	55	9.1	2.7	19.8	3.8	1.4	2.6	1.6	2.4	27.6	18.8	20.7	14.5	5.2	9.2	3.9	0.35	1.15	0.50	1.6	5.22	2.27
23-Jan	19	51	587	23	27.5	10.5	77	18	9.2	4.3	19.0	3.7	1.3	2.5	0.8	2.2	27.7	18.8	20.8	14.5	6.7	7.8	4.1	0.35	1.15	0.50	1.6	5.11	2.22
24-Jan	19	51	587	24	25.0	9.0	88	27	9.6	3.7	17.0	3.2	1.1	2.2	0.9	2.0	27.8	18.1	20.8	14.0	5.9	8.1	3.7	0.35	1.15	0.50	1.9	6.14	2.67
25-Jan	19	51	587	25	25.0	8.0	66	19	9.3	3.7	16.5	3.2	1.1	2.1	0.7	1.9	27.9	17.6	20.9	13.6	6.2	7.4	3.6	0.35	1.15	0.50	1.3	4.25	1.85
26-Jan	19	51	587	26	27.5	9.0	63	18	9.2	5.3	18.3	3.7	1.1	2.4	0.7	2.2	28.0	19.0	21.0	14.6	6.9	7.7	4.5	0.35	1.15	0.50	1.4	4.69	2.04
27-Jan	19	51	587	27	25.0	9.5	68	20	9.1	4.5	17.3	3.2	1.2	2.2	0.7	1.7	28.1	19.1	21.1	14.7	6.7	7.9	3.8	0.35	1.15	0.50	1.1	3.60	1.56
28-Jan	19	51	587	28	26.8	9.0	59	44	9.0	2.7	17.9	3.5	1.1	2.3	1.1	1.9	28.2	19.1	21.2	14.7	5.9	8.8	3.5	0.35	1.15	0.50	1.2	4.06	1.76
29-Jan	19	51	587	29	28.0	8.0	77	46	9.3	3.0	18.0	3.8	1.1	2.4	1.3	2.1	28.4	19.2	21.3	14.8	5.6	9.2	3.9	0.35	1.15	0.50	1.3	4.35	1.89
30-Jan	19	51	587	30	27.0	10.0	61	29	9.1	4.9	18.5	3.6	1.2	2.4	0.9	2.2	28.5	19.2	21.4	14.8	6.4	8.4	4.5	0.35	1.15	0.50	0.8	2.68	1.17
31-Jan	19	51	587	31	25.0	10.0	51	20	9.0	5.0	17.5	3.2	1.2	2.2	0.6	2.0	28.6	19.3	21.5	14.9	6.9	7.9	4.2	0.35	1.15	0.50	1.0	3.19	1.39

Appendix III

Step wise procedure for computation of crop water requirement of Pigeon pea crop in MS Excel

Date	Lat	Lat	Alt.	JD	Tmax	Tmin	RH	RH	BSS	WS	T	e	e	es	ea	es-ea	Ra	Rs	Rso	Rns	Rnl	Rn	ETo	Pigeon pea			Crop water req.		
	(°)	(Min.)	(Z)				max	min	n	uz	mean	Tmax	Tmin	SVP	AVP	VPD								Kcini	Kcmid	Kcend	ini	mid	end
1-Jan	19	51	587	1	31.0	12.5	72	25	7.2	3.7	21.8	4.5	1.4	3.0	1.1	2.7	26.0	12.9	19.5	10.0	4.0	6.0	3.6	0.50	1.15	1.10	1.9	4.43	4.23
2-Jan	19	51	587	2	30.0	12.0	79	28	9.0	4.1	21.0	4.2	1.4	2.8	1.1	2.4	26.0	16.2	19.5	12.5	5.4	7.1	3.9	0.50	1.15	1.10	1.4	3.20	3.06
3-Jan	19	51	587	3	29.0	13.0	71	42	6.8	3.8	21.0	4.0	1.5	2.8	1.4	2.3	26.0	12.3	19.5	9.4	3.2	6.2	3.5	0.50	1.15	1.10	2.5	5.78	5.53
4-Jan	19	51	587	4	30.0	13.0	81	43	8.9	4.4	21.5	4.2	1.5	2.9	1.5	2.3	26.1	16.1	19.6	12.4	4.7	7.7	4.1	0.50	1.15	1.10	2.6	5.87	5.61
5-Jan	19	51	587	5	31.0	14.0	71	55	9.0	5.1	22.5	4.5	1.6	3.0	1.8	2.8	26.2	16.3	19.6	12.5	4.4	8.1	4.9	0.50	1.15	1.10	1.8	4.05	3.87
6-Jan	19	51	587	6	29.5	13.0	66	21	9.6	4.8	21.3	4.1	1.5	2.8	0.9	2.4	26.2	17.4	19.7	13.4	6.4	7.0	4.1	0.50	1.15	1.10	1.7	3.99	3.82
7-Jan	19	51	587	7	28.0	13.5	67	46	8.9	4.5	20.8	3.8	1.5	2.7	1.4	2.2	26.3	16.1	19.7	12.4	4.9	7.6	4.0	0.50	1.15	1.10	2.3	5.24	5.01
8-Jan	19	51	587	8	27.0	14.0	65	48	6.2	4.6	20.5	3.6	1.6	2.6	1.4	2.2	26.3	11.3	19.8	8.7	2.7	6.0	3.6	0.50	1.15	1.10	2.1	4.79	4.59
9-Jan	19	51	587	9	29.0	12.0	70	42	9.0	4.2	20.5	4.0	1.4	2.7	1.3	2.5	26.4	16.4	19.8	12.6	5.0	7.6	4.1	0.50	1.15	1.10	1.8	4.14	3.96
10-Jan	19	51	587	10	30.5	11.5	80	25	9.0	3.6	21.0	4.4	1.4	2.9	1.1	2.5	26.5	16.4	19.9	12.6	5.5	7.2	3.8	0.50	1.15	1.10	2.1	4.74	4.53
11-Jan	19	51	587	11	30.0	13.0	73	39	9.0	4.5	21.5	4.2	1.5	2.9	1.4	2.5	26.5	16.4	19.9	12.7	5.0	7.7	4.3	0.50	1.15	1.10	1.9	4.36	4.17
12-Jan	19	51	587	12	31.0	12.0	80	39	9.9	3.1	21.5	4.5	1.4	2.9	1.4	2.5	26.6	18.1	20.0	14.0	5.6	8.4	3.9	0.50	1.15	1.10	2.0	4.66	4.46
13-Jan	19	51	587	13	31.0	14.0	71	44	9.5	5.0	22.5	4.5	1.6	3.0	1.6	2.6	26.7	17.4	20.0	13.4	5.1	8.3	4.7	0.50	1.15	1.10	1.8	4.08	3.90
14-Jan	19	51	587	14	30.5	14.0	66	44	9.1	3.9	22.3	4.4	1.6	3.0	1.5	2.6	26.8	16.7	20.1	12.9	4.9	8.0	4.2	0.50	1.15	1.10	2.0	4.62	4.42
15-Jan	19	51	587	15	31.5	15.0	81	38	9.8	5.0	23.3	4.6	1.7	3.2	1.6	2.8	26.9	18.1	20.2	13.9	5.4	8.5	4.9	0.50	1.15	1.10	2.1	4.85	4.64
16-Jan	19	51	587	16	31.0	15.0	64	34	9.4	2.8	23.0	4.5	1.7	3.1	1.3	2.7	27.0	17.4	20.2	13.4	5.5	7.9	3.7	0.50	1.15	1.10	1.9	4.42	4.23
17-Jan	19	51	587	17	32.0	13.0	79	35	9.5	2.2	22.5	4.8	1.5	3.1	1.4	2.9	27.1	18.5	20.3	14.3	5.8	8.5	3.7	0.50	1.15	1.10	2.0	4.68	4.48
18-Jan	19	51	587	18	30.0	12.0	70	18	9.3	2.6	21.0	4.2	1.4	2.8	0.9	2.4	27.2	18.6	20.4	14.3	6.8	7.5	3.4	0.50	1.15	1.10	1.4	3.16	3.02
19-Jan	19	51	587	19	29.0	11.5	69	41	9.1	4.0	20.3	4.0	1.4	2.7	1.3	2.3	27.3	18.6	20.4	14.3	5.8	8.5	4.1	0.50	1.15	1.10	2.3	5.37	5.13
20-Jan	19	51	587	20	29.0	12.0	63	42	9.0	3.9	20.5	4.0	1.4	2.7	1.3	2.3	27.4	18.7	20.5	14.4	5.8	8.5	4.2	0.50	1.15	1.10	2.6	5.93	5.67
21-Jan	19	51	587	21	29.5	12.0	70	37	9.9	3.3	20.8	4.1	1.4	2.8	1.3	2.2	27.5	18.7	20.6	14.4	5.9	8.5	3.8	0.50	1.15	1.10	2.0	4.59	4.39
22-Jan	19	51	587	22	28.0	11.5	79	55	9.1	2.7	19.8	3.8	1.4	2.6	1.6	2.4	27.6	18.8	20.7	14.5	5.2	9.2	3.9	0.50	1.15	1.10	2.3	5.22	4.99
23-Jan	19	51	587	23	27.5	10.5	77	18	9.2	4.3	19.0	3.7	1.3	2.5	0.8	2.2	27.7	18.8	20.8	14.5	6.7	7.8	4.1	0.50	1.15	1.10	2.2	5.11	4.89
24-Jan	19	51	587	24	25.0	9.0	88	27	9.6	3.7	17.0	3.2	1.1	2.2	0.9	2.0	27.8	18.1	20.8	14.0	5.9	8.1	3.7	0.50	1.15	1.10	2.7	6.14	5.87
25-Jan	19	51	587	25	25.0	8.0	66	19	9.3	3.7	16.5	3.2	1.1	2.1	0.7	1.9	27.9	17.6	20.9	13.6	6.2	7.4	3.6	0.50	1.15	1.10	1.8	4.25	4.06
26-Jan	19	51	587	26	27.5	9.0	63	18	9.2	5.3	18.3	3.7	1.1	2.4	0.7	2.2	28.0	19.0	21.0	14.6	6.9	7.7	4.5	0.50	1.15	1.10	2.0	4.69	4.49
27-Jan	19	51	587	27	25.0	9.5	68	20	9.1	4.5	17.3	3.2	1.2	2.2	0.7	1.7	28.1	19.1	21.1	14.7	6.7	7.9	3.8	0.50	1.15	1.10	1.6	3.60	3.44
28-Jan	19	51	587	28	26.8	9.0	59	44	9.0	2.7	17.9	3.5	1.1	2.3	1.1	1.9	28.2	19.1	21.2	14.7	5.9	8.8	3.5	0.50	1.15	1.10	1.8	4.06	3.88
29-Jan	19	51	587	29	28.0	8.0	77	46	9.3	3.0	18.0	3.8	1.1	2.4	1.3	2.1	28.4	19.2	21.3	14.8	5.6	9.2	3.9	0.50	1.15	1.10	1.9	4.35	4.16
30-Jan	19	51	587	30	27.0	10.0	61	29	9.1	4.9	18.5	3.6	1.2	2.4	0.9	2.2	28.5	19.2	21.4	14.8	6.4	8.4	4.5	0.50	1.15	1.10	1.2	2.68	2.56
31-Jan	19	51	587	31	25.0	10.0	51	20	9.0	5.0	17.5	3.2	1.2	2.2	0.6	2.0	28.6	19.3	21.5	14.9	6.9	7.9	4.2	0.50	1.15	1.10	1.4	3.19	3.05

Appendix IV

Step wise procedure for computation of crop water requirement of Soybean crop in MS Excel

Date	Lat	Lat	Alt.	JD	Tmax	Tmin	RH	RH	BSS	WS	T	e	e	es	ea	es-ea	Ra	Rs	Rso	Rns	Rnl	Rn	ETo	Soybean			Crop water req.		
	(°)	(Min.)	(Z)				max	min	n	uz	mean	Tmax	Tmin	SVP	AVP	VPD								Kcini	Kcmid	Kcend	ini	mid	end
1-Jan	19	51	587	1	31.0	12.5	72	25	7.2	3.7	21.8	4.5	1.4	3.0	1.1	2.7	26.0	12.9	19.5	10.0	4.0	6.0	3.6	0.40	1.15	0.50	1.5	4.43	1.92
2-Jan	19	51	587	2	30.0	12.0	79	28	9.0	4.1	21.0	4.2	1.4	2.8	1.1	2.4	26.0	16.2	19.5	12.5	5.4	7.1	3.9	0.40	1.15	0.50	1.1	3.20	1.39
3-Jan	19	51	587	3	29.0	13.0	71	42	6.8	3.8	21.0	4.0	1.5	2.8	1.4	2.3	26.0	12.3	19.5	9.4	3.2	6.2	3.5	0.40	1.15	0.50	2.0	5.78	2.51
4-Jan	19	51	587	4	30.0	13.0	81	43	8.9	4.4	21.5	4.2	1.5	2.9	1.5	2.3	26.1	16.1	19.6	12.4	4.7	7.7	4.1	0.40	1.15	0.50	2.0	5.87	2.55
5-Jan	19	51	587	5	31.0	14.0	71	55	9.0	5.1	22.5	4.5	1.6	3.0	1.8	2.8	26.2	16.3	19.6	12.5	4.4	8.1	4.9	0.40	1.15	0.50	1.4	4.05	1.76
6-Jan	19	51	587	6	29.5	13.0	66	21	9.6	4.8	21.3	4.1	1.5	2.8	0.9	2.4	26.2	17.4	19.7	13.4	6.4	7.0	4.1	0.40	1.15	0.50	1.4	3.99	1.74
7-Jan	19	51	587	7	28.0	13.5	67	46	8.9	4.5	20.8	3.8	1.5	2.7	1.4	2.2	26.3	16.1	19.7	12.4	4.9	7.6	4.0	0.40	1.15	0.50	1.8	5.24	2.28
8-Jan	19	51	587	8	27.0	14.0	65	48	6.2	4.6	20.5	3.6	1.6	2.6	1.4	2.2	26.3	11.3	19.8	8.7	2.7	6.0	3.6	0.40	1.15	0.50	1.7	4.79	2.08
9-Jan	19	51	587	9	29.0	12.0	70	42	9.0	4.2	20.5	4.0	1.4	2.7	1.3	2.5	26.4	16.4	19.8	12.6	5.0	7.6	4.1	0.40	1.15	0.50	1.4	4.14	1.80
10-Jan	19	51	587	10	30.5	11.5	80	25	9.0	3.6	21.0	4.4	1.4	2.9	1.1	2.5	26.5	16.4	19.9	12.6	5.5	7.2	3.8	0.40	1.15	0.50	1.6	4.74	2.06
11-Jan	19	51	587	11	30.0	13.0	73	39	9.0	4.5	21.5	4.2	1.5	2.9	1.4	2.5	26.5	16.4	19.9	12.7	5.0	7.7	4.3	0.40	1.15	0.50	1.5	4.36	1.90
12-Jan	19	51	587	12	31.0	12.0	80	39	9.9	3.1	21.5	4.5	1.4	2.9	1.4	2.5	26.6	18.1	20.0	14.0	5.6	8.4	3.9	0.40	1.15	0.50	1.6	4.66	2.03
13-Jan	19	51	587	13	31.0	14.0	71	44	9.5	5.0	22.5	4.5	1.6	3.0	1.6	2.6	26.7	17.4	20.0	13.4	5.1	8.3	4.7	0.40	1.15	0.50	1.4	4.08	1.77
14-Jan	19	51	587	14	30.5	14.0	66	44	9.1	3.9	22.3	4.4	1.6	3.0	1.5	2.6	26.8	16.7	20.1	12.9	4.9	8.0	4.2	0.40	1.15	0.50	1.6	4.62	2.01
15-Jan	19	51	587	15	31.5	15.0	81	38	9.8	5.0	23.3	4.6	1.7	3.2	1.6	2.8	26.9	18.1	20.2	13.9	5.4	8.5	4.9	0.40	1.15	0.50	1.7	4.85	2.11
16-Jan	19	51	587	16	31.0	15.0	64	34	9.4	2.8	23.0	4.5	1.7	3.1	1.3	2.7	27.0	17.4	20.2	13.4	5.5	7.9	3.7	0.40	1.15	0.50	1.5	4.42	1.92
17-Jan	19	51	587	17	32.0	13.0	79	35	9.5	2.2	22.5	4.8	1.5	3.1	1.4	2.9	27.1	18.5	20.3	14.3	5.8	8.5	3.7	0.40	1.15	0.50	1.6	4.68	2.04
18-Jan	19	51	587	18	30.0	12.0	70	18	9.3	2.6	21.0	4.2	1.4	2.8	0.9	2.4	27.2	18.6	20.4	14.3	6.8	7.5	3.4	0.40	1.15	0.50	1.1	3.16	1.37
19-Jan	19	51	587	19	29.0	11.5	69	41	9.1	4.0	20.3	4.0	1.4	2.7	1.3	2.3	27.3	18.6	20.4	14.3	5.8	8.5	4.1	0.40	1.15	0.50	1.9	5.37	2.33
20-Jan	19	51	587	20	29.0	12.0	63	42	9.0	3.9	20.5	4.0	1.4	2.7	1.3	2.3	27.4	18.7	20.5	14.4	5.8	8.5	4.2	0.40	1.15	0.50	2.1	5.93	2.58
21-Jan	19	51	587	21	29.5	12.0	70	37	9.9	3.3	20.8	4.1	1.4	2.8	1.3	2.2	27.5	18.7	20.6	14.4	5.9	8.5	3.8	0.40	1.15	0.50	1.6	4.59	1.99
22-Jan	19	51	587	22	28.0	11.5	79	55	9.1	2.7	19.8	3.8	1.4	2.6	1.6	2.4	27.6	18.8	20.7	14.5	5.2	9.2	3.9	0.40	1.15	0.50	1.8	5.22	2.27
23-Jan	19	51	587	23	27.5	10.5	77	18	9.2	4.3	19.0	3.7	1.3	2.5	0.8	2.2	27.7	18.8	20.8	14.5	6.7	7.8	4.1	0.40	1.15	0.50	1.8	5.11	2.22
24-Jan	19	51	587	24	25.0	9.0	88	27	9.6	3.7	17.0	3.2	1.1	2.2	0.9	2.0	27.8	18.1	20.8	14.0	5.9	8.1	3.7	0.40	1.15	0.50	2.1	6.14	2.67
25-Jan	19	51	587	25	25.0	8.0	66	19	9.3	3.7	16.5	3.2	1.1	2.1	0.7	1.9	27.9	17.6	20.9	13.6	6.2	7.4	3.6	0.40	1.15	0.50	1.5	4.25	1.85
26-Jan	19	51	587	26	27.5	9.0	63	18	9.2	5.3	18.3	3.7	1.1	2.4	0.7	2.2	28.0	19.0	21.0	14.6	6.9	7.7	4.5	0.40	1.15	0.50	1.6	4.69	2.04
27-Jan	19	51	587	27	25.0	9.5	68	20	9.1	4.5	17.3	3.2	1.2	2.2	0.7	1.7	28.1	19.1	21.1	14.7	6.7	7.9	3.8	0.40	1.15	0.50	1.3	3.60	1.56
28-Jan	19	51	587	28	26.8	9.0	59	44	9.0	2.7	17.9	3.5	1.1	2.3	1.1	1.9	28.2	19.1	21.2	14.7	5.9	8.8	3.5	0.40	1.15	0.50	1.4	4.06	1.76
29-Jan	19	51	587	29	28.0	8.0	77	46	9.3	3.0	18.0	3.8	1.1	2.4	1.3	2.1	28.4	19.2	21.3	14.8	5.6	9.2	3.9	0.40	1.15	0.50	1.5	4.35	1.89
30-Jan	19	51	587	30	27.0	10.0	61	29	9.1	4.9	18.5	3.6	1.2	2.4	0.9	2.2	28.5	19.2	21.4	14.8	6.4	8.4	4.5	0.40	1.15	0.50	0.9	2.68	1.17
31-Jan	19	51	587	31	25.0	10.0	51	20	9.0	5.0	17.5	3.2	1.2	2.2	0.6	2.0	28.6	19.3	21.5	14.9	6.9	7.9	4.2	0.40	1.15	0.50	1.1	3.19	1.39

Appendix V

Step wise procedure for computation of crop water requirement of Maize crop in MS Excel

Date	Lat	Lat	Alt.	JD	Tmax	Tmin	RH	RH	BSS	WS	T	e	e	es	ea	es-ea	Ra	Rs	Rso	Rns	Rnl	Rn	ETo	Maize			Crop water req.		
	(°)	(Min.)	(Z)				max	min	n	uz	mean	Tmax	Tmin	SVP	AVP	VPD								Kcini	Kcmid	Kcend	ini	mid	end
1-Jan	19	51	587	1	31.0	12.5	72	25	7.2	3.7	21.8	4.5	1.4	3.0	1.1	2.7	26.0	12.9	19.5	10.0	4.0	6.0	3.6	0.30	1.20	0.35	1.2	4.62	1.35
2-Jan	19	51	587	2	30.0	12.0	79	28	9.0	4.1	21.0	4.2	1.4	2.8	1.1	2.4	26.0	16.2	19.5	12.5	5.4	7.1	3.9	0.30	1.20	0.35	0.8	3.34	0.97
3-Jan	19	51	587	3	29.0	13.0	71	42	6.8	3.8	21.0	4.0	1.5	2.8	1.4	2.3	26.0	12.3	19.5	9.4	3.2	6.2	3.5	0.30	1.20	0.35	1.5	6.03	1.76
4-Jan	19	51	587	4	30.0	13.0	81	43	8.9	4.4	21.5	4.2	1.5	2.9	1.5	2.3	26.1	16.1	19.6	12.4	4.7	7.7	4.1	0.30	1.20	0.35	1.5	6.13	1.79
5-Jan	19	51	587	5	31.0	14.0	71	55	9.0	5.1	22.5	4.5	1.6	3.0	1.8	2.8	26.2	16.3	19.6	12.5	4.4	8.1	4.9	0.30	1.20	0.35	1.1	4.22	1.23
6-Jan	19	51	587	6	29.5	13.0	66	21	9.6	4.8	21.3	4.1	1.5	2.8	0.9	2.4	26.2	17.4	19.7	13.4	6.4	7.0	4.1	0.30	1.20	0.35	1.0	4.17	1.22
7-Jan	19	51	587	7	28.0	13.5	67	46	8.9	4.5	20.8	3.8	1.5	2.7	1.4	2.2	26.3	16.1	19.7	12.4	4.9	7.6	4.0	0.30	1.20	0.35	1.4	5.46	1.59
8-Jan	19	51	587	8	27.0	14.0	65	48	6.2	4.6	20.5	3.6	1.6	2.6	1.4	2.2	26.3	11.3	19.8	8.7	2.7	6.0	3.6	0.30	1.20	0.35	1.3	5.00	1.46
9-Jan	19	51	587	9	29.0	12.0	70	42	9.0	4.2	20.5	4.0	1.4	2.7	1.3	2.5	26.4	16.4	19.8	12.6	5.0	7.6	4.1	0.30	1.20	0.35	1.1	4.32	1.26
10-Jan	19	51	587	10	30.5	11.5	80	25	9.0	3.6	21.0	4.4	1.4	2.9	1.1	2.5	26.5	16.4	19.9	12.6	5.5	7.2	3.8	0.30	1.20	0.35	1.2	4.95	1.44
11-Jan	19	51	587	11	30.0	13.0	73	39	9.0	4.5	21.5	4.2	1.5	2.9	1.4	2.5	26.5	16.4	19.9	12.7	5.0	7.7	4.3	0.30	1.20	0.35	1.1	4.55	1.33
12-Jan	19	51	587	12	31.0	12.0	80	39	9.9	3.1	21.5	4.5	1.4	2.9	1.4	2.5	26.6	18.1	20.0	14.0	5.6	8.4	3.9	0.30	1.20	0.35	1.2	4.87	1.42
13-Jan	19	51	587	13	31.0	14.0	71	44	9.5	5.0	22.5	4.5	1.6	3.0	1.6	2.6	26.7	17.4	20.0	13.4	5.1	8.3	4.7	0.30	1.20	0.35	1.1	4.26	1.24
14-Jan	19	51	587	14	30.5	14.0	66	44	9.1	3.9	22.3	4.4	1.6	3.0	1.5	2.6	26.8	16.7	20.1	12.9	4.9	8.0	4.2	0.30	1.20	0.35	1.2	4.82	1.41
15-Jan	19	51	587	15	31.5	15.0	81	38	9.8	5.0	23.3	4.6	1.7	3.2	1.6	2.8	26.9	18.1	20.2	13.9	5.4	8.5	4.9	0.30	1.20	0.35	1.3	5.06	1.48
16-Jan	19	51	587	16	31.0	15.0	64	34	9.4	2.8	23.0	4.5	1.7	3.1	1.3	2.7	27.0	17.4	20.2	13.4	5.5	7.9	3.7	0.30	1.20	0.35	1.2	4.61	1.35
17-Jan	19	51	587	17	32.0	13.0	79	35	9.5	2.2	22.5	4.8	1.5	3.1	1.4	2.9	27.1	18.5	20.3	14.3	5.8	8.5	3.7	0.30	1.20	0.35	1.2	4.89	1.43
18-Jan	19	51	587	18	30.0	12.0	70	18	9.3	2.6	21.0	4.2	1.4	2.8	0.9	2.4	27.2	18.6	20.4	14.3	6.8	7.5	3.4	0.30	1.20	0.35	0.8	3.30	0.96
19-Jan	19	51	587	19	29.0	11.5	69	41	9.1	4.0	20.3	4.0	1.4	2.7	1.3	2.3	27.3	18.6	20.4	14.3	5.8	8.5	4.1	0.30	1.20	0.35	1.4	5.60	1.63
20-Jan	19	51	587	20	29.0	12.0	63	42	9.0	3.9	20.5	4.0	1.4	2.7	1.3	2.3	27.4	18.7	20.5	14.4	5.8	8.5	4.2	0.30	1.20	0.35	1.5	6.19	1.81
21-Jan	19	51	587	21	29.5	12.0	70	37	9.9	3.3	20.8	4.1	1.4	2.8	1.3	2.2	27.5	18.7	20.6	14.4	5.9	8.5	3.8	0.30	1.20	0.35	1.2	4.79	1.40
22-Jan	19	51	587	22	28.0	11.5	79	55	9.1	2.7	19.8	3.8	1.4	2.6	1.6	2.4	27.6	18.8	20.7	14.5	5.2	9.2	3.9	0.30	1.20	0.35	1.4	5.44	1.59
23-Jan	19	51	587	23	27.5	10.5	77	18	9.2	4.3	19.0	3.7	1.3	2.5	0.8	2.2	27.7	18.8	20.8	14.5	6.7	7.8	4.1	0.30	1.20	0.35	1.3	5.34	1.56
24-Jan	19	51	587	24	25.0	9.0	88	27	9.6	3.7	17.0	3.2	1.1	2.2	0.9	2.0	27.8	18.1	20.8	14.0	5.9	8.1	3.7	0.30	1.20	0.35	1.6	6.40	1.87
25-Jan	19	51	587	25	25.0	8.0	66	19	9.3	3.7	16.5	3.2	1.1	2.1	0.7	1.9	27.9	17.6	20.9	13.6	6.2	7.4	3.6	0.30	1.20	0.35	1.1	4.43	1.29
26-Jan	19	51	587	26	27.5	9.0	63	18	9.2	5.3	18.3	3.7	1.1	2.4	0.7	2.2	28.0	19.0	21.0	14.6	6.9	7.7	4.5	0.30	1.20	0.35	1.2	4.89	1.43
27-Jan	19	51	587	27	25.0	9.5	68	20	9.1	4.5	17.3	3.2	1.2	2.2	0.7	1.7	28.1	19.1	21.1	14.7	6.7	7.9	3.8	0.30	1.20	0.35	0.9	3.75	1.09
28-Jan	19	51	587	28	26.8	9.0	59	44	9.0	2.7	17.9	3.5	1.1	2.3	1.1	1.9	28.2	19.1	21.2	14.7	5.9	8.8	3.5	0.30	1.20	0.35	1.1	4.23	1.23
29-Jan	19	51	587	29	28.0	8.0	77	46	9.3	3.0	18.0	3.8	1.1	2.4	1.3	2.1	28.4	19.2	21.3	14.8	5.6	9.2	3.9	0.30	1.20	0.35	1.1	4.54	1.32
30-Jan	19	51	587	30	27.0	10.0	61	29	9.1	4.9	18.5	3.6	1.2	2.4	0.9	2.2	28.5	19.2	21.4	14.8	6.4	8.4	4.5	0.30	1.20	0.35	0.7	2.80	0.82
31-Jan	19	51	587	31	25.0	10.0	51	20	9.0	5.0	17.5	3.2	1.2	2.2	0.6	2.0	28.6	19.3	21.5	14.9	6.9	7.9	4.2	0.30	1.20	0.35	0.8	3.33	0.97

Appendix VI

Step wise procedure for computation of crop water requirement of Pearl millet crop in MS Excel

Date	Lat	Lat	Alt.	JD	Tmax	Tmin	RH	RH	BSS	WS	T	e	e	es	ea	es-ea	Ra	Rs	Rso	Rns	Rnl	Rn	ETo	Pearl Millet			Crop water req.		
	(°)	(Min.)	(Z)				max	min	n	uz	mean	Tmax	Tmin	SVP	AVP	VPD								Kcini	Kcmid	Kcend	ini	mid	end
1-Jan	19	51	587	1	31.0	12.5	72	25	7.2	3.7	21.8	4.5	1.4	3.0	1.1	2.7	26.0	12.9	19.5	10.0	4.0	6.0	3.6	0.30	1.00	0.30	1.2	3.85	1.15
2-Jan	19	51	587	2	30.0	12.0	79	28	9.0	4.1	21.0	4.2	1.4	2.8	1.1	2.4	26.0	16.2	19.5	12.5	5.4	7.1	3.9	0.30	1.00	0.30	0.8	2.78	0.83
3-Jan	19	51	587	3	29.0	13.0	71	42	6.8	3.8	21.0	4.0	1.5	2.8	1.4	2.3	26.0	12.3	19.5	9.4	3.2	6.2	3.5	0.30	1.00	0.30	1.5	5.03	1.51
4-Jan	19	51	587	4	30.0	13.0	81	43	8.9	4.4	21.5	4.2	1.5	2.9	1.5	2.3	26.1	16.1	19.6	12.4	4.7	7.7	4.1	0.30	1.00	0.30	1.5	5.10	1.53
5-Jan	19	51	587	5	31.0	14.0	71	55	9.0	5.1	22.5	4.5	1.6	3.0	1.8	2.8	26.2	16.3	19.6	12.5	4.4	8.1	4.9	0.30	1.00	0.30	1.1	3.52	1.06
6-Jan	19	51	587	6	29.5	13.0	66	21	9.6	4.8	21.3	4.1	1.5	2.8	0.9	2.4	26.2	17.4	19.7	13.4	6.4	7.0	4.1	0.30	1.00	0.30	1.0	3.47	1.04
7-Jan	19	51	587	7	28.0	13.5	67	46	8.9	4.5	20.8	3.8	1.5	2.7	1.4	2.2	26.3	16.1	19.7	12.4	4.9	7.6	4.0	0.30	1.00	0.30	1.4	4.55	1.37
8-Jan	19	51	587	8	27.0	14.0	65	48	6.2	4.6	20.5	3.6	1.6	2.6	1.4	2.2	26.3	11.3	19.8	8.7	2.7	6.0	3.6	0.30	1.00	0.30	1.3	4.17	1.25
9-Jan	19	51	587	9	29.0	12.0	70	42	9.0	4.2	20.5	4.0	1.4	2.7	1.3	2.5	26.4	16.4	19.8	12.6	5.0	7.6	4.1	0.30	1.00	0.30	1.1	3.60	1.08
10-Jan	19	51	587	10	30.5	11.5	80	25	9.0	3.6	21.0	4.4	1.4	2.9	1.1	2.5	26.5	16.4	19.9	12.6	5.5	7.2	3.8	0.30	1.00	0.30	1.2	4.12	1.24
11-Jan	19	51	587	11	30.0	13.0	73	39	9.0	4.5	21.5	4.2	1.5	2.9	1.4	2.5	26.5	16.4	19.9	12.7	5.0	7.7	4.3	0.30	1.00	0.30	1.1	3.79	1.14
12-Jan	19	51	587	12	31.0	12.0	80	39	9.9	3.1	21.5	4.5	1.4	2.9	1.4	2.5	26.6	18.1	20.0	14.0	5.6	8.4	3.9	0.30	1.00	0.30	1.2	4.06	1.22
13-Jan	19	51	587	13	31.0	14.0	71	44	9.5	5.0	22.5	4.5	1.6	3.0	1.6	2.6	26.7	17.4	20.0	13.4	5.1	8.3	4.7	0.30	1.00	0.30	1.1	3.55	1.06
14-Jan	19	51	587	14	30.5	14.0	66	44	9.1	3.9	22.3	4.4	1.6	3.0	1.5	2.6	26.8	16.7	20.1	12.9	4.9	8.0	4.2	0.30	1.00	0.30	1.2	4.02	1.20
15-Jan	19	51	587	15	31.5	15.0	81	38	9.8	5.0	23.3	4.6	1.7	3.2	1.6	2.8	26.9	18.1	20.2	13.9	5.4	8.5	4.9	0.30	1.00	0.30	1.3	4.22	1.27
16-Jan	19	51	587	16	31.0	15.0	64	34	9.4	2.8	23.0	4.5	1.7	3.1	1.3	2.7	27.0	17.4	20.2	13.4	5.5	7.9	3.7	0.30	1.00	0.30	1.2	3.84	1.15
17-Jan	19	51	587	17	32.0	13.0	79	35	9.5	2.2	22.5	4.8	1.5	3.1	1.4	2.9	27.1	18.5	20.3	14.3	5.8	8.5	3.7	0.30	1.00	0.30	1.2	4.07	1.22
18-Jan	19	51	587	18	30.0	12.0	70	18	9.3	2.6	21.0	4.2	1.4	2.8	0.9	2.4	27.2	18.6	20.4	14.3	6.8	7.5	3.4	0.30	1.00	0.30	0.8	2.75	0.82
19-Jan	19	51	587	19	29.0	11.5	69	41	9.1	4.0	20.3	4.0	1.4	2.7	1.3	2.3	27.3	18.6	20.4	14.3	5.8	8.5	4.1	0.30	1.00	0.30	1.4	4.67	1.40
20-Jan	19	51	587	20	29.0	12.0	63	42	9.0	3.9	20.5	4.0	1.4	2.7	1.3	2.3	27.4	18.7	20.5	14.4	5.8	8.5	4.2	0.30	1.00	0.30	1.5	5.16	1.55
21-Jan	19	51	587	21	29.5	12.0	70	37	9.9	3.3	20.8	4.1	1.4	2.8	1.3	2.2	27.5	18.7	20.6	14.4	5.9	8.5	3.8	0.30	1.00	0.30	1.2	3.99	1.20
22-Jan	19	51	587	22	28.0	11.5	79	55	9.1	2.7	19.8	3.8	1.4	2.6	1.6	2.4	27.6	18.8	20.7	14.5	5.2	9.2	3.9	0.30	1.00	0.30	1.4	4.54	1.36
23-Jan	19	51	587	23	27.5	10.5	77	18	9.2	4.3	19.0	3.7	1.3	2.5	0.8	2.2	27.7	18.8	20.8	14.5	6.7	7.8	4.1	0.30	1.00	0.30	1.3	4.45	1.33
24-Jan	19	51	587	24	25.0	9.0	88	27	9.6	3.7	17.0	3.2	1.1	2.2	0.9	2.0	27.8	18.1	20.8	14.0	5.9	8.1	3.7	0.30	1.00	0.30	1.6	5.34	1.60
25-Jan	19	51	587	25	25.0	8.0	66	19	9.3	3.7	16.5	3.2	1.1	2.1	0.7	1.9	27.9	17.6	20.9	13.6	6.2	7.4	3.6	0.30	1.00	0.30	1.1	3.69	1.11
26-Jan	19	51	587	26	27.5	9.0	63	18	9.2	5.3	18.3	3.7	1.1	2.4	0.7	2.2	28.0	19.0	21.0	14.6	6.9	7.7	4.5	0.30	1.00	0.30	1.2	4.08	1.22
27-Jan	19	51	587	27	25.0	9.5	68	20	9.1	4.5	17.3	3.2	1.2	2.2	0.7	1.7	28.1	19.1	21.1	14.7	6.7	7.9	3.8	0.30	1.00	0.30	0.9	3.13	0.94
28-Jan	19	51	587	28	26.8	9.0	59	44	9.0	2.7	17.9	3.5	1.1	2.3	1.1	1.9	28.2	19.1	21.2	14.7	5.9	8.8	3.5	0.30	1.00	0.30	1.1	3.53	1.06
29-Jan	19	51	587	29	28.0	8.0	77	46	9.3	3.0	18.0	3.8	1.1	2.4	1.3	2.1	28.4	19.2	21.3	14.8	5.6	9.2	3.9	0.30	1.00	0.30	1.1	3.78	1.13
30-Jan	19	51	587	30	27.0	10.0	61	29	9.1	4.9	18.5	3.6	1.2	2.4	0.9	2.2	28.5	19.2	21.4	14.8	6.4	8.4	4.5	0.30	1.00	0.30	0.7	2.33	0.70
31-Jan	19	51	587	31	25.0	10.0	51	20	9.0	5.0	17.5	3.2	1.2	2.2	0.6	2.0	28.6	19.3	21.5	14.9	6.9	7.9	4.2	0.30	1.00	0.30	0.8	2.77	0.83

Appendix VII

Step wise procedure for computation of crop water requirement of Onion crop in MS Excel

Date	Lat	Lat	Alt.	JD	Tmax	Tmin	RH	RH	BSS	WS	T	e	e	es	ea	es-ea	Ra	Rs	Rso	Rns	Rnl	Rn	ETo	Onion			Crop water req.		
	(°)	(Min.)	(Z)				max	min	n	uz	mean	Tmax	Tmin	SVP	AVP	VPD								Kcini	Kcmid	Kcend	ini	mid	end
1-Jan	19	51	587	1	31.0	12.5	72	25	7.2	3.7	21.8	4.5	1.4	3.0	1.1	2.7	26.0	12.9	19.5	10.0	4.0	6.0	3.6	1.05	0.75	0.40	4.0	2.89	1.54
2-Jan	19	51	587	2	30.0	12.0	79	28	9.0	4.1	21.0	4.2	1.4	2.8	1.1	2.4	26.0	16.2	19.5	12.5	5.4	7.1	3.9	1.05	0.75	0.40	2.9	2.09	1.11
3-Jan	19	51	587	3	29.0	13.0	71	42	6.8	3.8	21.0	4.0	1.5	2.8	1.4	2.3	26.0	12.3	19.5	9.4	3.2	6.2	3.5	1.05	0.75	0.40	5.3	3.77	2.01
4-Jan	19	51	587	4	30.0	13.0	81	43	8.9	4.4	21.5	4.2	1.5	2.9	1.5	2.3	26.1	16.1	19.6	12.4	4.7	7.7	4.1	1.05	0.75	0.40	5.4	3.83	2.04
5-Jan	19	51	587	5	31.0	14.0	71	55	9.0	5.1	22.5	4.5	1.6	3.0	1.8	2.8	26.2	16.3	19.6	12.5	4.4	8.1	4.9	1.05	0.75	0.40	3.7	2.64	1.41
6-Jan	19	51	587	6	29.5	13.0	66	21	9.6	4.8	21.3	4.1	1.5	2.8	0.9	2.4	26.2	17.4	19.7	13.4	6.4	7.0	4.1	1.05	0.75	0.40	3.6	2.60	1.39
7-Jan	19	51	587	7	28.0	13.5	67	46	8.9	4.5	20.8	3.8	1.5	2.7	1.4	2.2	26.3	16.1	19.7	12.4	4.9	7.6	4.0	1.05	0.75	0.40	4.8	3.41	1.82
8-Jan	19	51	587	8	27.0	14.0	65	48	6.2	4.6	20.5	3.6	1.6	2.6	1.4	2.2	26.3	11.3	19.8	8.7	2.7	6.0	3.6	1.05	0.75	0.40	4.4	3.13	1.67
9-Jan	19	51	587	9	29.0	12.0	70	42	9.0	4.2	20.5	4.0	1.4	2.7	1.3	2.5	26.4	16.4	19.8	12.6	5.0	7.6	4.1	1.05	0.75	0.40	3.8	2.70	1.44
10-Jan	19	51	587	10	30.5	11.5	80	25	9.0	3.6	21.0	4.4	1.4	2.9	1.1	2.5	26.5	16.4	19.9	12.6	5.5	7.2	3.8	1.05	0.75	0.40	4.3	3.09	1.65
11-Jan	19	51	587	11	30.0	13.0	73	39	9.0	4.5	21.5	4.2	1.5	2.9	1.4	2.5	26.5	16.4	19.9	12.7	5.0	7.7	4.3	1.05	0.75	0.40	4.0	2.84	1.52
12-Jan	19	51	587	12	31.0	12.0	80	39	9.9	3.1	21.5	4.5	1.4	2.9	1.4	2.5	26.6	18.1	20.0	14.0	5.6	8.4	3.9	1.05	0.75	0.40	4.3	3.04	1.62
13-Jan	19	51	587	13	31.0	14.0	71	44	9.5	5.0	22.5	4.5	1.6	3.0	1.6	2.6	26.7	17.4	20.0	13.4	5.1	8.3	4.7	1.05	0.75	0.40	3.7	2.66	1.42
14-Jan	19	51	587	14	30.5	14.0	66	44	9.1	3.9	22.3	4.4	1.6	3.0	1.5	2.6	26.8	16.7	20.1	12.9	4.9	8.0	4.2	1.05	0.75	0.40	4.2	3.01	1.61
15-Jan	19	51	587	15	31.5	15.0	81	38	9.8	5.0	23.3	4.6	1.7	3.2	1.6	2.8	26.9	18.1	20.2	13.9	5.4	8.5	4.9	1.05	0.75	0.40	4.4	3.16	1.69
16-Jan	19	51	587	16	31.0	15.0	64	34	9.4	2.8	23.0	4.5	1.7	3.1	1.3	2.7	27.0	17.4	20.2	13.4	5.5	7.9	3.7	1.05	0.75	0.40	4.0	2.88	1.54
17-Jan	19	51	587	17	32.0	13.0	79	35	9.5	2.2	22.5	4.8	1.5	3.1	1.4	2.9	27.1	18.5	20.3	14.3	5.8	8.5	3.7	1.05	0.75	0.40	4.3	3.06	1.63
18-Jan	19	51	587	18	30.0	12.0	70	18	9.3	2.6	21.0	4.2	1.4	2.8	0.9	2.4	27.2	18.6	20.4	14.3	6.8	7.5	3.4	1.05	0.75	0.40	2.9	2.06	1.10
19-Jan	19	51	587	19	29.0	11.5	69	41	9.1	4.0	20.3	4.0	1.4	2.7	1.3	2.3	27.3	18.6	20.4	14.3	5.8	8.5	4.1	1.05	0.75	0.40	4.9	3.50	1.87
20-Jan	19	51	587	20	29.0	12.0	63	42	9.0	3.9	20.5	4.0	1.4	2.7	1.3	2.3	27.4	18.7	20.5	14.4	5.8	8.5	4.2	1.05	0.75	0.40	5.4	3.87	2.06
21-Jan	19	51	587	21	29.5	12.0	70	37	9.9	3.3	20.8	4.1	1.4	2.8	1.3	2.2	27.5	18.7	20.6	14.4	5.9	8.5	3.8	1.05	0.75	0.40	4.2	2.99	1.60
22-Jan	19	51	587	22	28.0	11.5	79	55	9.1	2.7	19.8	3.8	1.4	2.6	1.6	2.4	27.6	18.8	20.7	14.5	5.2	9.2	3.9	1.05	0.75	0.40	4.8	3.40	1.81
23-Jan	19	51	587	23	27.5	10.5	77	18	9.2	4.3	19.0	3.7	1.3	2.5	0.8	2.2	27.7	18.8	20.8	14.5	6.7	7.8	4.1	1.05	0.75	0.40	4.7	3.33	1.78
24-Jan	19	51	587	24	25.0	9.0	88	27	9.6	3.7	17.0	3.2	1.1	2.2	0.9	2.0	27.8	18.1	20.8	14.0	5.9	8.1	3.7	1.05	0.75	0.40	5.6	4.00	2.13
25-Jan	19	51	587	25	25.0	8.0	66	19	9.3	3.7	16.5	3.2	1.1	2.1	0.7	1.9	27.9	17.6	20.9	13.6	6.2	7.4	3.6	1.05	0.75	0.40	3.9	2.77	1.48
26-Jan	19	51	587	26	27.5	9.0	63	18	9.2	5.3	18.3	3.7	1.1	2.4	0.7	2.2	28.0	19.0	21.0	14.6	6.9	7.7	4.5	1.05	0.75	0.40	4.3	3.06	1.63
27-Jan	19	51	587	27	25.0	9.5	68	20	9.1	4.5	17.3	3.2	1.2	2.2	0.7	1.7	28.1	19.1	21.1	14.7	6.7	7.9	3.8	1.05	0.75	0.40	3.3	2.35	1.25
28-Jan	19	51	587	28	26.8	9.0	59	44	9.0	2.7	17.9	3.5	1.1	2.3	1.1	1.9	28.2	19.1	21.2	14.7	5.9	8.8	3.5	1.05	0.75	0.40	3.7	2.65	1.41
29-Jan	19	51	587	29	28.0	8.0	77	46	9.3	3.0	18.0	3.8	1.1	2.4	1.3	2.1	28.4	19.2	21.3	14.8	5.6	9.2	3.9	1.05	0.75	0.40	4.0	2.84	1.51
30-Jan	19	51	587	30	27.0	10.0	61	29	9.1	4.9	18.5	3.6	1.2	2.4	0.9	2.2	28.5	19.2	21.4	14.8	6.4	8.4	4.5	1.05	0.75	0.40	2.4	1.75	0.93
31-Jan	19	51	587	31	25.0	10.0	51	20	9.0	5.0	17.5	3.2	1.2	2.2	0.6	2.0	28.6	19.3	21.5	14.9	6.9	7.9	4.2	1.05	0.75	0.40	2.9	2.08	1.11

Appendix VIII

Step wise procedure for computation of crop water requirement of Tomato crop in MS Excel

Date	Lat	Lat	Alt.	JD	Tmax	Tmin	RH	RH	BSS	WS	T	e	e	es	ea	es-ea	Ra	Rs	Rso	Rns	Rnl	Rn	ETo	Tomato			Crop water req.		
	(º)	(Min.)	(Z)				max	min	n	uz	mean	Tmax	Tmin	SVP	AVP	VPD								Kcini	Kcmid	Kcend	ini	mid	end
1-Jan	19	51	587	1	31.0	12.5	72	25	7.2	3.7	21.8	4.5	1.4	3.0	1.1	2.7	26.0	12.9	19.5	10.0	4.0	6.0	3.6	0.60	1.15	0.70	2.3	4.43	2.69
2-Jan	19	51	587	2	30.0	12.0	79	28	9.0	4.1	21.0	4.2	1.4	2.8	1.1	2.4	26.0	16.2	19.5	12.5	5.4	7.1	3.9	0.60	1.15	0.70	1.7	3.20	1.95
3-Jan	19	51	587	3	29.0	13.0	71	42	6.8	3.8	21.0	4.0	1.5	2.8	1.4	2.3	26.0	12.3	19.5	9.4	3.2	6.2	3.5	0.60	1.15	0.70	3.0	5.78	3.52
4-Jan	19	51	587	4	30.0	13.0	81	43	8.9	4.4	21.5	4.2	1.5	2.9	1.5	2.3	26.1	16.1	19.6	12.4	4.7	7.7	4.1	0.60	1.15	0.70	3.1	5.87	3.57
5-Jan	19	51	587	5	31.0	14.0	71	55	9.0	5.1	22.5	4.5	1.6	3.0	1.8	2.8	26.2	16.3	19.6	12.5	4.4	8.1	4.9	0.60	1.15	0.70	2.1	4.05	2.46
6-Jan	19	51	587	6	29.5	13.0	66	21	9.6	4.8	21.3	4.1	1.5	2.8	0.9	2.4	26.2	17.4	19.7	13.4	6.4	7.0	4.1	0.60	1.15	0.70	2.1	3.99	2.43
7-Jan	19	51	587	7	28.0	13.5	67	46	8.9	4.5	20.8	3.8	1.5	2.7	1.4	2.2	26.3	16.1	19.7	12.4	4.9	7.6	4.0	0.60	1.15	0.70	2.7	5.24	3.19
8-Jan	19	51	587	8	27.0	14.0	65	48	6.2	4.6	20.5	3.6	1.6	2.6	1.4	2.2	26.3	11.3	19.8	8.7	2.7	6.0	3.6	0.60	1.15	0.70	2.5	4.79	2.92
9-Jan	19	51	587	9	29.0	12.0	70	42	9.0	4.2	20.5	4.0	1.4	2.7	1.3	2.5	26.4	16.4	19.8	12.6	5.0	7.6	4.1	0.60	1.15	0.70	2.2	4.14	2.52
10-Jan	19	51	587	10	30.5	11.5	80	25	9.0	3.6	21.0	4.4	1.4	2.9	1.1	2.5	26.5	16.4	19.9	12.6	5.5	7.2	3.8	0.60	1.15	0.70	2.5	4.74	2.89
11-Jan	19	51	587	11	30.0	13.0	73	39	9.0	4.5	21.5	4.2	1.5	2.9	1.4	2.5	26.5	16.4	19.9	12.7	5.0	7.7	4.3	0.60	1.15	0.70	2.3	4.36	2.65
12-Jan	19	51	587	12	31.0	12.0	80	39	9.9	3.1	21.5	4.5	1.4	2.9	1.4	2.5	26.6	18.1	20.0	14.0	5.6	8.4	3.9	0.60	1.15	0.70	2.4	4.66	2.84
13-Jan	19	51	587	13	31.0	14.0	71	44	9.5	5.0	22.5	4.5	1.6	3.0	1.6	2.6	26.7	17.4	20.0	13.4	5.1	8.3	4.7	0.60	1.15	0.70	2.1	4.08	2.48
14-Jan	19	51	587	14	30.5	14.0	66	44	9.1	3.9	22.3	4.4	1.6	3.0	1.5	2.6	26.8	16.7	20.1	12.9	4.9	8.0	4.2	0.60	1.15	0.70	2.4	4.62	2.81
15-Jan	19	51	587	15	31.5	15.0	81	38	9.8	5.0	23.3	4.6	1.7	3.2	1.6	2.8	26.9	18.1	20.2	13.9	5.4	8.5	4.9	0.60	1.15	0.70	2.5	4.85	2.95
16-Jan	19	51	587	16	31.0	15.0	64	34	9.4	2.8	23.0	4.5	1.7	3.1	1.3	2.7	27.0	17.4	20.2	13.4	5.5	7.9	3.7	0.60	1.15	0.70	2.3	4.42	2.69
17-Jan	19	51	587	17	32.0	13.0	79	35	9.5	2.2	22.5	4.8	1.5	3.1	1.4	2.9	27.1	18.5	20.3	14.3	5.8	8.5	3.7	0.60	1.15	0.70	2.4	4.68	2.85
18-Jan	19	51	587	18	30.0	12.0	70	18	9.3	2.6	21.0	4.2	1.4	2.8	0.9	2.4	27.2	18.6	20.4	14.3	6.8	7.5	3.4	0.60	1.15	0.70	1.6	3.16	1.92
19-Jan	19	51	587	19	29.0	11.5	69	41	9.1	4.0	20.3	4.0	1.4	2.7	1.3	2.3	27.3	18.6	20.4	14.3	5.8	8.5	4.1	0.60	1.15	0.70	2.8	5.37	3.27
20-Jan	19	51	587	20	29.0	12.0	63	42	9.0	3.9	20.5	4.0	1.4	2.7	1.3	2.3	27.4	18.7	20.5	14.4	5.8	8.5	4.2	0.60	1.15	0.70	3.1	5.93	3.61
21-Jan	19	51	587	21	29.5	12.0	70	37	9.9	3.3	20.8	4.1	1.4	2.8	1.3	2.2	27.5	18.7	20.6	14.4	5.9	8.5	3.8	0.60	1.15	0.70	2.4	4.59	2.79
22-Jan	19	51	587	22	28.0	11.5	79	55	9.1	2.7	19.8	3.8	1.4	2.6	1.6	2.4	27.6	18.8	20.7	14.5	5.2	9.2	3.9	0.60	1.15	0.70	2.7	5.22	3.18
23-Jan	19	51	587	23	27.5	10.5	77	18	9.2	4.3	19.0	3.7	1.3	2.5	0.8	2.2	27.7	18.8	20.8	14.5	6.7	7.8	4.1	0.60	1.15	0.70	2.7	5.11	3.11
24-Jan	19	51	587	24	25.0	9.0	88	27	9.6	3.7	17.0	3.2	1.1	2.2	0.9	2.0	27.8	18.1	20.8	14.0	5.9	8.1	3.7	0.60	1.15	0.70	3.2	6.14	3.74
25-Jan	19	51	587	25	25.0	8.0	66	19	9.3	3.7	16.5	3.2	1.1	2.1	0.7	1.9	27.9	17.6	20.9	13.6	6.2	7.4	3.6	0.60	1.15	0.70	2.2	4.25	2.58
26-Jan	19	51	587	26	27.5	9.0	63	18	9.2	5.3	18.3	3.7	1.1	2.4	0.7	2.2	28.0	19.0	21.0	14.6	6.9	7.7	4.5	0.60	1.15	0.70	2.4	4.69	2.86
27-Jan	19	51	587	27	25.0	9.5	68	20	9.1	4.5	17.3	3.2	1.2	2.2	0.7	1.7	28.1	19.1	21.1	14.7	6.7	7.9	3.8	0.60	1.15	0.70	1.9	3.60	2.19
28-Jan	19	51	587	28	26.8	9.0	59	44	9.0	2.7	17.9	3.5	1.1	2.3	1.1	1.9	28.2	19.1	21.2	14.7	5.9	8.8	3.5	0.60	1.15	0.70	2.1	4.06	2.47
29-Jan	19	51	587	29	28.0	8.0	77	46	9.3	3.0	18.0	3.8	1.1	2.4	1.3	2.1	28.4	19.2	21.3	14.8	5.6	9.2	3.9	0.60	1.15	0.70	2.3	4.35	2.65
30-Jan	19	51	587	30	27.0	10.0	61	29	9.1	4.9	18.5	3.6	1.2	2.4	0.9	2.2	28.5	19.2	21.4	14.8	6.4	8.4	4.5	0.60	1.15	0.70	1.4	2.68	1.63
31-Jan	19	51	587	31	25.0	10.0	51	20	9.0	5.0	17.5	3.2	1.2	2.2	0.6	2.0	28.6	19.3	21.5	14.9	6.9	7.9	4.2	0.60	1.15	0.70	1.7	3.19	1.94

Appendix IX

Step wise procedure for computation of crop water requirement of Brinjal crop in MS Excel

Date	Lat	Lat	Alt.	JD	Tmax	Tmin	RH	RH	BSS	WS	T	e	e	es	ea	es-ea	Ra	Rs	Rso	Rns	Rnl	Rn	ETo	Brinjal			Crop water req.		
	(º)	(Min.)	(Z)				max	min	n	uz	mean	Tmax	Tmin	SVP	AVP	VPD								Kcini	Kcmid	Kcend	ini	mid	end
1-Jan	19	51	587	1	31.0	12.5	72	25	7.2	3.7	21.8	4.5	1.4	3.0	1.1	2.7	26.0	12.9	19.5	10.0	4.0	6.0	3.6	0.60	1.05	0.90	2.3	4.04	3.46
2-Jan	19	51	587	2	30.0	12.0	79	28	9.0	4.1	21.0	4.2	1.4	2.8	1.1	2.4	26.0	16.2	19.5	12.5	5.4	7.1	3.9	0.60	1.05	0.90	1.7	2.92	2.50
3-Jan	19	51	587	3	29.0	13.0	71	42	6.8	3.8	21.0	4.0	1.5	2.8	1.4	2.3	26.0	12.3	19.5	9.4	3.2	6.2	3.5	0.60	1.05	0.90	3.0	5.28	4.53
4-Jan	19	51	587	4	30.0	13.0	81	43	8.9	4.4	21.5	4.2	1.5	2.9	1.5	2.3	26.1	16.1	19.6	12.4	4.7	7.7	4.1	0.60	1.05	0.90	3.1	5.36	4.59
5-Jan	19	51	587	5	31.0	14.0	71	55	9.0	5.1	22.5	4.5	1.6	3.0	1.8	2.8	26.2	16.3	19.6	12.5	4.4	8.1	4.9	0.60	1.05	0.90	2.1	3.70	3.17
6-Jan	19	51	587	6	29.5	13.0	66	21	9.6	4.8	21.3	4.1	1.5	2.8	0.9	2.4	26.2	17.4	19.7	13.4	6.4	7.0	4.1	0.60	1.05	0.90	2.1	3.65	3.13
7-Jan	19	51	587	7	28.0	13.5	67	46	8.9	4.5	20.8	3.8	1.5	2.7	1.4	2.2	26.3	16.1	19.7	12.4	4.9	7.6	4.0	0.60	1.05	0.90	2.7	4.78	4.10
8-Jan	19	51	587	8	27.0	14.0	65	48	6.2	4.6	20.5	3.6	1.6	2.6	1.4	2.2	26.3	11.3	19.8	8.7	2.7	6.0	3.6	0.60	1.05	0.90	2.5	4.38	3.75
9-Jan	19	51	587	9	29.0	12.0	70	42	9.0	4.2	20.5	4.0	1.4	2.7	1.3	2.5	26.4	16.4	19.8	12.6	5.0	7.6	4.1	0.60	1.05	0.90	2.2	3.78	3.24
10-Jan	19	51	587	10	30.5	11.5	80	25	9.0	3.6	21.0	4.4	1.4	2.9	1.1	2.5	26.5	16.4	19.9	12.6	5.5	7.2	3.8	0.60	1.05	0.90	2.5	4.33	3.71
11-Jan	19	51	587	11	30.0	13.0	73	39	9.0	4.5	21.5	4.2	1.5	2.9	1.4	2.5	26.5	16.4	19.9	12.7	5.0	7.7	4.3	0.60	1.05	0.90	2.3	3.98	3.41
12-Jan	19	51	587	12	31.0	12.0	80	39	9.9	3.1	21.5	4.5	1.4	2.9	1.4	2.5	26.6	18.1	20.0	14.0	5.6	8.4	3.9	0.60	1.05	0.90	2.4	4.26	3.65
13-Jan	19	51	587	13	31.0	14.0	71	44	9.5	5.0	22.5	4.5	1.6	3.0	1.6	2.6	26.7	17.4	20.0	13.4	5.1	8.3	4.7	0.60	1.05	0.90	2.1	3.73	3.19
14-Jan	19	51	587	14	30.5	14.0	66	44	9.1	3.9	22.3	4.4	1.6	3.0	1.5	2.6	26.8	16.7	20.1	12.9	4.9	8.0	4.2	0.60	1.05	0.90	2.4	4.22	3.61
15-Jan	19	51	587	15	31.5	15.0	81	38	9.8	5.0	23.3	4.6	1.7	3.2	1.6	2.8	26.9	18.1	20.2	13.9	5.4	8.5	4.9	0.60	1.05	0.90	2.5	4.43	3.80
16-Jan	19	51	587	16	31.0	15.0	64	34	9.4	2.8	23.0	4.5	1.7	3.1	1.3	2.7	27.0	17.4	20.2	13.4	5.5	7.9	3.7	0.60	1.05	0.90	2.3	4.04	3.46
17-Jan	19	51	587	17	32.0	13.0	79	35	9.5	2.2	22.5	4.8	1.5	3.1	1.4	2.9	27.1	18.5	20.3	14.3	5.8	8.5	3.7	0.60	1.05	0.90	2.4	4.28	3.67
18-Jan	19	51	587	18	30.0	12.0	70	18	9.3	2.6	21.0	4.2	1.4	2.8	0.9	2.4	27.2	18.6	20.4	14.3	6.8	7.5	3.4	0.60	1.05	0.90	1.6	2.89	2.47
19-Jan	19	51	587	19	29.0	11.5	69	41	9.1	4.0	20.3	4.0	1.4	2.7	1.3	2.3	27.3	18.6	20.4	14.3	5.8	8.5	4.1	0.60	1.05	0.90	2.8	4.90	4.20
20-Jan	19	51	587	20	29.0	12.0	63	42	9.0	3.9	20.5	4.0	1.4	2.7	1.3	2.3	27.4	18.7	20.5	14.4	5.8	8.5	4.2	0.60	1.05	0.90	3.1	5.42	4.64
21-Jan	19	51	587	21	29.5	12.0	70	37	9.9	3.3	20.8	4.1	1.4	2.8	1.3	2.2	27.5	18.7	20.6	14.4	5.9	8.5	3.8	0.60	1.05	0.90	2.4	4.19	3.59
22-Jan	19	51	587	22	28.0	11.5	79	55	9.1	2.7	19.8	3.8	1.4	2.6	1.6	2.4	27.6	18.8	20.7	14.5	5.2	9.2	3.9	0.60	1.05	0.90	2.7	4.76	4.08
23-Jan	19	51	587	23	27.5	10.5	77	18	9.2	4.3	19.0	3.7	1.3	2.5	0.8	2.2	27.7	18.8	20.8	14.5	6.7	7.8	4.1	0.60	1.05	0.90	2.7	4.67	4.00
24-Jan	19	51	587	24	25.0	9.0	88	27	9.6	3.7	17.0	3.2	1.1	2.2	0.9	2.0	27.8	18.1	20.8	14.0	5.9	8.1	3.7	0.60	1.05	0.90	3.2	5.60	4.80
25-Jan	19	51	587	25	25.0	8.0	66	19	9.3	3.7	16.5	3.2	1.1	2.1	0.7	1.9	27.9	17.6	20.9	13.6	6.2	7.4	3.6	0.60	1.05	0.90	2.2	3.88	3.32
26-Jan	19	51	587	26	27.5	9.0	63	18	9.2	5.3	18.3	3.7	1.1	2.4	0.7	2.2	28.0	19.0	21.0	14.6	6.9	7.7	4.5	0.60	1.05	0.90	2.4	4.28	3.67
27-Jan	19	51	587	27	25.0	9.5	68	20	9.1	4.5	17.3	3.2	1.2	2.2	0.7	1.7	28.1	19.1	21.1	14.7	6.7	7.9	3.8	0.60	1.05	0.90	1.9	3.28	2.82
28-Jan	19	51	587	28	26.8	9.0	59	44	9.0	2.7	17.9	3.5	1.1	2.3	1.1	1.9	28.2	19.1	21.2	14.7	5.9	8.8	3.5	0.60	1.05	0.90	2.1	3.70	3.18
29-Jan	19	51	587	29	28.0	8.0	77	46	9.3	3.0	18.0	3.8	1.1	2.4	1.3	2.1	28.4	19.2	21.3	14.8	5.6	9.2	3.9	0.60	1.05	0.90	2.3	3.97	3.40
30-Jan	19	51	587	30	27.0	10.0	61	29	9.1	4.9	18.5	3.6	1.2	2.4	0.9	2.2	28.5	19.2	21.4	14.8	6.4	8.4	4.5	0.60	1.05	0.90	1.4	2.45	2.10
31-Jan	19	51	587	31	25.0	10.0	51	20	9.0	5.0	17.5	3.2	1.2	2.2	0.6	2.0	28.6	19.3	21.5	14.9	6.9	7.9	4.2	0.60	1.05	0.90	1.7	2.91	2.50

APPENDIX-X

Crops, their season and length of crop growth stages for various sowing periods (days)

Sr. No.	Crops	Season	Length of growth stages (days)				Sowing dates		Duration
			Initial	Developmental	Mid-season	Late-season	Sowing	Harvesting	Days
1	Cotton	*kharif*	30	50	60	55	15-Jun	26-Dec	195
2	Soybean	*kharif*	20	25	75	30	15-Jun	11-Nov	150
3	Pigeon pea	*kharif*	55	45	60	38	15-Jun	31-Dec	200
4	Maize	*kharif*	16	31	38	20	15-Jun	27-Sep	105
5	Pearl millet	*kharif*	15	28	35	17	15-Jun	17-Sep	95
6	Onion	*kharif*	15	25	70	40	15-Jun	15-Nov	150
7	Tomato	*kharif*	35	40	50	30	15-Jun	16-Nov	155
8	Brinjal	*kharif*	30	45	40	25	15-Jun	1-Nov	140

(Source : FAO-56)

APPENDIX- XI

USEFUL UNIT CONVERSIONS

1 mm	=	0.003937 inch	1 millibar (mbar)	=	0.1 kPa
1 mm d^{-1}	=	2.45 MJ m^{-2} d^{-1}	1 cm of water	=	0.09807 kPa
1 J cm^{-2} d^{-1}	=	0.01 MJ m^{-2} d^{-1}	1 mm of Hg	=	0.1333 kPa
1 calorie	=	4.1868 J	1 atmosphere	=	101.325 kPa
1 cal cm^{-2} d^{-1}	=	4.1868×10^{-2} MJ m^{-2} d^{-1}	1 lb/in^{-2} (psi)	=	6.896 kPa
1 W	=	1 J s^{-1}	1 m s^{-1}	=	0.477 mile h^{-}
1 W m^{-2}	=	0.0864 MJ m^{-2}	1 km $hour^{-1}$	=	0.277 m s^{-1}
^{o}C	=	$(^{o}F-32)^{5/9}$	1 km day^{-1}	=	0.3048 m s^{-1}
Kelvin	=	(^{o}C) + 273.16	1 f s^{-1}	=	0.3048 m s^{-1}
1 bar	=	100 kPa	-----	=	-----

(Source- FAO-56)

CURRICULUM VITAE

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Academic qualification

Course / Degree	Name of the college / Institute	University/ Board	Year of passing	Percentage (%) / CGPA	Class / Grade
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HSC	Jay Tuljabhavani Arts, Science and Commerce College, Tembhurni	Pune	2015	75.69	First
B.Sc. (Agri.)	Dadasaheb Mokashi College of Agriculture, Rajmachi	MPKV, Rahuri	2019	77.50	First

Place : Parbhani

Date : 06/08/2021

SAKhadake

(Khadake Snehal Anil)