# Calibration of Crop Water Requirement

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**Objective**

This document describes the preparation of two key inputs to the IITB multi-crop plugin, viz., the ET0 - the reference crop evapotranspiration table, and Kc, the crop-specific multiplier. The objective is to reconcile three sets of data:

(i) FAO data on Kc for a majority of crops.

(ii) ET0 values supplied by WALMI for six key locations

(iii) Total crop duration and crop-water requirements (CWR) for a variety of crops, for the agroclimatic zones in Maharashtra, as specified by WALMI.

**Outcome**

The outcome of this exercise is –

1. Districts mapped to 6 ET0 stations in PoCRA districts namely – Parbhani, Amravati, Aurangabad, Nanded, Yavatmal, Wardha.
2. Finalized set of Kc values for a set of 27 Kharif, Kharif Vegetables, Long Kharif and Annual crops, and 5 non-agricultural Land Use types
3. Finalized set of crop growth stage duration for same set of 27 Kharif, Kharif Vegetables, Long Kharif and Annual crops, and 5 non-agricultural Land Use types
4. Various recommendations for more accurate choice of Kc values
5. Set of 47 crops (27 Kharif, Long Kharif, Annual, 5 Land use, 15 Rabi) in IITB Plugin

The *Kc data* resides in *constant dictionary lookup* part of *plugin code* whereas the *ET0 data file* must be added by user to *cluster folder* before running the plugin. ET0 data is picked up from this file by the plugin. The user can add regional duration of crop growth stages and Kc data for additional crops or additional ET0 stations (Eg. Kc for Sorgum_Parbhani, Sorgum_Aurangabad) in the *constant dictionary lookup* part of code.

This document recommends using Kc values calibrated on Amravati weather station for set of 27 kharif, kharif vegetables, long kharif, annual crops as given in Appendix III. Whereas it recommends the user to add regional Kc values for 7 annual (Grapes, Banana, Pomegranate, Citrus, Orange, Mosambi, Sugarcane), 1 Long Kharif (Turmeric) and 2 Vegetable crops (Chilly-'Mirchi' and Brinjal) whose error is beyond 50 mm acceptable range.

# 1. Introduction

The basic equation is ET0 X Kc = ETc and crop duration and water requirement. The procedure is to use specified ET0 and crop water requirements at matching locations and prepare a Kc for a given crop. This Kc is fixed for the given crop. In the IITB plugin, this Kc, along with the local ET0 is used to compute local crop water requirements.

## Agroclimatic Zones

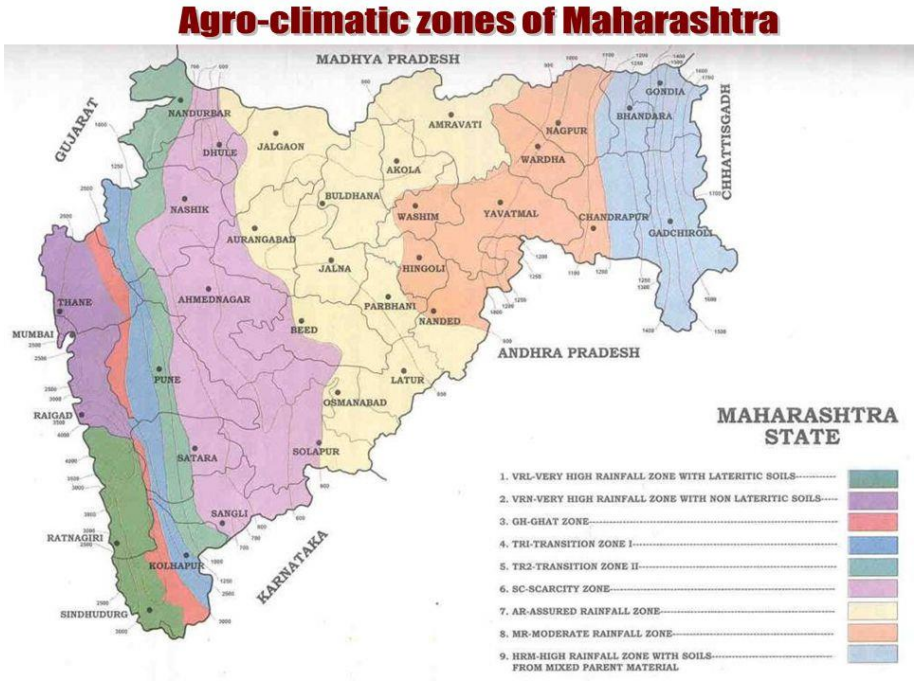



*Figure 1-1 Maharashtra Agroclimatic zone map [2]*

Maharashtra state is divided into 9 agroclimatic zones based on rainfall and land/soil type as shown in Figure 1-1. These zones serve as important input in agricultural research and planning. WALMI, Aurangabad has published agroclimatic zone wise range for crop water requirement and crop duration for major crops grown in each zone [1], which has been utilized to calibrate crop water requirement for IITB multi crop plugin.

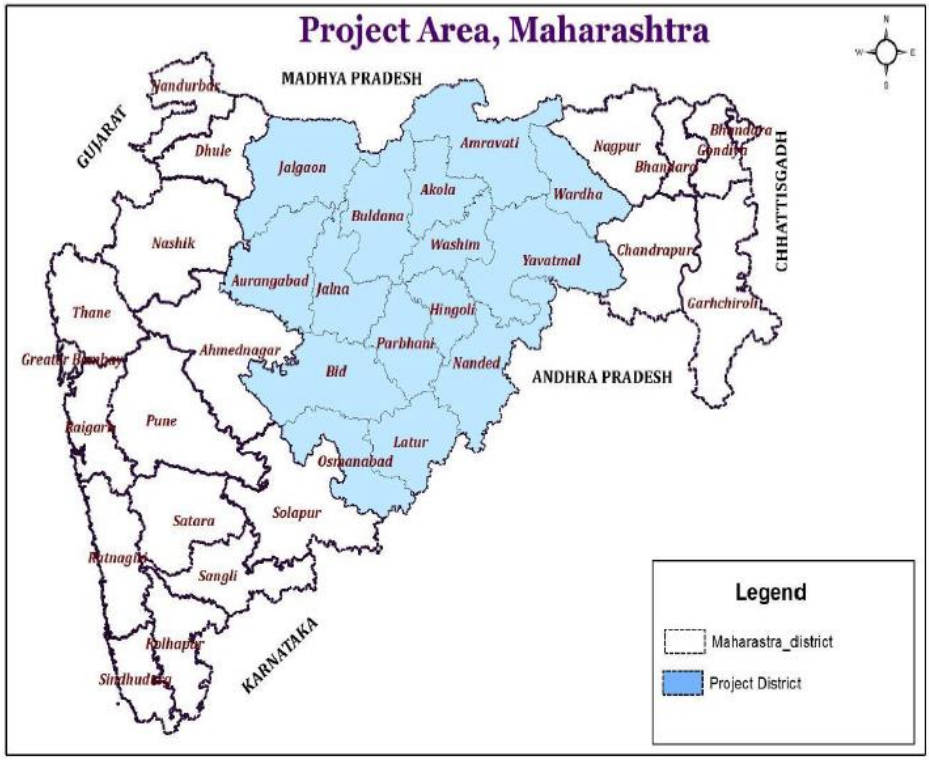



*Figure 1-2 PoCRA districts map [3]*

PoCRA project spans across 15 districts in Maharashtra lying in Marathwada and Vidarbha region. These districts fall largely in two agroclimatic zones as seen from Figures 1-1 and 1-2, Assured rainfall zone 7 with 700 – 900 mm annual rainfall and Moderate rainfall zone – 8 with 900 – 1200 mm annual rainfall. The agroclimatic zone wise mapping of districts is given in Table 1-1. This mapping along with WALMI crop water requirement data has been used as the basis to calibrate and run the soil moisture balance model of IITB.

*Table 1-1 Mapping of PoCRA districts to agroclimatic zones*

| Sr. no. | Region | District | Agro climatic zone |
|---|---|---|---|
| 1 | Marathwada | Aurangabad | Scarcity Zone 6 and Assured Rainfall Zone 7 |
| 2 | Marathwada | Beed | Scarcity Zone 6 and Assured Rainfall Zone 7 |
| 3 | Marathwada | Parbhani | Assured Rainfall Zone 7 |
| 4 | Marathwada | Hingoli | Moderate Rainfall Zone 8 |
| 5 | Marathwada | Osmanabed | Scarcity Zone 6 and Assured Rainfall Zone 7 |
| 6 | Marathwada | Jalna | Assured Rainfall Zone 7 |
| 7 | Marathwada | Latur | Assured Rainfall Zone 7 |
| 8 | Marathwada | Nanded | Assured Rainfall Zone 7 and Moderate Rainfall Zone 8 |
| 9 | Vidarbha | Buldhana | Assured Rainfall Zone 7 |
| 10 | Vidarbha | Akola | Assured Rainfall Zone 7 |
| 11 | Vidarbha | Amravati | Assured Rainfall Zone 7 |
| 12 | Vidarbha | Washim | Moderate Rainfall Zone 8 |

| Sr. no. | Region | District | Agro climatic zone |
|---|---|---|---|
| 13 | Vidarbha | Wardha | Moderate Rainfall Zone 8 |
| 14 | Vidarbha | Yavatmal | Moderate Rainfall Zone 8 |
| 15 | Khandesh | Jalgaon | Assured Rainfall Zone 7 |

## 2. Crop Water Requirement

As per FAO, Crop water requirement is defined as the "depth of water needed to meet the water loss through evapotranspiration (ETc) of a disease-free crop, growing in large fields under non-restricting soil conditions including soil water and fertility, and achieving full production potential under the given growing environment" [4]

Crop water requirement is a function of two main parameters namely:

1. Climate (ET0)
2. Crop Characteristics (Kc and growth stages)

### 1. Climate

Water loss in crops mainly occurs in two ways - Evaporation and Transpiration which are dependent on climatic conditions such as temperature, wind speed, humidity, radiation and sunshine hours. The influence of these climatic conditions on crop water requirement is computed in terms of a factor called reference crop evapotranspiration (ET0).

Reference crop evapotranspiration (ET0) is the evaporation and transpiration computed for a uniformly growing grass crop attaining its full productivity in given climatic conditions. Here grass is considered as the reference crop for capturing the influence of climate on crop water requirement. This concept is illustrated in Figure 2-1.

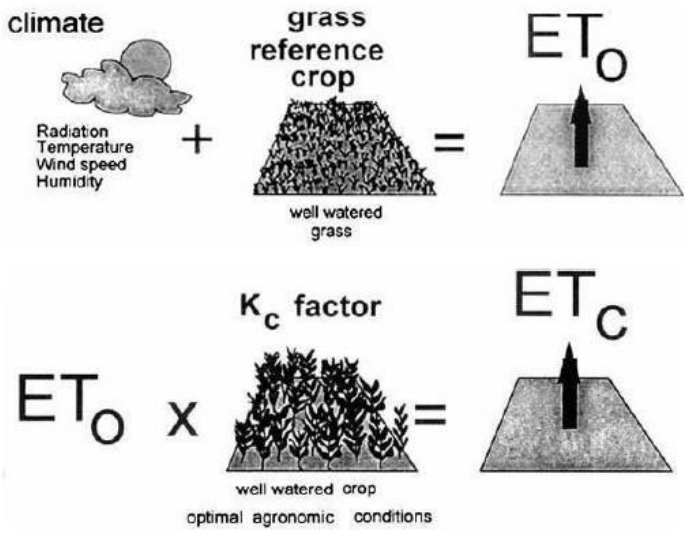



*Figure 2-1 Parameters determining Crop Water Requirement [4]*

The Evapotranspiration values vary on yearly basis and ideally, they must be computed every year. There are various methods used for computing ET0 values such as Blaney-Criddle, Penman, Pan Evaporation, Radiation as illustrated in FAO manuals [4], whose accuracy vary from region to region. For IITB multicrop plugin we have taken into account the ET0 values of local weather stations as per WALMI.

**Measurement and Data format**

Evapotranspiration is measured in mm/day and it represents the mean over a given period. The ET0 values for any weather station are made available in monthly format. Table 2-1 shows the ET0 values for a sample weather station.

*Table 2-1 Sample ET0 data table [5]*

| ET0 in mm/day | Jan | Feb | March | April | May | June | July | Aug | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parbhani | 3.95 | 5.17 | 5.29 | 7.03 | 8.25 | 7.51 | 4.77 | 4.55 | 4.78 | 4.8 | 3.9 | 3.48 |

## 2. Crop Characteristics

Crop is identified by two main parameters - crop duration in number of days and total crop water requirement in mm. The way these two parameters vary during crop growth period is called as crop characteristics and is defined for 4 stages of crop growth as illustrated in Figure 2-2. These stages are namely - Initial stage, Crop Development stage, Mid-season stage and Late season stage. Details of these stages can be found in [4]. A mean Kc value is given for each of this growth stage. The IITB model allows for different Kc values for different stages. This follows the usual SWAT implementation.

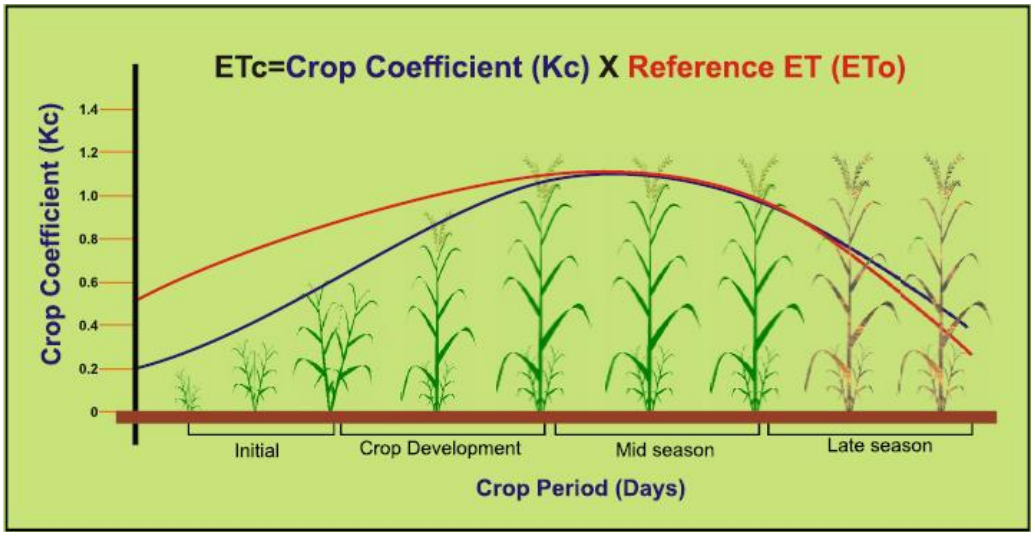



*Figure 2-1 Growth Stage wise crop coefficient Kc*

The duration of crop growth stages is defined in number of days and crop coefficient Kc is a fraction for each growth stage. The crop coefficient Kc represents the evapotranspiration of given crop as a factor with respect to reference grass crop.

As illustrated in Figure 2-2 the climatic factor in terms of evapotranspiration ET0 of reference grass crop and the crop coefficient Kc, together give the evapotranspiration ETc needs of any given crop.

$$ETc = ET0 \times Kc$$

# 3. Methodology for Adaptation of Datasets to Model

This section illustrates the methodology used to map the ET0 station dataset for PoCRA districts and generate the growth stage wise crop parameters of crop duration and crop coefficient (Kc) values for a variety of crops to match the local conditions.

## a. Mapping PoCRA districts to WALMI weather stations

Each of the PoCRA districts is matched to one weather station to assign it with ET0 values. The matching is done based on the agroclimatic zone in which the district lies, and the nearness to any weather station. There are 6 weather stations in PoCRA districts as shown in Figure 3-1. Of which 3 stations Parbhani, Aurangabad and Amravati lie in zone 7, Wardha, Yavatmal lie in zone 8, Northern part of Nanded lies in zone 8 and southern part in zone 7.

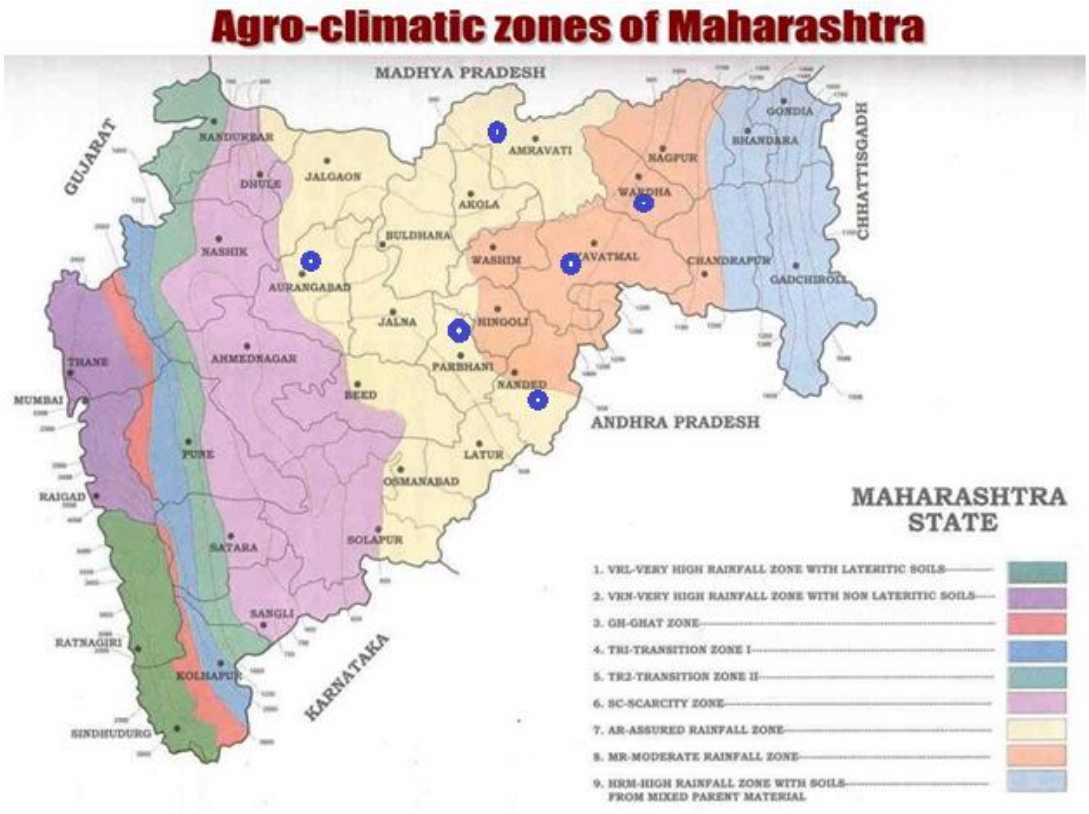



*Figure 3-1 WALMI Weather stations in PoCRA districts*

Table 3-1 shows the mapping of each PoCRA district to one ET0 weather station. The user must refer this table and decide the ET0 station to be used for selected region while running the IITB plugin. The user must decide the ET0 station for selected region based on the region's district and mapped station.

*Table 3-1 Mapping of PoCRA districts to ET0 stations*

| Sr. no. | Region | District | Mapped to ET0 Station | Agro climatic zone of station |
|---|---|---|---|---|
| 1 | Marathwada | Aurangabad | Aurangabad | Assured rainfall zone – 7 |
| 2 | Marathwada | Beed | Parbhani | Assured rainfall zone – 7 |
| 3 | Marathwada | Parbhani | Parbhani | Assured rainfall zone – 7 |
| 4 | Marathwada | Hingoli | Nanded | Assured Rainfall Zone 7 and Moderate Rainfall Zone 8 |
| 5 | Marathwada | Osmanabed | Parbhani | Assured rainfall zone – 7 |
| 6 | Marathwada | Jalna | Aurangabad | Assured rainfall zone – 7 |
| 7 | Marathwada | Latur | Parbhani | Assured rainfall zone – 7 |
| 8 | Marathwada | Nanded | Nanded | Assured Rainfall Zone 7 and Moderate Rainfall Zone 8 |
| 9 | Vidarbha | Buldhana | Amravati | Assured rainfall zone – 7 |
| 10 | Vidarbha | Akola | Amravati | Assured rainfall zone – 7 |
| 11 | Vidarbha | Amravati | Amravati | Assured rainfall zone – 7 |
| 12 | Vidarbha | Washim | Nanded | Assured Rainfall Zone 7 and Moderate Rainfall Zone 8 |
| 13 | Vidarbha | Wardha | Wardha | Moderate Rainfall Zone – 8 |
| 14 | Vidarbha | Yavatmal | Yavatmal | Moderate Rainfall Zone – 8 |
| 15 | Khandesh | Jalgaon | Aurangabad | Assured rainfall zone – 7 |

**ET0 values for PoCRA districts**

Table 3-2 gives the ET0 values for 6 weather stations in PoCRA region. The user must refer this table to create ET0 file for his selected region. Since, the crop water requirement or demand and Actual Evapotranspiration (AET) or water used by crop are influenced by ET0 along with rainfall pattern, it becomes essential that appropriate ET0 is input to the model for selected region.

*Table3-2 Evapotranspiration (ET0) values for WALMI stations in PoCRA districts [5]*

| ET0 in mm/day | Jan | Feb | March | April | May | June | July | Aug | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parbhani | 3.95 | 5.17 | 5.29 | 7.03 | 8.25 | 7.51 | 4.77 | 4.55 | 4.78 | 4.8 | 3.9 | 3.48 |
| Aurangabad | 4.36 | 5.6 | 6.5 | 7.55 | 8.86 | 6.32 | 4.64 | 3.98 | 4.39 | 5.02 | 4.52 | 4.16 |

| ET0 in mm/day | Jan | Feb | March | April | May | June | July | Aug | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Amravati | 4.74 | 5.89 | 7.03 | 8.13 | 9.09 | 8.2 | 4.61 | 4.45 | 4.7 | 5.32 | 4.76 | 4.36 |
| Nanded | 4.29 | 5.42 | 6.39 | 7.33 | 8.22 | 7.03 | 5.26 | 4.77 | 5.03 | 5.01 | 5.57 | 4.57 |
| Yavatmal | 4.77 | 5.93 | 7.05 | 7.96 | 9.26 | 7.96 | 4.55 | 3.93 | 4.5 | 4.84 | 4.23 | 4.22 |
| Wardha | 3.93 | 6.05 | 6.71 | 5.8 | 9 | 7.17 | 4.63 | 4.06 | 4.83 | 4.42 | 4.3 | 3.55 |

**Creating ET0 file for Plugin**

In the single crop/multicrop plugin the user is required to save the ET0 file in '.csv' format in the cluster folder (the folder where all input shapefiles of cluster *(soil, lulc, cadastral)* are saved). The plugin picks up the ET0 file from this folder and runs the model based on the ET0 values provided in file. The ET0 file saved in cluster folder must be named as 'ET0_file'. Table 3-3 shows the data table format of ET0 file. The ET0 file must be prepared in this format for plugin to be able to read the ET0 values.

File format: '.csv'
File name: 'ET0_file'
Row Headings: 'Month' and 'ET0'
ET0 station: As per ET0 station mapping in Table 3-1 for district where the cluster lies.
File folder: cluster folder given as input to model
Data table format:

*Table 3-3 Data table format for ET0_file*

| Month | ET0 |
|---|---|
| June | 6.32 |
| July | 4.64 |
| Aug | 3.98 |
| Sept | 4.39 |
| Oct | 5.02 |
| Nov | 4.52 |
| Dec | 4.16 |
| Jan | 4.36 |
| Feb | 5.6 |
| March | 6.5 |
| April | 7.55 |
| May | 8.86 |

**b. Calibrating crop coefficient Kc**

As illustrated in section two – crop water requirements, the growth period of each crop is divided into 4 stages (initial, crop development, mid-season and late-season) and characterized by two parameters –

duration of growth stage and mean crop coefficient Kc of growth stage. This data for majority of crop families is available with FAO [4]. Appendix I gives the growth stage wise crop parameters available on FAO website [4] which have been used as base values for model calibration.

Appendix I also shows WALMI data of total crop duration and total crop water requirement (CWR) for agroclimatic zone 7, for calibration purpose. The total crop water requirement for calibration is taken as the mid value of crop water requirement range given by WALMI.

Thus, for each crop, there are 6 possibilities for solving the equation

$$ET0\ (i)\ X\ Kc = ETc\ (i)$$

One for each weather station (i) and the CWR for the zone which contains weather station (i). Each choice will give us a Kc set. We describe below the procedure adopted to select one out of these six possibilities.

**Base Datasets Used for Calibration**

- **ET0 station:** Amravati
- **Expected CWR:** WALMI – Mid value of CWR range given for assured rainfall zone 7 (Agroclimatic zone for Amravati) – Appendix III

The crop water requirement range considered here for model's calibration is that of assured rainfall zone 7, where ET0 station Amravati lies. The methodology used to calibrate the FAO data for local WALMI dataset is as follows. The FAO's growth stage wise crop coefficient dataset Kc, is calibrated to get target expected WALMI crop water requirement, based on values of Amravati ET0 station.

The process followed to calibrate FAO Kc dataset to match WALMI CWR dataset is as follows:

1. **Calibrate duration of crop growth stages:** Duration of crop growth stages is calibrated first to match WALMI 's total crop duration. This process is illustrated through an example.

    - **Bajra Crop**
    - **Expected WALMI crop Duration:** 90 days
    - **FAO Crop growth stages (days):** 15, 25, 40, 25
    - **Total FAO crop duration:** 105 days
    - **Multiplication factor:** Expected value/Actual value = WALMI value/FAO value = 90/105

*Table 3-4 Calibration of duration for crop growth stages of Bajra*

| Growth stages | FAO duration (days) | Weighting based on WALMI | Calibrated values |
|---|---|---|---|
| Initial | 15 | 15 x (90/105) | 13 |
| Crop Development | 25 | 25 x (90/105) | 21 |
| Mid season | 40 | 40 x (90/105) | 34 |

| Growth stages | FAO duration (days) | Weighting based on WALMI | Calibrated values |
|---|---|---|---|
| Late Season | 25 | 25 x (90/105) | 21 |
| **Total duration in days** | **105** | | **90** |

Calibrated duration of crop growth stages used in model: 13, 21, 34, 21

2. **Calibrate crop coefficients (Kc) for crop growth stages:** The process followed here is similar to that followed for calibration of crop duration. In this process the total crop water requirement (CWR) based on FAO Kc values as per Amravati ET0 station is computed. These Kc values are adjusted by multiplying with a factor based on, computed CWR and expected WALMI CWR. These calibrated Kc values are then fed into the model.

   This process is illustrated with an example.

   - **Bajra**
     - **Expected WALMI CWR:** 312.5 mm
     - **FAO Kc values for growth stages:** 0.35, 0.7, 1.1, 0.65
     - **Computed FAO CWR:** 327 mm
     - **Multiplication Factor:** Expected Value/Actual Value = WALMI Expected CWR/Computed FAO CWR

       = 312/327

*Table 3-5 Calibration of crop growth stage wise Kc values for Bajra*

| Growth stages | FAO Kc values | Weighting based on WALMI | Calibrated values |
|---|---|---|---|
| Initial | 0.35 | 0.35 x (312/327) | 0.34 |
| Crop Development | 0.7 | 0.7 x (312/327) | 0.67 |
| Mid season | 1.1 | 1.1 x (312/327) | 1.05 |
| Late Season | 0.65 | 0.65 x (312/327) | 0.62 |
| **Total CWR** | **327** | | **312.5** |

In this manner the crop duration and crop coefficients are calibrated for crop growth stages of each crop added to plugin. Appendix II shows final calibrated values of duration and crop coefficients for the crops added to IITB plugin.

3. **Selecting Base Station:**

As the crop coefficient Kc is calibrated based on single ET0 station the CWR computed for other ET0 stations, using calibrated Kc values for selected ET0 station, would vary from expected WALMI CWR at that station. This variation from expected WALMI CWR is accepted, if the CWR for other ET0 station

lies within WALMI CWR range for the agroclimatic region of that ET0 station. The variation outside this range is considered an error.

**Error:** Variation of selected ET0 station CWR, outside WALMI CWR range for selected ET0 station's agroclimatic zone.

Appendix III shows the CWR/PET of crops for all 6 ET0 stations in PoCRA districts. It is computed based on Kc values calibrated as per Amravati Base station. The PET of each station is compared with the WALMI PET range for agroclimatic zone of that station, which gives the error outside the WALMI CWR range for each crop. ET0 stations Amravati, Aurangabad, Parbhani and Nanded lie in Agroclimatic zone 7, stations Wardha and Yavatmal lie in Agroclimatic zone 8. Appendix III also gives the WALMI PET range for agroclimatic zones 7 and 8. The cells 'highlighted' in green in Appendix III have CWR within the WALMI range, whereas those 'not highlighted' have CWR outside the range, which means they have error.

**Acceptable Error:** The error is considered acceptable if it is less than 50 mm, which is the water required for one irrigation.

**Analysis and Calibration**

The process of Kc calibration was done for all 6 ET0 stations and 6 Kc sets calibrated to the ET0 station's WALMI CWR parameters were generated. 6 PET sets of all ET0 stations, based on 6 Kc sets were computed and error in PET values of ET0 stations for main crops in PoCRA region were plotted for each Kc set. This was done to find the best fit Kc values set for IITB Plugin. The best fit Kc values set will be the one which gives minimal error for PET of main crops for all ET0 stations based on that Kc set. The error plots of PET for main crops, for 6 set of Kc values can be found in Appendix IV of this document.

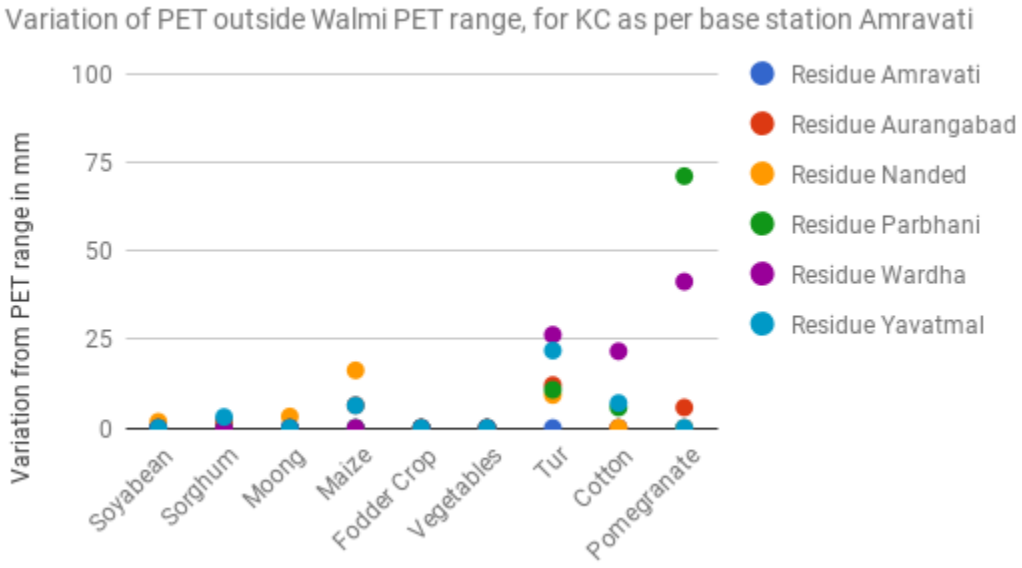



*Figure 3-2 Error plot for main crops in other ET0 stations as per base station Amravati*

From these error plots it is clear that Amravati station Kc set gives the least error in other ET0 stations, for main crops namely – Soybean, Sorgum, Maize, Moong, Fodder crop, Vegetables, Cotton and Tur as compared to remaining 5 Kc sets. The PET error in all stations as per Kc values of Amravati ET0 station can be seen in Figure 3-2. As per the plot, these errors are less than 25 mm for main crops. Much less than our acceptable error range of ±50 mm which is water requirement for one irrigation. Annual crop is an outlier for all Kc sets.

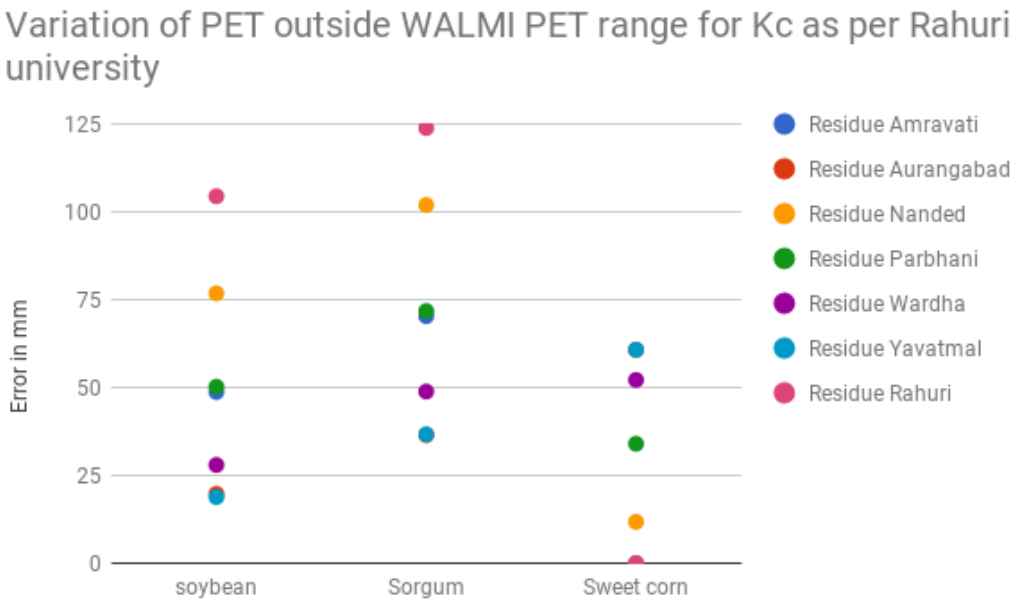



*Figure 3-3 PET error as per Rahuri University Kc set*

We also computed the PET for all ET0 stations as per Kc values available from Rahuri university research experiments. Weekly Kc values were available for three kharif crops – Soybean, Sorgum and Sweet Corn. Figure 3-3 shows the error in PET values in all ET0 stations as per Rahuri Kc values set [7].

It can be seen that Soybean and Sorgum crops have an error of more than 100 mm for Rahuri base station when compared with WALMI CWR range of Rahuri region lying in agroclimatic zone 6. The error in all other stations also seems to be high, and scattered between 25 mm to 125 mm with 4 stations having error greater than 50 mm. The PET values obtained based on Rahuri Kc set are comparatively higher which has resulted in higher error. The reason behind higher PET values in base station as well as other ET0 stations may be that, experiments were carried out on university crops grown in ideal conditions, translating to comparatively higher PET values than WALMI. The table for PET values of ET0 stations based on Rahuri Kc set can be found in Appendix V. Considering these scenarios we finalized the Kc set based on Amravati station as the final Kc set used for IITB plugin.

## 4. Observations and Analysis

In case if the PET for any station, for any crop has error greater than 50 mm for Kc set adopted in plugin. This is a considerable error. Such error is seen mainly for annual crops which have considerable PET

error. The error for annual crops based on Amravati and Parbhani Kc values is plotted in Figure 4-1 and 4-2 respectively.

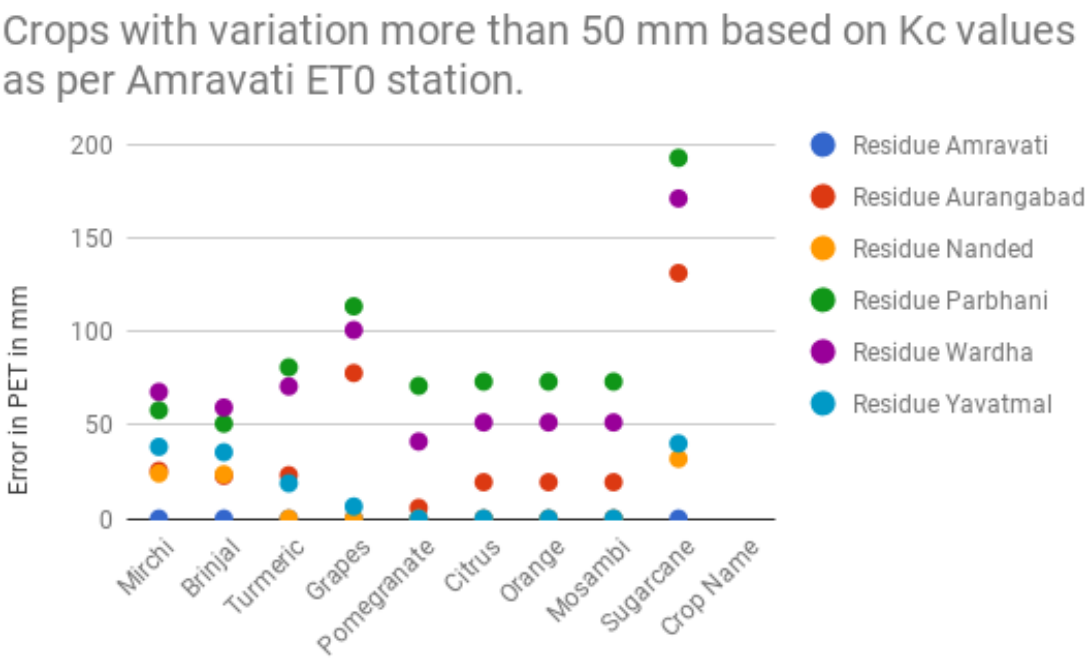



*Figure 4-1 Crop water requirement of stations based on Amravati ET0 Values*

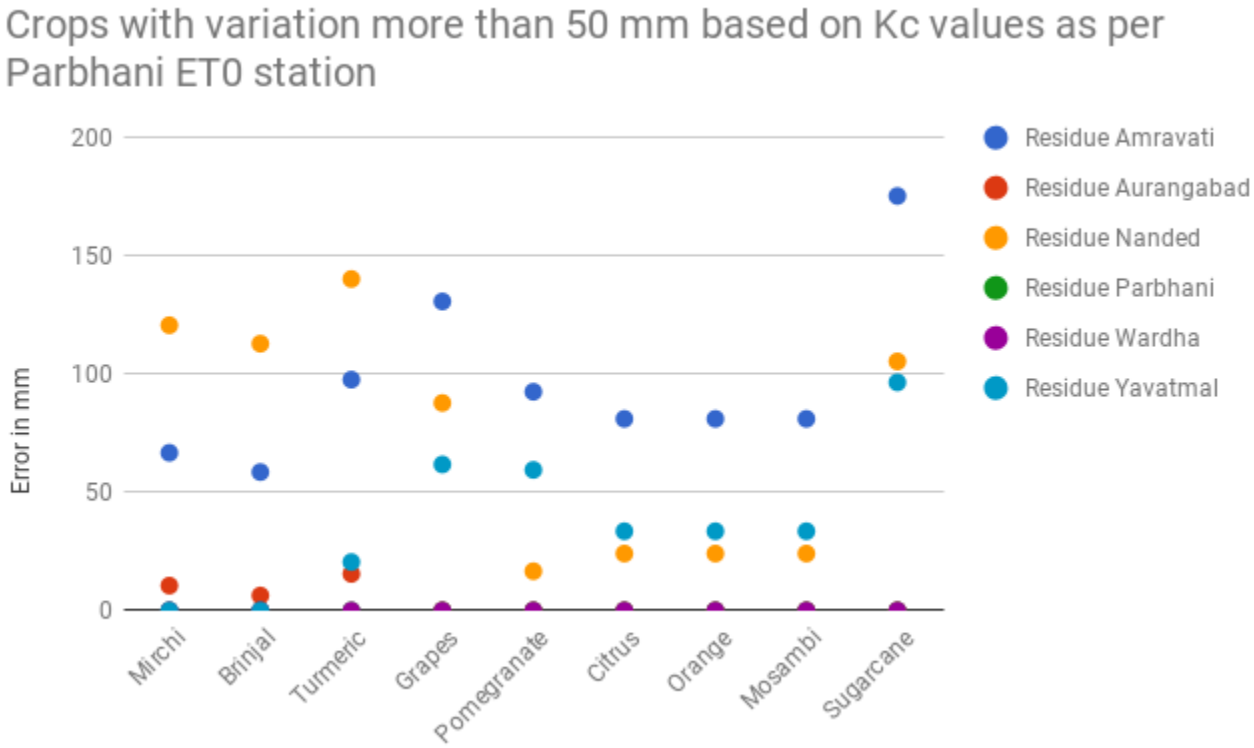



*Figure 4-2 Crop water requirement of stations based on Amravati ET0 Values*

**Observations**

These plots show that error for few high CWR and long duration vegetable and annual crops is scattered in both set of Kc values. For most of the stations as can be seen from PET table in Appendix III the error is on lower side of WALMI CWR range (PET is reducing for these crops in other stations).

1. Amravati Base station:
    a. The error in Wardha, Parbhani and Aurangabad stations is greater than 50 mm for plotted annual and vegetable crops
    b. The error in Amravati, Nanded and Yavatmal for plotted crops is within 50 mm acceptable range.
    c. The Kc set as per Amravati base station for these crops can be used for Amravati, Nanded and Yavatmal station

2. Parbhani Base station:
    a. The error in Amravati, Yavatmal and Nanded stations is greater than 50 mm for plotted crops.
    b. The error in Wardha, Parbhani and Aurangabad are within 50 mm acceptable range.
    c. The Kc set as per Parbhani base station for these crops can be used for Wardha, Parbhani and Aurangabad station.

The user can add Kc values for plotted annual and vegetable crops as per Parbhani station by obtaining appropriate dataset.

This higher variation in annual crops can be explained if we look at ET0 values of these 6 stations (Table 3-2) for main cropping kharif season between July to October. The ET0 for all stations is around 5 mm during this period. Whereas it varies substantially between stations during remaining part of the year, especially in the months of March – May. The effect of this can be seen in terms of much lower variation in kharif or long kharif crops and higher variation in annual crops outside the WALMI CWR range.

**Observations in yield-watering and its implication on Deficits in water budget**

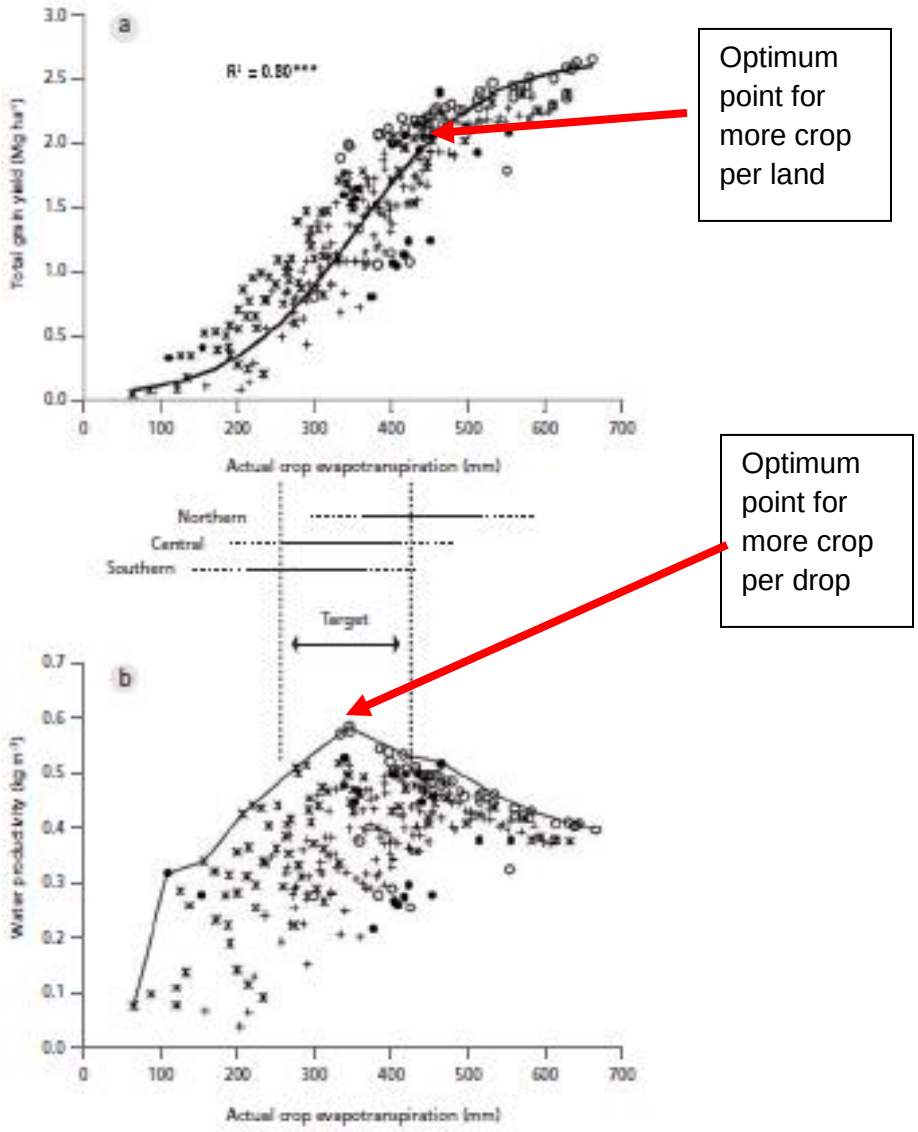



*Figure 4-2 Simulated yield of Quiona with Acqua Crop software [8]*

The deficits computed in water budget for monsoon and post monsoon season are based on the Kc set calibrated as per WALMI dataset. However as per field observations the farmer gives less water to his crops than the CWR as per WALMI dataset. He tries to go for more crop per land than more crop per drop (eg. – Farmer gives 1 watering less to cotton to save watering's for gram – 'Harbara'). He tries to get average yield by sowing more crops. In such case the monsoon and post monsoon index – which indicates the entire WALMI demand versus supply must be adjusted to this reduced demand for average yield. This adjustment should be done by finding farmer's operating point on yield watering curve.

## 5. Recommendations:

1. The ET0 station to be used for particular district should be chosen based on Table 3-1 ‘Mapping of PoCRA Districts to ET0 stations’. The ET0 station data given in Table 3-2 ‘Evapotranspiration values for WALMI stations in PoCRA districts’ should be used for same.
2. The Kc values calibrated as per Amravati ET0 have been finalized for a set of 27 Kharif, Kharif Vegetables, Long Kharif and Annual crops, and 5 land use types. These values are used in IITB Plugin. Appendix III gives the final crop growth stages and Kc values.
3. User should add regional Kc values for 7 annual (Grapes, Banana, Pomegranate, Citrus, Orange, Mosambi, Sugarcane), 1 Long Kharif Crop – Turmeric and 2 Vegetable crops (Chilly-‘Mirchi’ and Brinjal) in the plugin, whose error is beyond 50 mm acceptable range.
4. Total CWR of 15 Rabi crops based on WALMI data has also been incorporated into plugin. Note that the calibration process is not followed for rabi crops instead their total CWR is used in plugin considering the water allocation to be done for them, instead of running the model daily in post monsoon period. The user should add additional rabi crops as per requirement.

## References


1. WALMI (2013), “Irrigated Crops – Part I, Fifth Edition”, Water and Land Management Institute Publication no. 44, Aurangabad, Maharashtra.
2. Rashtriya Krishi Vikas Yojana (2009),” Agricultural profile Maharashtra” rkvy.nic.in/static/download/strategy/Maharastra.ppt
3. Department of Agriculture, “Project on Climate Resilient Agriculture – Project Implementation plan” Government of Maharashtra, The World Bank.
4. Food and Agricultural Organization “Chapter 3 – Crop Water Needs”. http://www.fao.org/docrep/S2022E/s2022e07.htm
5. WALMI (1988), “Crop Water Requirements”, Water and Land Management Institute Publication no. 30 Aurangabad, Maharashtra.
6. Food and Agricultural Organization “Chapter 8 – ETc under soil water stress conditions”. http://www.fao.org/docrep/X0490E/x0490e0e.htm
7. MPKV Res. Pub./194/2016 “AICRP on Irrigation Water Management” Mahatma Phule Krishi Vidyapeeth, Rahuri, Maharashtra, 2016.
8. Food and Agricultural Organization, Irrigation and Drainage Paper no.66, “Crop Yield Response to Water”, Rome, 2012.
9. Water Budgeting Guidelines (IIT Bombay), Water and Soil Conservation Department, Maharashtra, 2017.

## Appendix I

*Input Parameters– KC and growth stages [4]*

| Crop Season | Data Source | FAO | FAO | FAO | FAO | FAO | FAO | FAO | FAO | FAO | WALMI – Agroclimatic zone 7 | WALMI – Agroclimatic zone 7 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Parameter | | Duration (days) | | | | Kc (factor) | | | | Expected Duration | Expected PET |
| | Main crop | Matched FAO crop | Initial | Crop Development | Mid Season | Late Season | Initial | Crop Development | Mid Season | Late Season | Total (days) | Total (mm) |
| Kharif_Main | Sorghum | Sorgum | 20 | 30 | 40 | 30 | 0.35 | 0.75 | 1.1 | 0.65 | 120 | 425 |
| Kharif_Main | Bajri | Millet | 15 | 25 | 40 | 25 | 0.35 | 0.7 | 1.1 | 0.65 | 90 | 312.5 |
| Kharif_Main | Moong | Lentils | 20 | 30 | 60 | 40 | 0.45 | 0.75 | 1.1 | 0.5 | 60 | 275 |
| Kharif_Main | Udid | Lentils | 20 | 30 | 60 | 40 | 0.45 | 0.75 | 1.1 | 0.5 | 83 | 275 |
| Kharif_Main | Soybean | Soybean | 20 | 30 | 60 | 25 | 0.35 | 0.75 | 1.1 | 0.6 | 105 | 375 |
| Kharif_Main | Maize | Maize | 20 | 35 | 40 | 30 | 0.4 | 0.8 | 1.15 | 0.7 | 90 | 475 |
| Kharif_Main | Groundnut | Groundnut | 25 | 35 | 45 | 25 | 0.45 | 0.75 | 1.05 | 0.7 | 120 | 475 |
| Kharif_Main | Sunflower | Sunflower | 20 | 35 | 45 | 25 | 0.35 | 0.75 | 1.15 | 0.55 | 105 | 400 |
| Kharif_Main | Fodder Crop | Maize | 20 | 35 | 40 | 30 | 0.4 | 0.8 | 1.15 | 0.7 | 90 | 300 |
| Kharif_Vegetables | Onion | Onion | 15 | 25 | 70 | 40 | 0.5 | 0.7 | 1 | 1 | 115 | 525 |
| Kharif_Vegetables | Mirchi | Pepper | 25 | 35 | 40 | 20 | 0.35 | 0.7 | 1.05 | 0.9 | 190 | 875 |
| Kharif_Vegetables | Brinjal | Egg plant | 30 | 40 | 40 | 20 | 0.45 | 0.75 | 1.15 | 0.8 | 190 | 825 |
| Kharif_Vegetables | Tomato | Tomato | 30 | 40 | 40 | 25 | 0.45 | 0.75 | 1.15 | 0.8 | 137 | 700 |
| Kharif_Vegetables | Cauliflower | Cabbage | 20 | 25 | 60 | 15 | 0.45 | 0.75 | 1.05 | 0.9 | 85 | 475 |
| Kharif_Vegetables | Vegetables (okra, gawar, carrot, palak,bitter | Tomato | 30 | 40 | 40 | 25 | 0.45 | 0.75 | 1.15 | 0.8 | 110 | 500 |

| Crop Season | Data Source | FAO | FAO | FAO | FAO | FAO | FAO | FAO | FAO | FAO | WALMI – Agroclimatic zone 7 | WALMI – Agroclimatic zone 7 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Parameter | | Duration (days) | | | | Kc (factor) | | | | Expected Duration | Expected PET |
| | Main crop | Matched FAO crop | Initial | Crop Development | Mid Season | Late Season | Initial | Crop Development | Mid Season | Late Season | Total (days) | Total (mm) |
| | gourd ..) | | | | | | | | | | | |
| Kharif_Vegetables | Small Vegetables (group - coriander, radish, palak,letttuce..) | Spinach | 20 | 20 | 15 | 5 | 0.45 | 0.6 | 1 | 0.9 | 60 | 300 |
| Long_Kharif | Tur | Cotton | 30 | 50 | 55 | 45 | 0.45 | 0.75 | 1.15 | 0.75 | 165 | 625 |
| Long_Kharif | Turmeric | Cotton | 30 | 50 | 55 | 45 | 0.45 | 0.75 | 1.15 | 0.75 | 240 | 1250 |
| Long_Kharif | Potato | Potato | 25 | 30 | 30 | 20 | 0.45 | 0.75 | 1.15 | 0.85 | 105 | 550 |
| Long_Kharif | Cotton | Cotton | 30 | 50 | 55 | 45 | 0.45 | 0.75 | 1.15 | 0.75 | 180 | 800 |
| Annual | Grapes | Grapes | 20 | 40 | 120 | 60 | 0.3 | 1.05 | 0.5 | 0.5 | 365 | 1750 |
| Annual | Banana | Banana | 120 | 90 | 120 | 60 | 0.5 | 1.1 | 1 | 1 | 365 | 2100 |
| Annual | Pomegranate | Pomegranate | 21 | 77 | 56 | 210 | 3.34 | 1.9 | 4.02 | 5.07 | 365 | 1300 |
| Annual | Citrus | Citrus | 60 | 90 | 120 | 95 | 0.7 | 0.65 | 0.7 | 0.7 | 365 | 1500 |
| Annual | Orange | Citrus | 60 | 90 | 120 | 95 | 0.7 | 0.65 | 0.7 | 0.7 | 365 | 1500 |
| Annual | Mosambi | Citrus | 60 | 90 | 120 | 95 | 0.7 | 0.65 | 0.7 | 0.7 | 365 | 1500 |
| Annual | Sugarcane | Sugarcane | 35 | 60 | 190 | 175 | 0.4 | 1.25 | 0.75 | 0.75 | 365 | 2125 |

## Appendix II

*Finalized Kc values [6]*

| Finalized Kc values | | Duration in days | | | | KC (factor) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Season | Crop Name | Initial Duration | Crop dev Duration | Mid Season Duration | Late Duration | Initial Kc | Crop dev Kc | Mid Season Kc | Late Kc | PET (mm) |
| Kharif_Main | Sorghum | 20 | 30 | 40 | 30 | 0.34 | 0.72 | 1.06 | 0.63 | 425.96 |
| Kharif_Main | Bajri | 13 | 21 | 34 | 22 | 0.34 | 0.67 | 1.05 | 0.62 | 311.6 |
| Kharif_Main | Moong | 8 | 12 | 24 | 16 | 0.57 | 0.95 | 1.4 | 0.63 | 274.96 |
| Kharif_Main | Udid | 11 | 17 | 33 | 22 | 0.41 | 0.69 | 1.01 | 0.46 | 274.16 |
| Kharif_Main | Soybean | 16 | 23 | 47 | 19 | 0.33 | 0.7 | 1.03 | 0.56 | 375.18 |
| Kharif_Main | Maize | 14 | 25 | 29 | 22 | 0.56 | 1.11 | 1.6 | 0.97 | 475.4 |
| Kharif_Main | Groundnut | 23 | 32 | 42 | 23 | 0.47 | 0.79 | 1.1 | 0.74 | 474.23 |
| Kharif_Main | Sunflower | 17 | 29 | 38 | 21 | 0.36 | 0.78 | 1.19 | 0.57 | 400.78 |
| Kharif_Main | Fodder Crop | 14 | 25 | 29 | 22 | 0.35 | 0.7 | 1.01 | 0.61 | 299.53 |
| Kharif_Vegetables | Onion | 12 | 19 | 54 | 30 | 0.53 | 0.75 | 1.07 | 1.07 | 526.7 |
| Kharif_Vegetables | Mirchi | 40 | 55 | 63 | 32 | 0.44 | 0.87 | 1.31 | 1.12 | 875.26 |
| Kharif_Vegetables | Brinjal | 44 | 58 | 58 | 30 | 0.51 | 0.84 | 1.29 | 0.9 | 824.43 |
| Kharif_Vegetables | Tomato | 30 | 41 | 41 | 25 | 0.58 | 0.97 | 1.49 | 1.04 | 698.6 |
| Kharif_Vegetables | Cauliflower | 14 | 18 | 43 | 10 | 0.63 | 1.05 | 1.46 | 1.25 | 474.68 |
| Kharif_Vegetables | Vegetables | 24 | 33 | 33 | 20 | 0.53 | 0.89 | 1.36 | 0.94 | 500.66 |
| Kharif_Vegetables | Small Vegetables | 20 | 20 | 15 | 5 | 0.73 | 0.97 | 1.61 | 1.45 | 300.62 |
| Long_Kharif | Tur | 28 | 46 | 50 | 41 | 0.43 | 0.72 | 1.1 | 0.72 | 625.35 |

| Finalized Kc values | | Duration in days | | | | KC (factor) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Season | Crop Name | Initial Duration | Crop dev Duration | Mid Season Duration | Late Duration | Initial Kc | Crop dev Kc | Mid Season Kc | Late Kc | PET (mm) |
| Long_Kharif | Turmeric | 40 | 67 | 73 | 60 | 0.59 | 0.98 | 1.51 | 0.98 | 1250.21 |
| Long_Kharif | Potato | 25 | 30 | 30 | 20 | 0.62 | 1.03 | 1.58 | 1.16 | 550.91 |
| Long_Kharif | Cotton | 30 | 50 | 55 | 45 | 0.51 | 0.85 | 1.3 | 0.85 | 802.51 |
| Annual | Grapes | 30 | 61 | 183 | 91 | 0.44 | 1.52 | 0.73 | 0.73 | 1755.94 |
| Annual | Banana | 112 | 84 | 112 | 57 | 0.53 | 1.17 | 1.06 | 1.06 | 2051.66 |
| Annual | Pomegranate | 21 | 77 | 56 | 211 | 0.46 | 0.26 | 0.56 | 0.7 | 1292.29 |
| Annual | Citrus | 60 | 90 | 120 | 95 | 0.7 | 0.65 | 0.7 | 0.7 | 1490.98 |
| Annual | Orange | 60 | 90 | 120 | 95 | 0.7 | 0.65 | 0.7 | 0.7 | 1490.98 |
| Annual | Mosambi | 60 | 90 | 120 | 95 | 0.7 | 0.65 | 0.7 | 0.7 | 1490.98 |
| Annual | Sugarcane | 28 | 48 | 151 | 138 | 0.51 | 1.58 | 0.95 | 0.95 | 2130.53 |
| Landuse* | current fallow | 30 | 30 | 31 | 31 | 0.16 | 0.1 | 0.26 | 0.47 | 150.00 |
| Landuse* | Forest | 45 | 60 | 90 | 170 | 0.3 | 1.13 | 0.69 | 0.1 | 800.00 |
| Landuse* | Wasteland | 120 | 60 | 120 | 65 | 0.38 | 0.19 | 0.11 | 0.08 | 300.00 |
| Landuse* | Scrub | 30 | 60 | 60 | 215 | 0.13 | 0.31 | 0.22 | 0.09 | 400.00 |
| Landuse* | permanent fallow | 30 | 30 | 31 | 31 | 0.16 | 0.1 | 0.26 | 0.47 | 150.00 |

*In collaboration with Sudhanshu Deshmukh, M.Tech Computer Science at IITB*

*PET for LU types has been referred from JYS GR [9] and field observations.

## Appendix III

*PET of all crops for 6 key ET0 stations based on Kc values calibrated as per Amravati station [1]*

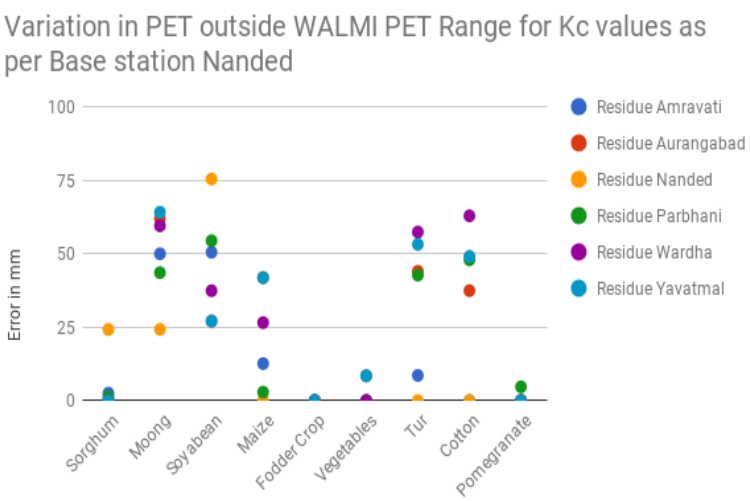
| Season | Crop Name | Agroclimatic zone 7 - ET0 stations | | | | WALMI Agroclimatic zone 7 – CWR range | | Agroclimatic zone 8 ET0 stations | | WALMI Agroclimatic zone 8 CWR range | | Base ET0 station |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | PET Base station Amravati | PET Aurangabad | PET Nanded | PET Parbhani | Minimum CWR | Maximum CWR | PET Wardha | PET Yawatmal | Minimum CWR | Maximum CWR | |
| Kharif_Main | Sorghum | 425.96 | 398.18 | 448.74 | 424.57 | 400 | 450 | 404.18 | 396.91 | 400 | 450 | Amravati |
| Kharif_Main | Bajri | 311.6 | 290.18 | 338.12 | 318.51 | 300 | 325 | 301.01 | 290.11 | 300 | 325 | Amravati |
| Kharif_Main | Moong | 274.96 | 261.83 | 303.24 | 282 | 250 | 300 | 264.51 | 259.45 | 250 | 300 | Amravati |
| Kharif_Main | Udid | 274.16 | 256.58 | 298.88 | 280.53 | 250 | 300 | 263.29 | 255.56 | 250 | 300 | Amravati |
| Kharif_Main | Soybean | 375.18 | 350.09 | 401.77 | 379.33 | 350 | 400 | 361.13 | 350.07 | 350 | 400 | Amravati |
| Kharif_Main | Maize | 475.4 | 443.6 | 516.25 | 485.97 | 450 | 500 | 460.21 | 443.65 | 450 | 500 | Amravati |
| Kharif_Main | Groundnut | 474.23 | 443.84 | 498 | 471.22 | 450 | 500 | 448.98 | 442.4 | 450 | 500 | Amravati |
| Kharif_Main | Sunflower | 400.78 | 374.1 | 429.45 | 405.4 | 375 | 425 | 386.28 | 374.21 | 375 | 425 | Amravati |
| Kharif_Main | Fodder Crop | 299.53 | 279.48 | 325.27 | 306.19 | 250 | 350 | 289.94 | 279.51 | 250 | 350 | Amravati |
| Kharif_Vegetables | Onion | 526.7 | 493.08 | 553.8 | 523.64 | 500 | 550 | 497.06 | 490.69 | 500 | 550 | Amravati |
| Kharif_Vegetables | Mirchi | 875.26 | 824.42 | 924.15 | 792.04 | 850 | 900 | 782.23 | 811.63 | 850 | 900 | Amravati |
| Kharif_Vegetables | Brinjal | 824.43 | 777.1 | 873.71 | 749.2 | 800 | 850 | 740.58 | 764.49 | 800 | 850 | Amravati |
| Kharif_Vegetables | Tomato | 698.6 | 655.04 | 730.47 | 675.45 | 650 | 750 | 649.35 | 647.35 | 650 | 750 | Amravati |
| Kharif_Vegetables | Cauliflower | 474.68 | 443.03 | 515.26 | 485.09 | 450 | 500 | 460 | 443.46 | 450 | 500 | Amravati |
| Kharif_Vegetables | Vegetables | 500.66 | 468.11 | 530.34 | 501.48 | 450 | 550 | 479.47 | 468.13 | 450 | 550 | Amravati |
| Kharif_Vegetables | Small Vegetables | 300.62 | 280.7 | 327.88 | 307.56 | 250 | 350 | 284.74 | 278.87 | 250 | 350 | Amravati |

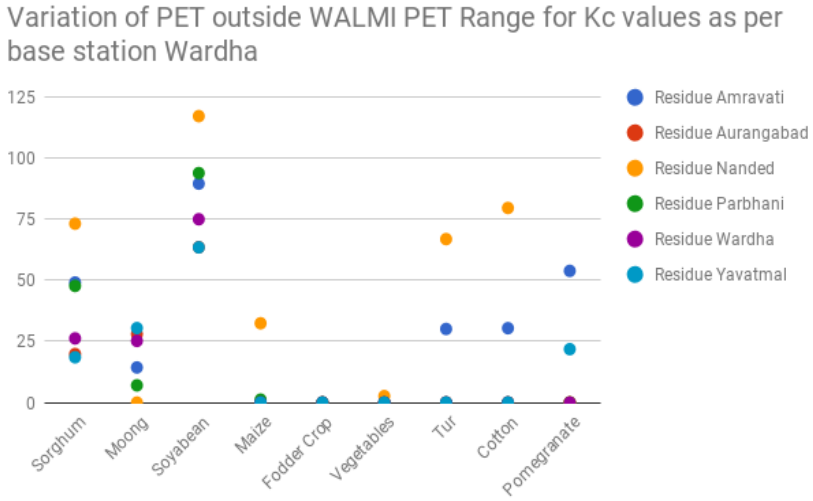
| Season | Crop Name | Agroclimatic zone 7 - ET0 stations | | | | WALMI Agroclimatic zone 7 – CWR range | | Agroclimatic zone 8 ET0 stations | | WALMI Agroclimatic zone 8 CWR range | | Base ET0 station |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | PET Base station Amravati | PET Aurangabad | PET Nanded | PET Parbhani | Minimum CWR | Maximum CWR | PET Wardha | PET Yawatmal | Minimum CWR | Maximum CWR | |
| Long_Kharif | Tur | 625.35 | 587.89 | 659.28 | 589.24 | 600 | 650 | 573.74 | 578.17 | 600 | 650 | Amravati |
| Long_Kharif | Turmeric | 1250.21 | 1176.77 | 1288.48 | 1119.1 | 1200 | 1300 | 1129.29 | 1181.1 | 1200 | 1300 | Amravati |
| Long_Kharif | Potato | 550.91 | 514.57 | 586.32 | 554.19 | 500 | 600 | 529.88 | 515.23 | 500 | 600 | Amravati |
| Long_Kharif | Cotton | 802.51 | 755.32 | 847.46 | 744.23 | 750 | 850 | 728.37 | 742.98 | 750 | 850 | Amravati |
| Annual | Grapes | 1755.94 | 1622.14 | 1716.32 | 1586.47 | 1700 | 1800 | 1599.16 | 1693.5 | 1700 | 1800 | Amravati |
| Annual | Banana | 2051.66 | 1897.05 | 1962.45 | 1793 | 2000 | 2100 | 1840.39 | 1999.65 | 2000 | 2100 | Amravati |
| Annual | Pomegranate | 1292.29 | 1194.23 | 1226.84 | 1129 | 1200 | 1400 | 1158.74 | 1263.5 | 1200 | 1400 | Amravati |
| Annual | Citrus | 1490.98 | 1380.5 | 1440.58 | 1326.73 | 1400 | 1600 | 1348.54 | 1448.76 | 1400 | 1600 | Amravati |
| Annual | Orange | 1490.98 | 1380.5 | 1440.58 | 1326.73 | 1400 | 1600 | 1348.54 | 1448.76 | 1400 | 1600 | Amravati |
| Annual | Mosambi | 1490.98 | 1380.5 | 1440.58 | 1326.73 | 1400 | 1600 | 1348.54 | 1448.76 | 1400 | 1600 | Amravati |
| Annual | Sugarcane | 2130.53 | 1968.68 | 2067.99 | 1907.09 | 2100 | 2200 | 1928.8 | 2059.81 | 2100 | 2200 | Amravati |
| Landuse* | current fallow | 150.94 | 142.16 | 153.57 | 145.68 | - | - | 138.49 | 140.62 | - | - | Amravati |
| Landuse* | forest | 803.24 | 749.93 | 825.6 | 737.37 | - | - | 729.71 | 755.99 | - | - | Amravati |
| Landuse* | scrub | 398.92 | 372.76 | 403.31 | 369.19 | - | - | 365.69 | 380.36 | - | - | Amravati |
| Landuse* | wasteland | 299.99 | 278.39 | 300.34 | 275.17 | - | - | 274.42 | 285.75 | - | - | Amravati |
| Landuse* | Permanent fallow | 150.94 | 142.16 | 153.57 | 145.68 | - | - | 138.49 | 140.62 | - | - | Amravati |

*In collaboration with Sudhanshu Deshmukh, M.Tech Computer Science at IITB*

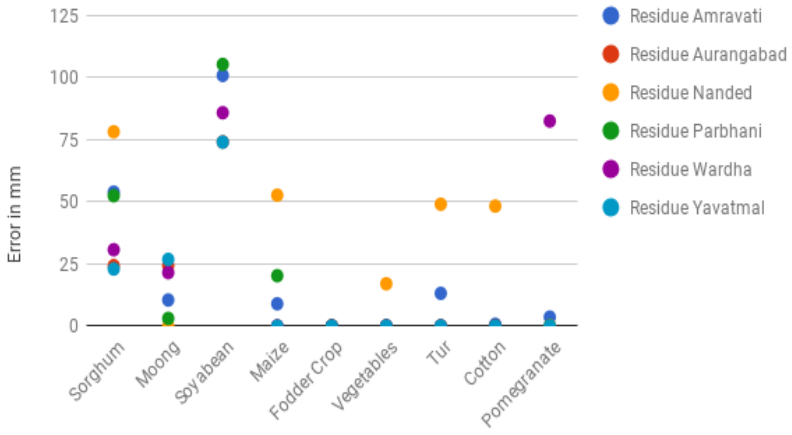
*PET for LU types has been referred from JYS GR [9] and field observations.
** cells highlighted in green (crop row, ET0 station column) lie within WALMI CWR range.

## Appendix IV : Variation of PET outside WALMI range

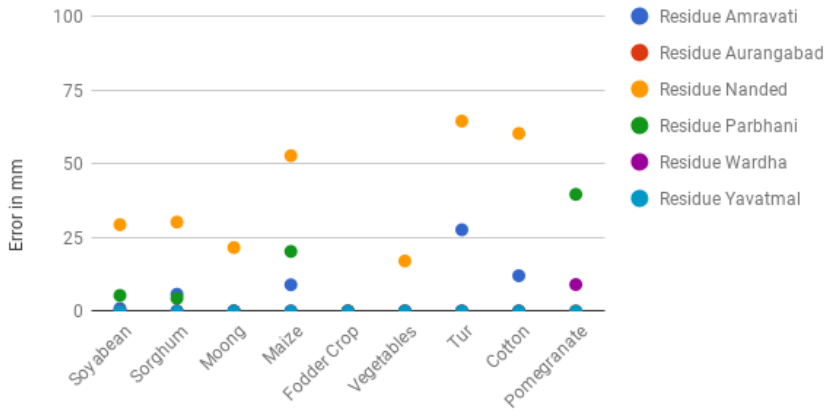


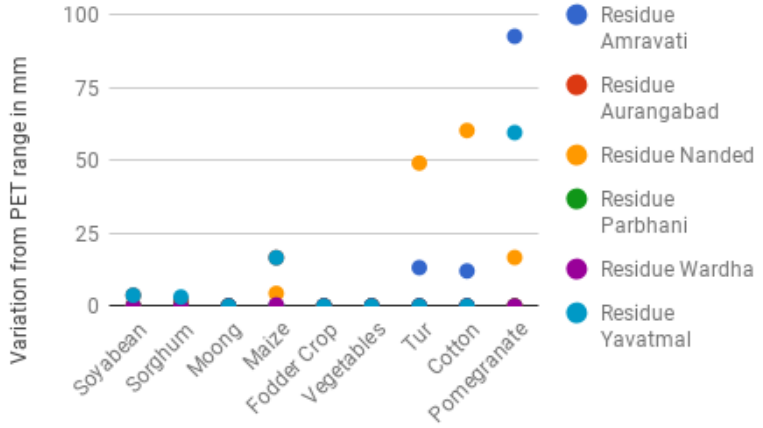
Variation of PET outside WALMI PET Range, for Kc values as per base station Aurangabad



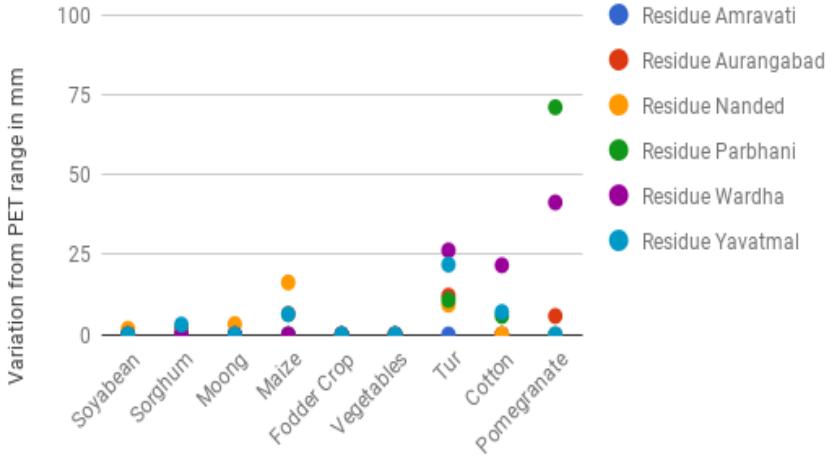

Variation of PET outside WALMI PET range, for Kc as per base station Yavatmal

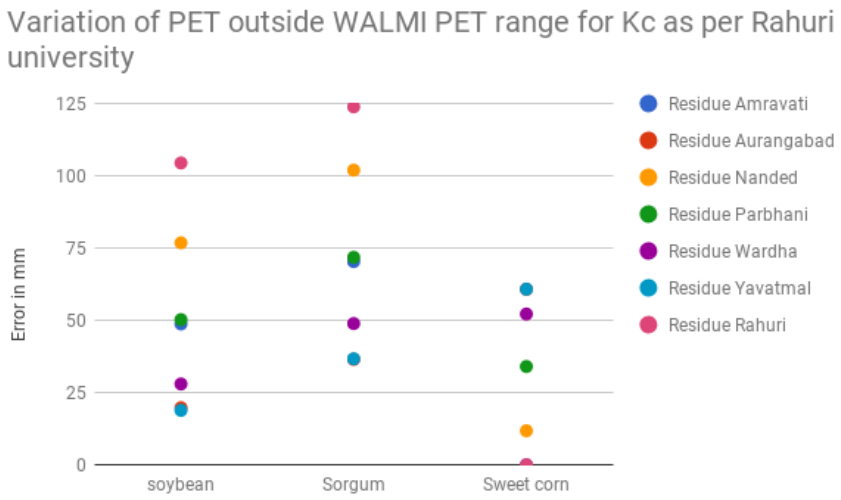



Variation of PET outside Walmi PET range, for KC as per base station Parbhani




Variation of PET outside Walmi PET range, for KC as per base station Amravati




Variation of PET outside WALMI PET range for Kc as per Rahuri university
Error in mm
125
100
75
50
25
0
soybean
Sorgum
Sweet corn
Residue Amravati
Residue Aurangabad
Residue Nanded
Residue Parbhani
Residue Wardha
Residue Yavatmal
Residue Rahuri

## Appendix V

PET as per Rahuri University Kc values [7]

| Rahuri Base station | | Agroclimatoc zone 7 - ET0 stations | | | | Walmi Agroclimatic zone 7 CWR range | | Agroclimatic zone 8 ET0 stations | | Walmi Agroclimatic zone 8 CWR range | | Agroclimatic zone 6 ET0 station | Walmi Agroclimatic zone 6 Rahuri CWR range | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Season** | **Crop Name** | **PET Amravati** | **PET Aurangabad** | **PET Nanded** | **PET Parbhani** | **Minimum CWR** | **Maximum CWR** | **PET Wardha** | **PET Yawatmal** | **Minimum CWR** | **Maximum CWR** | **PET Rahuri** | **Minimum CWR** | **Maximum CWR** |
| Kharif_Main | Soybean | 448.73 | 419.74 | 476.79 | 450.22 | 350 | 400 | 427.96 | 418.82 | 350 | 400 | 504.44 | 350 | 400 |
| Kharif_Main | Sorgum | 520.3 | 486.47 | 551.95 | 521.78 | 400 | 450 | 498.85 | 486.67 | 400 | 450 | 573.85 | 400 | 450 |
| Kharif_Main | Sweet corn | 362.49 | 339.27 | 388.24 | 366 | 400 | 450 | 347.84 | 339.24 | 400 | 450 | 417.73 | 400 | 450 |

*In collaboration with Sudhanshu Deshmukh, M.Tech Computer Science at IITB*