

Model for Reference Evapotranspiration Estimation

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Dated 10th May 2019

Introduction

Accurate estimation of reference evapotranspiration (ET_0) is essential for many studies such as hydrologic water balance, irrigation scheduling, and water resources planning and management. In the present study three existing evapotranspiration equations namely Hargreaves, Jensen-Haise and FAO-56 Penman Monteith were considered to calculate daily and monthly reference evapotranspiration (ET_0). The values computed using these methods were compared against the district wise ET_0 values published by Walmi. The daily meteorological data has been collected from skymet for the 21 districts of Maharashtra having 1325 circles in total.

Table 1 Number of skymet circles in different districts

District	Count
Ahmednagar	96
Akola	47
Amravati	86
Aurangabad	61
Beed	61
Buldana	87
Chandrapur	48
Dhule	37
Hingoli	29
Jalgaon	86
Jalna	45
Latur	53
Nagpur	64
Nanded	77
Nashik	89
Osmanabad	41
Parbhani	39
Solapur	91
Wardha	45
Washim	43
Yawatmal	100
Total	1325

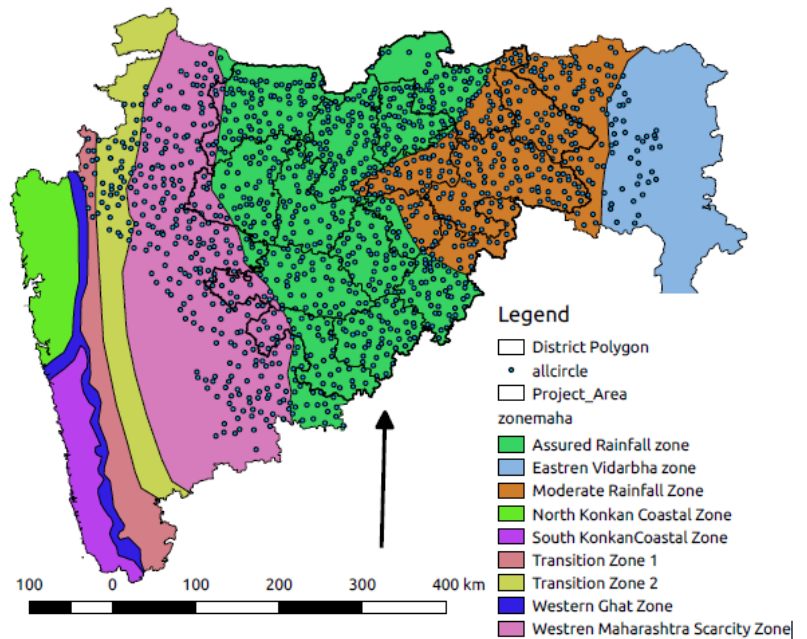


Fig 1 Skymet circles

Evapotranspiration is one of the most important and complicated phases of the hydrologic cycle. It redistributes the heat energy between surfaces and atmosphere. Estimation of evapotranspiration is essential in the design of reservoirs, irrigation systems, scheduling and frequency of irrigation and water balance and simulations studies. ET_0 is a complex phenomenon because it depends on several climatological factors, such as temperature, humidity, wind speed, radiation, type and growth stage of the crop. ET_0 can be either directly measured using lysimeter or water balance approaches or estimated indirectly using climatological data. However, it is not always possible to measure ET_0 using lysimeter because it is a time-consuming method and needs precise and carefully planned experiments. The indirect ET_0 estimation methods based

on climatological data vary from empirical relationships to complex methods such as the Penman Monteith method based on physical processes. These different methods of ET_o estimation can be grouped into temperature methods (Thornthwaite, SCS Blaney Criddle, FAO-24 Blaney Criddle, Hargreaves), radiation methods (Turc, Jensen-Haise, Priestley-Taylor, and FAO-24 radiation), combination theory types [Penman Monteith, FAO24 Penman ($c=1$), 1982 Kimberly Penman, 1972 Kimberly Penman, FAO 24 corrected Penman] and pan evaporation (FAO-24 pan) [1], [2]. Monteith (1965) modified the Penman method by incorporating stomatal resistance term specific to the type of crop in addition to the existing aerodynamic term and formulated the Penman-Monteith evapotranspiration model. The performance of different ET_o estimation varies with climatic conditions and availability of data, and the data requirements vary from method to method. Furthermore, ET_o estimation depends upon the quality of the meteorological data [3].

The Food and Agriculture Organization (FAO) of the United Nations recommended Penman-Monteith equation as the standard for estimation and evaluation of reference evapotranspiration. The basic difficulty in using the FAO-56 Penman-Monteith (FAO-56 PM) equation is the requirement of adequate weather data which may not be available in most of the meteorological stations. However, recommendations have been developed using the FAO Penman-Monteith method with limited climatic data, thereby largely eliminating the need for any other reference evapotranspiration methods and creating a consistent and transparent basis for a globally valid standard for crop water requirement calculations[2].

A common procedure for estimating crop reference evapotranspiration at any given time for a specific crop is to first estimate the reference evapotranspiration ET_o from a standard surface and then apply an empirical crop coefficient. Allen [2] defined the grass reference evapotranspiration as “the rate of evapotranspiration from a hypothetical reference crop with an assumed crop height of 0.12m, a fixed surface resistance of $70s\ m^{-1}$ and an albedo of 0.23 closely resembling the evapotranspiration from an extensive surface of green grass of uniform height actively growing completely shading the ground and with adequate water.

Many people have computed the ET using IMD data from different methods and compared it against the standard FAO method in different regions of Maharashtra. They have concluded that Hargreaves and Samani method gives good result in absence of full weather parameters [4], [5], [6], [7]. Hargreaves and Allen have analyzed the reference ET across the world at different locations using different methods. They have compared the PET with original lysimeters data and concluded that Hargreaves and Samani method gives suitable results with limited dataset. [8], [9]

METHODOLOGY

Hourly meteorological parameters viz., maximum temperature, minimum temperature, avg temperature minimum relative humidity, maximum relative humidity, average relative humidity, average wind speed, maximum wind speed and rainfall with latitude and longitude are provided by skymet through API. In the present study one equation from temperature theory, one equation from radiation theory, one equation from combination approach have been considered for performance analysis. Three existing evapotranspiration equations namely Hargreaves, and FAO-56 Penman Monteith and Jensen-Haise are considered to calculate daily and monthly reference evapotranspiration (ET_o).

Solar radiation data is missing from the data set provided by the skymet. Recommendations given by FAO to calculate the (ET_o) using the FAO Penman-Monteith method with limited climatic data have been used to calculate the missing solar radiation data given in table 3.

There are many circles where minimum relative humidity and maximum relative humidity data is missing. In such cases hourly average relative humidity data has been used to extract minimum and maximum relative humidity values for a day.

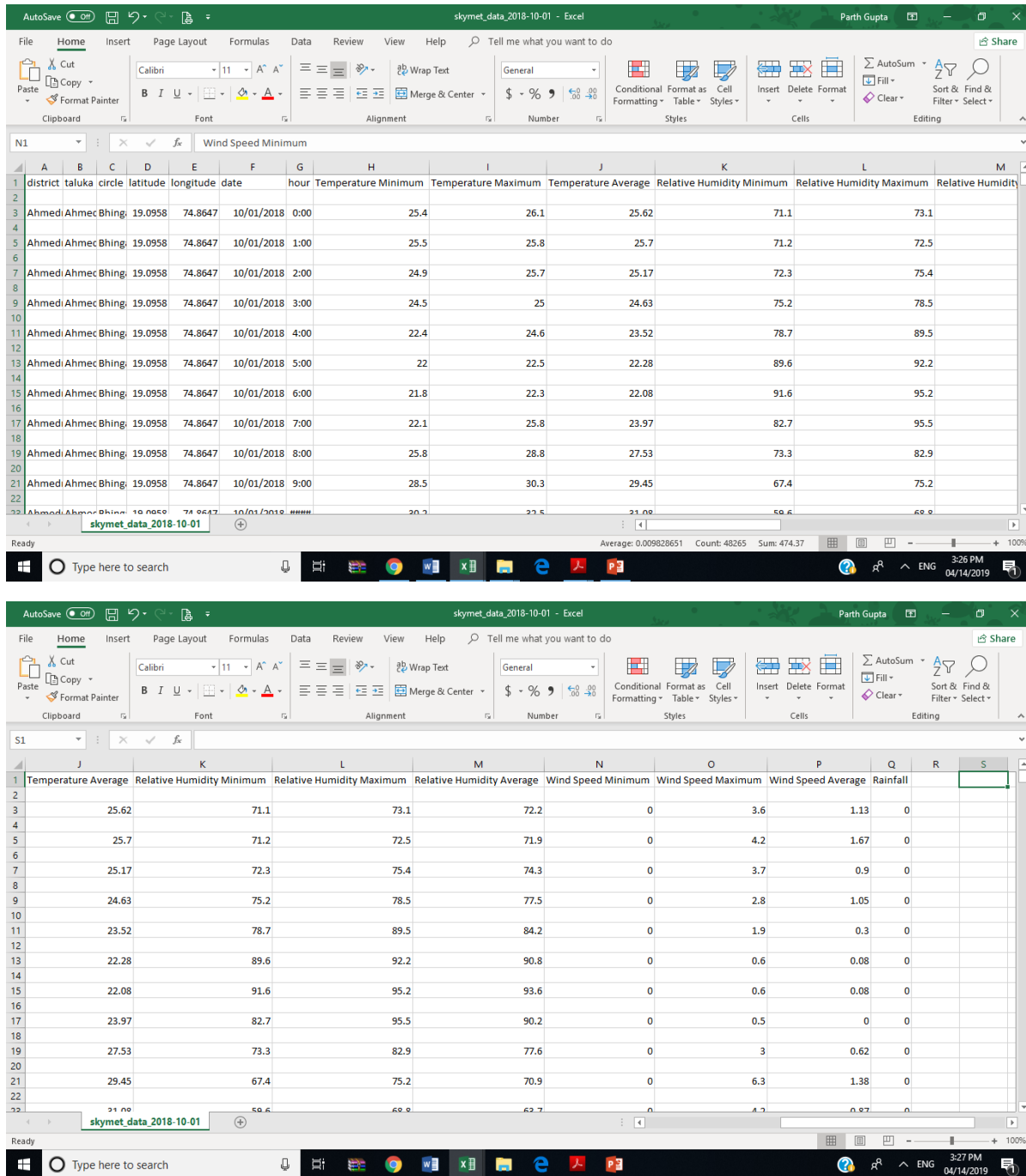


Fig 2 Skymet Weather Parameters

Hence for the present study, the FAO method and district values are chosen as the standard against which performance evaluation of the other methods was carried out for 16 circles falling in different climatic zones of Maharashtra given in Table 2 and Fig 3. The circles are selected in such a way that they cover different districts and climatic zones. The calculated daily values are converted to monthly values. The

reference ET values estimated from different methods are compared with the standard method i.e, FAO-56 PM and WALMI values. Performance evaluation is carried out between the values of PET estimated from standard FAO-56 PM and other methods i.e., Jensen-Haise and Hargreaves methods. The procedures for estimating missing data should be validated at the regional level. This can be done for weather stations with full data sets by comparing ET_0 calculated with full and with limited data sets. The ratio should be close to one. Where the ratio deviates significantly from one, the ratio can be used as a correction factor for estimates made with the limited data set. Where the standard error of estimate exceeds 20% of the mean ET_0 , a sensitivity analysis should be performed to determine causes (and limits) for the method utilized to import the missing data.

Table 2 Selected circles for analysis

Sr. No	District	Taluka	Circle	Latitude	Longitude
1	Yawatmal	Arni	Arni	20.0806	77.9536
2	Parbhani	Pathri	Babalgaon	19.1685	76.4237
3	Jalgaon	Dharangaon	Chandsar	21.1099	75.4518
4	Amravati	Chikhaldara	Chikhaldara	21.4015	77.3299
5	Nagpur	Ramtek	Deolapar	21.5885	79.3689
6	Ahmednagar	Shrigonda	Dev Daethan	18.8258	74.4481
7	Osmanabad	Tuljapur	Itkal	17.8329	76.1491
8	Beed	Aashti	Kada	18.8457	75.1141
9	Nashik	Kalwan	Kalwan	20.4624	73.9999
10	Wardha	Selu	Kelzhar	20.8493	78.798
11	Jalna	Jafrabad	Mahora	20.2597	75.9237
12	Chandrapur	Nagbhid	Midhala	20.5404	79.7277
13	Solapur	Madha	Modnimb	17.0966	75.4001
14	Latur	Udgir	Nagalgaon	18.3465	77.1721
15	Chandrapur	Rajura	Rajura	19.7847	79.3666
16	Dhule	Shindkheda	Wikharan	21.2852	74.6204

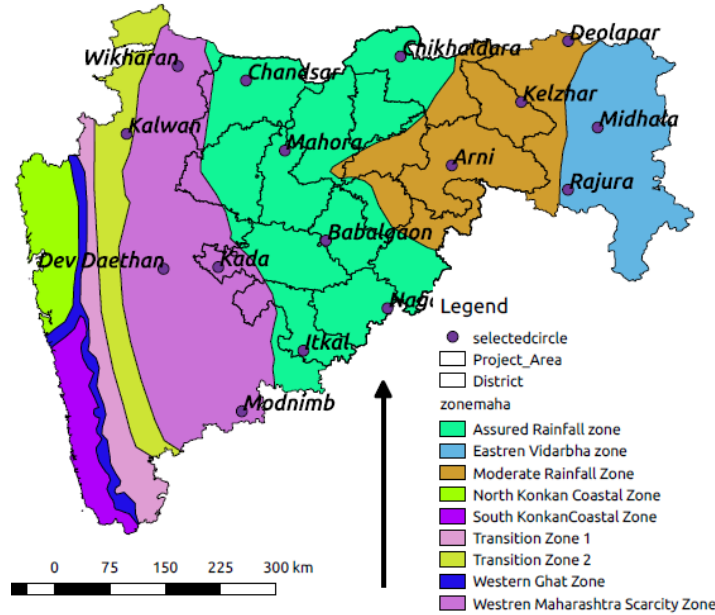


Fig 3 Selected circles for analysis

FAO- 56 Penman - Monteith Equation

The definition of PET by Allen et al (1994a) was the basis for FAO Penman – Monteith method in the estimation of Reference Evapotranspiration. This method overcomes the previous Penman Monteith methods and provides values more consistent results.

The FAO Penman – Monteith method to estimate reference crop evapotranspiration is as follows

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \quad (1)$$

where

ET_o = reference evapotranspiration [mm day^{-1}], R_n net radiation at the crop surface [$\text{MJ m}^{-2} \text{day}^{-1}$], G soil heat flux density [$\text{MJ m}^{-2} \text{day}^{-1}$], T mean daily air temperature at 2 m height [$^{\circ}\text{C}$], u_2 wind speed at 2 m height [m s^{-1}], e_s saturation vapour pressure [kPa], e_a actual vapour pressure [kPa], $e_s - e_a$ saturation vapour pressure deficit [kPa]. γ = psychrometric constant Δ = Slope of vapour pressure curve ($\text{kPa } ^{\circ}\text{C}^{-1}$); λ = latent heat of vaporization (MJ kg^{-1}).

Atmospheric pressure (P)

The atmospheric pressure, P, is the pressure exerted by the weight of the earth's atmosphere. Evaporation at high altitudes is promoted due to low atmospheric pressure as expressed in the psychrometric constant.

It can be calculated using equation 2 where P is atmospheric pressure [kPa], z is elevation above sea level [m],

Psychrometric constant (γ)

The psychrometric constant, γ , is given by equation 3: P atmospheric pressure [kPa], latent heat of vaporization, $2.45 \text{ [MJ kg}^{-1}]$ (λ), c_p specific heat at constant pressure, $1.013 \cdot 10^{-3} \text{ [MJ kg}^{-1} \text{ }^\circ\text{C}^{-1}]$, ϵ ratio molecular weight of water vapour/dry air = 0.622.

Slope of saturation vapour pressure curve (Δ)

The slope of the curve is given by equation 4. T is the mean air temperature.

Mean saturation vapour pressure (e_s)

As saturation vapour pressure is related to air temperature and can be calculated from it using equation 5 and 6. the mean saturation vapour pressure should be calculated as the mean between the saturation vapour pressure at both the daily maximum and minimum air temperature.

Actual vapour pressure (e_a) derived from relative humidity data

The actual vapour pressure can be calculated from the relative humidity using equation 7.

Vapour pressure deficit ($e_s - e_a$)

The vapour pressure deficit is the difference between the saturation (e_s) and actual vapour pressure (e_a) for a given time period using equation 8.

Extraterrestrial 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 (G_{sc}), is about $0.082 \text{ MJ m}^{-2} \text{ min}^{-1}$. The local intensity of radiation is, however, determined by the angle between the direction of the sun's rays and the normal to the surface of the atmosphere. This angle will change during the day and will be different at different latitudes and in different seasons. The solar radiation received at the top of the earth's atmosphere on a horizontal surface is called the extraterrestrial (solar) radiation, R_a and can be derived using equation 9.

The inverse relative distance Earth-Sun, d_r , and the solar declination, δ , are given by equation 10 and 11.

The sunset hour angle, ω_s , is given by equation 12. ϕ is latitude in (rad) [Radian] = $\pi/180$ [decimal degrees], J is the day of year.

Solar or shortwave radiation (R_s)

In the absence solar radiation data, Allen et al., (1998) presented procedure for computing solar radiation using the difference between the maximum and minimum air temperatures. Solar radiation was determined using the Equation 20 (see Table 2) as stated by Allen et al., (1998).

Relative shortwave radiation (R_s / R_{so})

The relative shortwave radiation is the ratio of the solar radiation (R_s) to the clear-sky solar radiation (R_{so}). R_s is the solar radiation that reaches the earth's surface in a given period, while R_{so} is the solar radiation that would reach the same surface during the same period but under cloudless conditions.

R_{so} is given by equation 15.

Albedo (α) and net solar radiation (R_{ns})

A considerable amount of solar radiation reaching the earth's surface is reflected. The fraction, α , of the solar radiation reflected by the surface is known as the albedo. A green vegetation cover has an albedo of about 0.20-0.25. For the green grass reference crop, α is assumed to have a value of 0.23. net solar radiation can be computed using equation 16.

Net longwave radiation (R_{nl})

the earth's surface both emits and receives longwave radiation. The difference between outgoing and incoming longwave radiation is called the net longwave radiation, R_{nl} given by equation 17.

Net radiation (R_n)

The net radiation, R_n , is the difference between incoming and outgoing radiation of both short and long wavelengths given by equation 18.

z is altitude, T_{max} and T_{min} are maximum and minimum air temperatures, T is mean air temperature, $mean RH$ is the mean of relative humidity, ϕ is latitude (rad), J is the day of year, σ is Stefan-Boltzmann constant ($4.903 \times 10^{-9} \text{ MJK}^{-4}\text{m}^{-2}\text{day}^{-1}$), α is albedo or canopy reflection coefficient (0.23), $s a$ and $s b$ are coefficients, $z u$ is the measurement height (m), $rs k$ is adjustment coefficient (0.16 to $0.19^\circ\text{C}^{-0.5}$).

Table 3 Equations Used for Computation

Equ.	Expression	Quantity	Unit
2	$P = 101.3 \left(\frac{293 - 0.0065z}{293} \right)^{5.26}$	Atmospheric pressure	KPa
3	$\gamma = \frac{c_p \times P}{\mathcal{E}l} = 0.665 \times 10^{-3} P$	Psychrometric constant	KPa°C ⁻¹
4	$\Delta = \frac{4098 \left[0.6108 \exp \left(\frac{17.27T}{T + 237.3} \right) \right]}{(T + 237.3)^2}$	Slope of the saturation vapour pressure curve	KPa°C ⁻¹
5	$e_s = \frac{e^o(T_{\max}) + e^o(T_{\min})}{2}$	Mean of the saturation vapour pressure	KPa
6	$e^o(T) = 0.6108 \times 2.7183^{\left[\frac{17.27T}{T+237.3} \right]}$	Saturation vapour pressure at either maximum or minimum air temperatures.	KPa
7	$e_a = \frac{RH_{mean}}{100} \left[\frac{e^o(T_{T_{\max}}) + e^o(T_{\min})}{2} \right]$	Actual vapour pressure	KPa
8	$e_s - e_a$	Vapour pressure deficit	KPa
9	$R_a = \frac{24(60)}{\pi} G_{sc} d_r [\omega_s \sin(\phi) \sin(\delta) + \cos(\phi) \sin(\omega_s)]$	Ra is the extraterrestrial radiation	MJm ⁻² d ⁻¹
10	$d_r = 1 + 0.033 \cos \left(\frac{2\pi}{365} J \right)$	Inverse relative distance Earth-Sun	Radian
11	$\delta = 0.409 \sin \left(\frac{2\pi}{365} J - 1.39 \right)$	Solar declination	Radian
12	$\omega_s = \arccos \left[-\tan(\phi) \tan(\delta) \right]$	Sun hour angle	Radian
13	$N = \frac{24}{\pi} \omega_s$	Possible daylight hour	hour
14	$R_s = \left(a_s + b_s \frac{n}{N} \right) R_a$	Solar radiation	MJm ⁻² d ⁻¹
15	$R_{s0} = (0.75 + 2 \times 10^{-5}) R_a$	Clear sky solar radiation;	MJm ⁻² d ⁻¹
16	$R_{ns} = (1 - \alpha) R_s$	Net shortwave radiation	MJm ⁻² d ⁻¹
17	$R_{nl} = \sigma \left[\frac{T_{\max}^4 + T_{\min}^4}{2} \right] (0.34 - 0.14 \sqrt{e_a}) \left(1.35 \frac{R_s}{R_{s0}} - 0.35 \right)$	Net outgoing longwave radiation	MJm ⁻² d ⁻¹
18	$R_n = R_{ns} - R_{nl}$	Net radiation	MJm ⁻² d ⁻¹
19	$u_z = \frac{4.87}{\ln(67.8z - 5.42)} u_s$	Wind speed at height z(m)	ms ⁻¹
20	$R_s = k_{rs} \sqrt{(T_{\max} - T_{\min})} R_a$	Solar radiation	MJm ⁻² d ⁻¹

Hargreaves model

In a situation where solar radiation, wind speed, relative humidity and other data are completely absent, reference evapotranspiration can also be estimated using the equation stated by Hargreaves and Samani (1982) and is given as:

$$ET_o = 0.0023 * (T_{\text{mean}} + 17.28) * (T_{\text{max}} - T_{\text{min}})^{0.5} * Ra * 0.408$$

Jensen Haise Model

$$ET_o = C_T (T_{\text{mean}} - T_x)$$

where ET_o is the reference evapotranspiration (mm-d⁻¹); T_x and C_T are constants expressed as

$$C_T = \frac{1}{\left[\left(45 - \frac{h}{137} \right) + \left(\frac{365}{e^0(T_{\text{max}}) - e^0(T_{\text{min}})} \right) \right]}$$

$$T_x = -2.5 - 0.14 \times (e^0(T_{\text{max}}) - e^0(T_{\text{min}})) - \frac{h}{500}$$

where, h is the altitude of location.

Table 4 provides the monthly values for different districts provided by WALMI.

Table 4 Monthly ET_o Values Region wise for POCRA Districts

Monthly ET_o	Parbhani	Aurangabad	Amravati	Nanded	Yavatmal	Wardha
Jan	3.95	4.36	4.74	4.29	4.77	3.93
Feb	5.17	5.6	5.89	5.42	5.93	6.05
March	5.29	6.5	7.03	6.39	7.05	0.71
April	7.03	7.55	8.13	7.33	7.96	5.8
May	8.25	8.86	9.09	8.22	9.26	9
June	7.51	6.32	8.2	7.03	7.96	7.17
July	4.77	4.64	4.61	5.26	4.55	4.63
Aug	4.55	3.98	4.45	4.77	3.93	4.06
Sept	4.78	4.39	4.7	5.03	4.5	4.83
Oct	4.8	5.02	5.32	5.01	4.84	4.42
Nov	3.9	4.52	4.76	5.57	4.23	4.3
Dec	3.48	4.16	4.36	4.57	4.22	3.55
Agro climatic zone	7	7	7	7&8	8	8
Mapped Districts	parbhani, latur, osmanabad, beed	Aurangabad, jalna, jalgaon	buldhana, Amravati, Akola	Washim, Nanded, Hingoli	Yavatmal	Wardha

Table 5 RMSE and Coefficient of determination between FAO and HS, JH methods

Sr. No	Circle	RMSE (mm d-1)		Coefficient of determination R2	
		FAO PM and HS	FAO PM and JH	FAO PM and HS	FAO PM and JH
1	Arni	1.37	1.27	0.85	0.62
2	Babalgaon	1.33	1.24	0.76	0.37
3	Chandsar	1.26	1.17	0.81	0.55
4	Chikhaldara	0.84	1.35	0.85	0.65
5	Deolapar	1.22	1.13	0.91	0.71
6	Dev Daethan	0.96	1.26	0.89	0.65
7	Itkal	0.81	1.26	0.76	0.57
8	Kada	1.23	1.24	0.78	0.44
9	Kalwan	0.88	1.26	0.82	0.60
10	Kelzhar	1.38	1.33	0.86	0.61
11	Mahora	0.81	1.42	0.78	0.60
12	Midhala	1.01	1.04	0.90	0.76
13	Modnimb	0.98	0.97	0.87	0.67
14	Nagalgaon	1.18	1.05	0.84	0.56
15	Rajura	1.44	1.19	0.77	0.49
16	Wikharan	1.13	1.46	0.70	0.45
	Average	1.13	1.23	0.90	0.58

Table 6 RMSE and Coefficient of determination between Walmi and FAO, HS, JH methods

Sr. No	Circle	RMSE (mm d-1)			Coefficient of determination R2		
		District ET0 and FAO PM	District ET0 and HS	District ET0 and JH	District ET0 and FAO PM	District ET0 and HS	District ET0 and JH
1	Arni	1.56	0.75	2.17	0.57	0.55	0.48
2	Babalgaon	1.05	1.09	1.83	0.55	0.29	0.09
3	Chandsar	1.25	0.81	1.76	0.50	0.52	0.45
4	Chikhaldara	2.40	1.76	3.61	0.58	0.50	0.39
5	Deolapar	1.62	0.92	2.26	0.58	0.54	0.46
6	Dev Daethan	0.98	0.71	1.98	0.63	0.55	0.38
7	Itkal	1.17	1.01	2.18	0.30	0.24	0.07
8	Kada	1.09	1.11	1.94	0.43	0.26	0.08
9	Kalwan	1.38	0.96	2.57	0.63	0.42	0.24
10	Kelzhar	1.47	1.00	2.08	0.56	0.45	0.35
11	Mahora	1.03	0.71	2.03	0.61	0.54	0.48
12	Midhala	1.56	1.02	2.51	0.60	0.49	0.39
13	Modnimb	1.57	0.98	2.11	0.24	0.26	0.28
14	Nagalgaon	1.19	0.89	1.93	0.58	0.41	0.22
15	Rajura	1.68	0.90	2.14	0.55	0.54	0.44
16	Wikharan	1.29	0.74	2.00	0.48	0.50	0.40
	Average	1.43	0.99	2.22	0.52	0.44	0.32

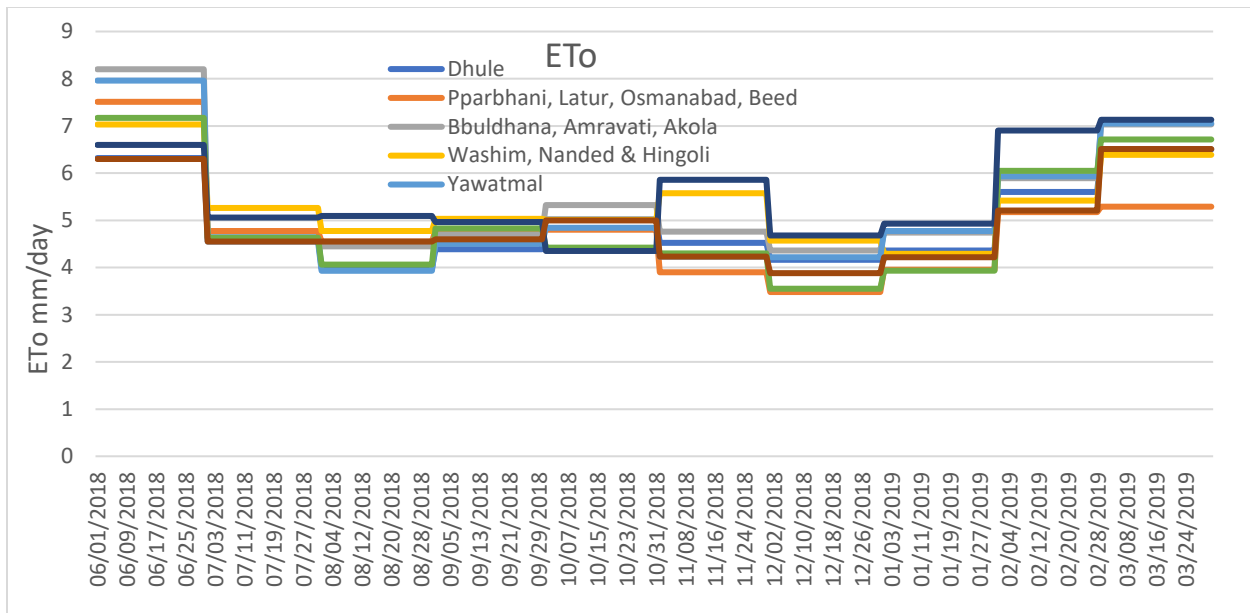


Fig 4 Variation in ETo in different districts

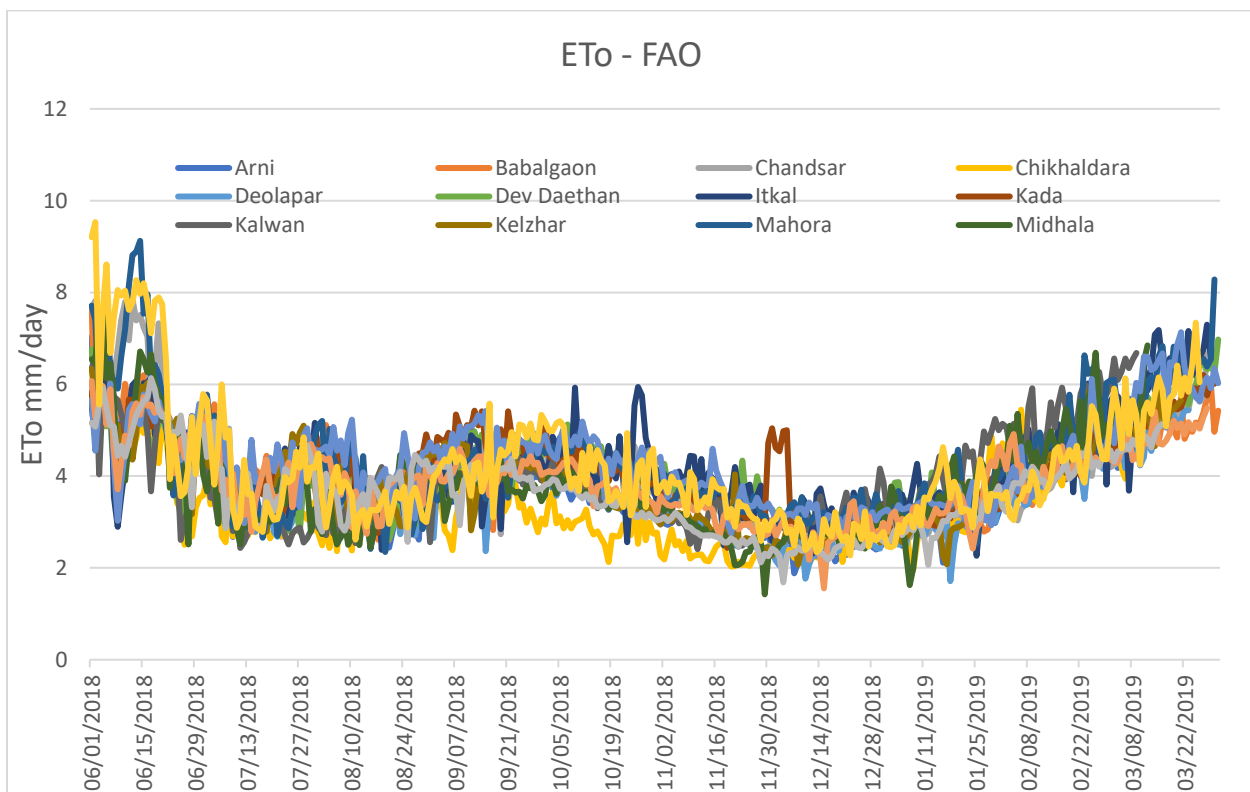


Fig 5 Variation in ETo in different circles using FAO method

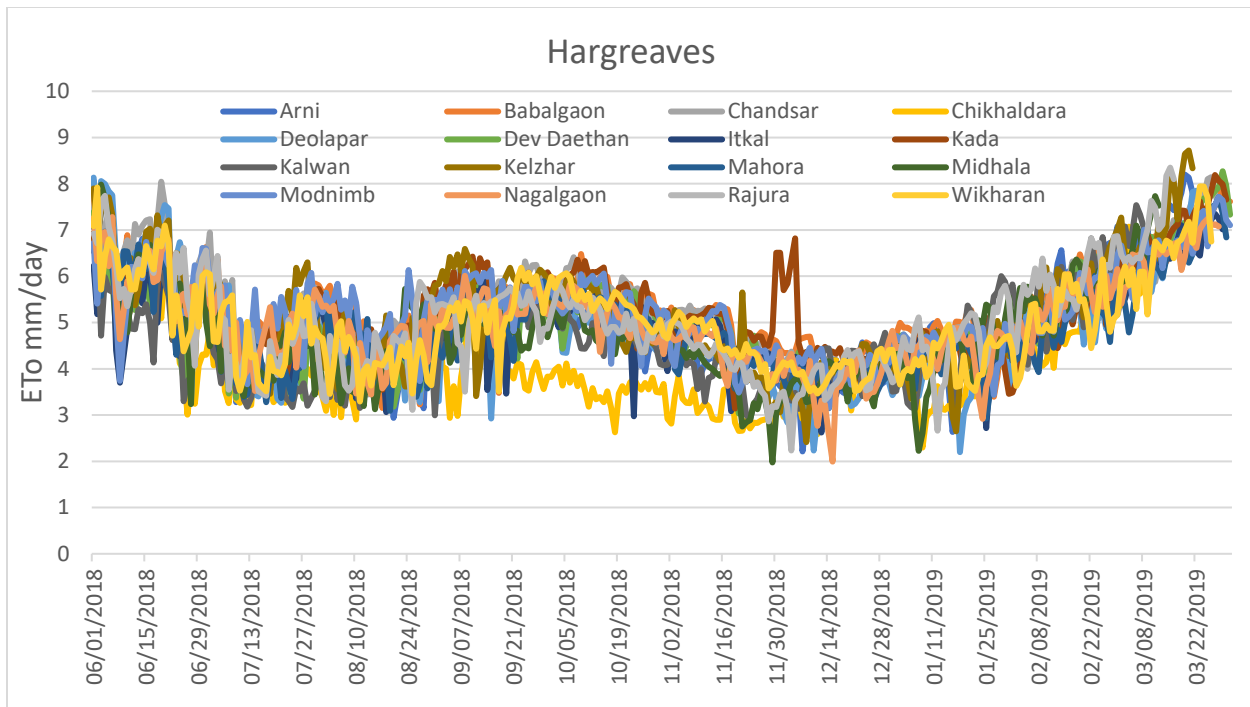


Fig 6 Variation in ETo in different circles using Hargreaves Samani method

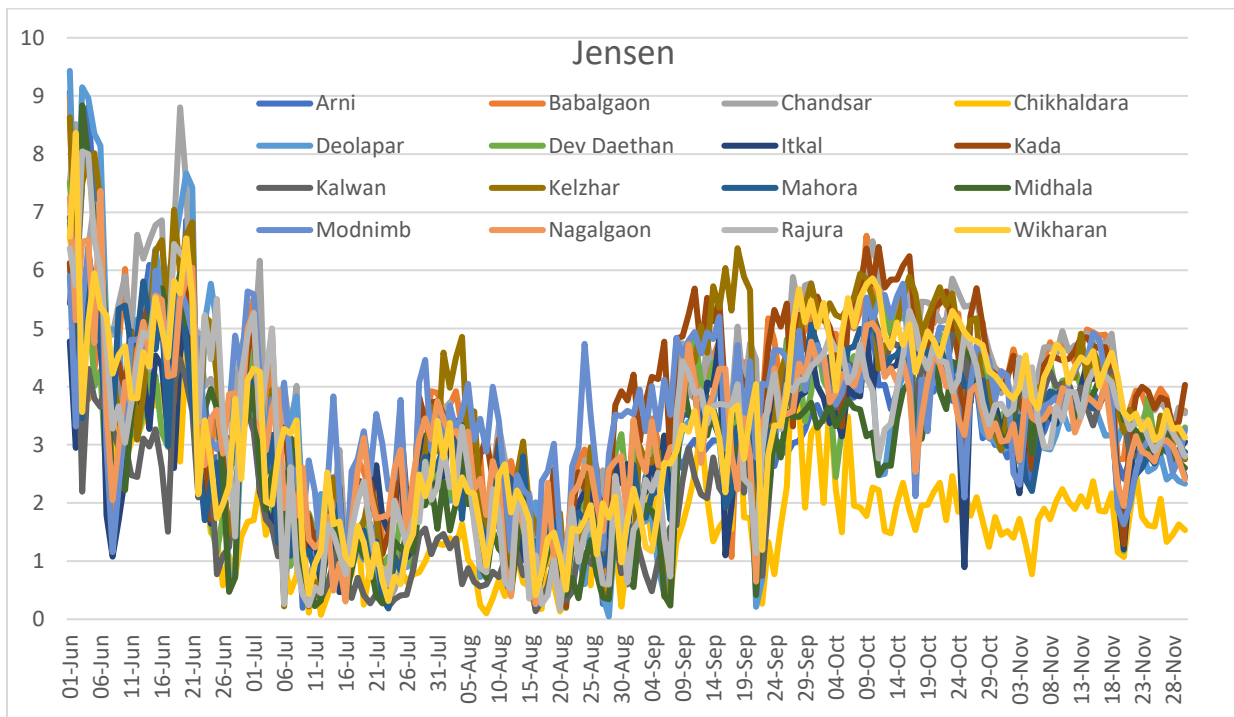


Fig 7 Variation in ETo in different circles using Jensen Haise method

Comparison of PET at Farm level using skymet and Walmi data

Point model is run on Gat number 328 of paradgaon village for soybean crop. It has sandy loam soil texture and 0.5m soil depth. Paradgaon falls in circle named Ghansawangi in Jalna district. To analyze the impact of refined weather parameters daily PET was computed with skymet data in daily water balance model. Similar calculations were done using monthly PET values given by Walmi. Results are given in table below. There is reduction in PET value for year 2018 during soybean growth period which leads to reduction in crop water deficit as compared to calculations done using Walmi PET. Skymet data leads to real time estimation of crop water deficits and water balance as compared to calculation done using walmi data.

Table PET calculated using Walmi and skymet data

Parameters	Walmi PET	Skymet PET 2018
Rainfall (input)	345.5	345.5
Runoff	37.71	38.17
Infiltration	307.79	307.33
SM	25.74	26.52
GW recharge	37.50	44.05
AET	244.55	236.76
PET (input)	366.56	326.07

Results and discussion

Currently for running the crop water model we are using the monthly reference crop evapotranspiration values published by WALMI given in table 4 and figure 4. However, with the availability of daily weather parameters we can calculate the daily reference crop evapotranspiration instead of using fixed monthly values. Daily reference crop evapotranspiration is calculated for selected 16 circles which falls across different climatic zones given in fig 3 and districts using three different methods namely FAO FAO- 56 Penman – Monteith, Hargreaves Samani and Jensen Haise given in figure 5, 6 and 7.

From figure 5,6,7 few observations can be drawn regarding variation in ET values across different region. ET values are highest during the month of June and march. As monsoon arrives ET values dip below 6mm for all the circles and hover around 3-5mm depending upon different circles which tries to climb during dry spells. Lowest ET values are observed during the month of December across all the circles. After November as monsoon fully retreat, the ET values starts to climb again from January with rise in temperature. Wikharan circle in dhule and mahora circle in jalna in month of June both shows the ET more than 9mm per day for few days. Itkal and modinimb circle in Osmanabad and Solapur district shows the lowest ET of 3mm per day for some days in month of June. Circles like Chikhaldara in Amravati and Dev Daethan in Ahmednagar, the ET values have not gone beyond 7mm per day during entire season where as some circles have shown values more than 8mm regularly. To capture such variations, it is necessary to compute daily or weekly ET values across different circles rather than using single value for entire month.

Root mean square error values and coefficient of determination have been computed for different circles keeping FAO method as standard and values are given in table 5. Anexure 4 gives the daily ET plots of all the 16 circles for different methods and Walmi published monthly values. Hargreaves method overpredicts the ET as compared to FAO and Jensen method underpredicts the ET when compared against the FAO method. To give an example have a look at fig 7 and fig 8 for Arni and Babalgaon circles. RMSE value for FAO and Hargreaves combination is 1.37mm/day and for Babalgaon circle it is 1.33 mm day for 9-month data. This means Hargreaves predicts more ET at these circles when compared to FAO. On average for all the circles Hargreaves predicts more ET by 1.13 mm/day. Hargreaves and FAO method shows high coefficient of determination for all the circles which is more than 0.7 and average for all the circles comes out to be 0.9. They follow similar trend. For most of the circles when ET from Jensen method is compared against the FAO it is observed that during monsoon season Jensen underpredict the ET and after monsoon it over predicts the ET. This can be observed for Arni and Babalgaon circles given in fig 7 and fig 8. The RMSE for all the circles is 1.23 mm/day for FAO and Jensen which is more than FAO and Hargreaves. As Jensen and FAO method do not follow similar trend the average coefficient of determination between them comes out to be 0.58 for all the circles.

Keeping Walmi published monthly values as standard other methods were compared against it using RMSE and coefficient of determination given in table 6. FAO and Jensen method underpredicts the ET as compared to Walmi whereas Hargreaves sometimes underpredict sometimes over predict. For Chikhaldara circle in figure 10 all the methods under predict the values as compared to Walmi where as for other circles e.g Babalgaon circle in fig 8 all the methods

sometimes over predict and some time under predict as compared to Walmi during 9 months of data. Overall Hargreaves method shows the least RMSE value which comes out to be 0.99 mm/day whereas for FAO it is 1.43mm/day and for Jensen it is 2.22mm/day. There is not much correlation exist between walmi and other methods as walmi has fixed monthly ET values and does not know much trend with in month.

To analyze the impact of change in various weather parameters on ET values computed by FAO method sensitivity analysis is done for all the selected circles. Details of individual circle ET values is given in Annexure 2 from table 24 to table 40. Maximum and minimum temperatures are increased and decreased by 4 °C. Wind speed was increased by 2m/s. Maximum relative humidity is decreased by 10% and minimum relative humidity was increased by 10%. To see the impact of these tables let's see one example for Arni circle given in table 25. With increase in maximum temperature by 4 °C the ET values have increased for all the months. With decrease in maximum temperature by 4 °C the ET values have decreased for all the months. With increase in minimum temp by 4 °C the ET values have decreased during all the months. With decrease in minimum temperature by 4 °C the ET values have decreased for all the months. With increase in the wind speed by 2m/s the ET values increased significantly. During dry months like jan, feb and march with decrease in Maximum relative humidity by 10% there is slight decrease in ET values. During the months of July, august and September when maximum humidity is near 100% and minimum humidity is also near 70%, there is slight increase in ET values with decrease in maximum humidity. During dry months like jan, feb and march with increase in minimum relative humidity by 10% there is rise in ET when minimum relative humidity is low. During the months of July, august and September when maximum humidity is near 100% and minimum humidity is also near 70%, increase in minimum relative humidity leads to decrease in ET values.

To analyze the impact of change in various weather parameters on ET values computed by Hargreaves and Jensen method sensitivity analysis is done for all the selected circles. Details of individual circle ET values is given in Annexure 3 from table 41 to 57. For both the methods with increase in maximum temperature by 4 °C the ET values have increased for all the months, with decrease in maximum temperature by 4 °C the ET values have decreased for all the months, with increase in minimum temp by 4 °C the ET values have decreased during all the months, with decrease in minimum temperature by 4 °C the ET values have decreased for all the months.

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Annexure 1

Monthly average of weather parameters for 16 circles

Table 7 Monthly average of weather parameters for 16 circles

Months	Temp_ Min	Temp_ Max	Temp_ Avg	RH_max	RH_min	Wind_Speed_ Max	Wind_Speed_ Avg
Jan	11.76	30.10	20.93	83.41	35.27	5.01	0.64
Feb	15.77	33.25	24.51	73.82	30.67	6.29	0.83
Mar	19.77	37.95	28.86	59.80	22.94	6.44	0.90
Jun	24.71	35.94	30.33	92.51	55.40	8.88	1.53
Jul	23.50	30.46	26.98	98.39	80.33	7.86	1.31
Aug	23.12	29.99	26.56	98.41	81.03	7.60	1.27
Sep	21.94	33.21	27.58	98.48	64.27	6.17	0.87
Oct	19.68	35.39	27.53	90.45	39.88	5.97	0.60
Nov	16.86	33.51	25.19	88.94	39.43	5.20	0.55
Dec	13.45	29.36	21.41	88.26	42.60	5.08	0.59
Average	19.07	32.90	25.98	87.32	49.33	6.45	0.91

Table 8 Monthly average of weather parameters for Arni circle

Months	Temp_ Min	Temp_ Max	Temp_ Avg	RH_max	RH_min	Wind_Speed_ Max	Wind_Speed_ Avg
Jan	12.31	30.03	21.17	93.54	38.30	4.02	0.31
Feb	16.37	34.35	25.36	78.00	31.12	4.72	0.39
Mar	20.92	39.57	30.25	60.82	22.60	5.05	0.46
Jun	25.25	36.88	31.07	92.23	54.67	6.68	0.76
Jul	24.30	30.38	27.34	99.79	86.41	4.64	0.46
Aug	24.02	29.95	26.99	99.75	85.56	4.70	0.35
Sep	23.21	32.85	28.03	99.98	68.08	3.97	0.31
Oct	19.93	34.80	27.37	97.09	42.12	4.00	0.31
Nov	17.17	33.29	25.23	96.92	41.19	3.88	0.23
Dec	13.78	28.97	21.37	96.51	46.07	4.08	0.33
Average	19.74	33.08	26.41	91.55	51.78	4.57	0.39

Table 9 Monthly average of weather parameters for Babalgaon circle

Month	Temp_ Min	Temp_ Max	Temp_ Avg	RH_max	RH_min	Wind_Speed_ Max	Wind_Speed_ Avg
Jan	10.33	32.17	21.26	85.39	30.01	4.73	0.48
Feb	14.53	35.33	24.93	73.91	25.34	6.26	0.60
Mar	18.69	38.68	28.69	54.65	20.07	5.38	0.65
Jun	24.18	35.97	30.08	89.96	51.09	8.80	1.26
Jul	23.51	32.04	27.78	94.49	66.36	8.04	1.04
Aug	22.96	31.07	27.02	95.45	69.68	8.00	1.11
Sep	21.59	34.42	28.01	96.93	53.13	5.57	0.69
Oct	18.49	36.57	27.53	89.43	32.38	5.82	0.44
Nov	15.77	34.82	25.30	90.28	33.93	4.97	0.44
Dec	11.95	31.35	21.66	88.15	36.44	4.84	0.46
Average	18.22	34.22	26.22	85.92	41.96	6.24	0.72

Table 10 Monthly average of weather parameters for Chandsar circle

Month	Temp_ Min	Temp_ Max	Temp_ Avg	RH_max	RH_min	Wind_Speed_ Max	Wind_Speed_ Avg
Jan	8.93	30.60	19.77	96.32	38.26	4.66	0.54
Feb	13.87	33.33	23.60	86.04	35.26	5.41	0.71
Mar	17.02	37.75	27.39	72.14	26.22	5.47	0.74
Jun	26.32	38.64	32.48	90.35	52.77	9.51	1.89
Jul	24.99	32.29	28.64	98.55	82.58	6.28	0.81
Aug	24.37	31.54	27.95	98.60	84.27	7.56	1.09
Sep	22.71	35.01	28.86	98.13	64.41	6.35	0.95
Oct	18.84	37.57	28.20	96.79	38.68	5.81	0.55
Nov	15.54	35.55	25.55	97.29	40.71	4.61	0.40
Dec	10.97	30.63	20.80	97.20	41.68	4.78	0.49
Average	18.37	34.28	26.32	93.19	50.61	6.04	0.82

Table 11 Monthly average of weather parameters for Chikhaldara circle

Month	Temp_ Min	Temp_ Max	Temp_ Avg	RH_max	RH_min	Wind_Speed_ Max	Wind_Speed_ Avg
Jan	11.33	27.94	19.64	81.51	37.65	3.85	0.59
Feb	15.89	28.15	22.02	66.70	34.48	8.11	1.18
Mar	19.53	34.08	26.80	53.64	24.40	4.86	0.79
Jun	21.49	31.74	26.62	94.41	64.94	7.57	1.14
Jul	20.80	26.09	23.45	97.89	95.28	6.88	1.08
Aug	20.73	25.32	23.03	98.03	95.37	6.69	1.10
Sep	20.55	28.90	24.72	97.28	79.39	5.50	0.98
Oct	19.28	29.53	24.40	83.04	52.36	5.51	0.74
Nov	16.96	28.18	22.57	78.26	48.02	4.07	0.50
Dec	13.10	25.10	19.10	81.19	47.98	4.00	0.50
Average	17.97	28.50	23.23	83.29	58.16	5.68	0.86

Table 12 Monthly average of weather parameters for Deolapar circle

Month	Temp_ Min	Temp_ Max	Temp_ Avg	RH_max	RH_min	Wind_Speed_ Max	Wind_Speed_ Avg
Jan	11.37	28.00	19.69	92.33	42.04	4.54	0.52
Feb	14.47	32.16	23.32	88.59	36.39	5.22	0.52
Mar	19.35	36.83	28.09	76.85	31.60	6.59	0.61
Jun	25.53	37.79	31.66	90.63	52.58	8.02	0.51
Jul	24.41	31.14	27.78	100.00	86.03	5.67	0.48
Aug	24.23	30.36	27.30	99.89	84.82	6.60	0.63
Sep	22.59	32.56	27.58	99.88	72.26	4.99	0.45
Oct	19.40	34.82	27.11	99.13	48.06	3.85	0.34
Nov	16.23	32.72	24.47	96.49	41.75	3.67	0.35
Dec	12.72	27.73	20.23	93.26	44.92	3.97	0.50
Average	19.05	32.40	25.73	93.74	54.20	5.31	0.49

Table 13 Monthly average of weather parameters for Dev Daethan circle

Month	Temp_ Min	Temp_ Max	Temp_ Avg	RH_max	RH_min	Wind_Speed_ Max	Wind_Speed_ Avg
Jan	10.03	30.69	20.36	90.42	30.66	7.05	0.85
Feb	12.86	33.33	23.10	83.88	27.10	7.77	0.95
Mar	15.59	38.02	26.81	70.51	17.02	7.89	1.00
Jun	23.64	34.32	28.98	95.84	56.94	9.87	1.41
Jul	22.67	29.37	26.02	99.83	76.87	9.54	1.39
Aug	22.00	29.04	25.52	99.73	77.35	9.21	1.39
Sep	20.55	33.10	26.83	99.62	54.69	8.70	1.14
Oct	19.76	35.36	27.56	87.07	34.20	8.37	0.95
Nov	16.49	33.20	24.85	89.31	37.97	7.15	0.87
Dec	12.69	30.41	21.55	91.49	36.15	6.48	0.74
Average	17.65	32.67	25.16	90.80	45.02	8.20	1.07

Table 14 Monthly average of weather parameters for Itkal circle

Month	Temp_ Min	Temp_ Max	Temp_ Avg	RH_max	RH_min	Wind_Speed_ Max	Wind_Speed_ Avg
Jan	14.74	31.34	23.04	72.57	32.75	4.49	0.74
Feb	18.48	34.25	26.37	62.73	28.07	7.01	1.14
Mar	21.89	38.62	30.25	46.39	20.31	7.85	1.40
Jun	23.51	33.86	28.69	96.21	59.16	9.44	2.51
Jul	22.17	29.77	25.97	97.14	73.20	9.15	2.21
Aug	21.74	29.67	25.71	97.82	74.35	7.09	1.60
Sep	21.29	32.55	26.92	97.69	61.23	6.37	1.14
Oct	19.97	34.45	27.21	87.91	40.06	7.09	1.16
Nov	18.59	33.41	26.00	84.56	39.80	5.86	0.95
Dec	16.53	30.62	23.58	85.52	44.22	5.36	0.92
Average	19.89	32.83	26.37	82.95	47.44	6.97	1.38

Table 15 Monthly average of weather parameters for Kada circle

Month	Temp_ Min	Temp_ Max	Temp_ Avg	RH_max	RH_min	Wind_Speed_ Max	Wind_Speed_ Avg
Jan	11.69	31.05	21.37	67.72	28.85	5.69	0.77
Feb	15.11	34.00	24.56	59.96	26.24	6.75	0.88
Mar	18.25	39.02	28.64	48.69	17.40	7.44	0.83
Jun	23.11	34.93	29.02	95.55	55.47	9.02	1.05
Jul	22.14	30.89	26.51	97.69	74.29	8.07	1.09
Aug	21.86	30.60	26.23	98.06	75.16	7.13	1.25
Sep	20.16	34.72	27.44	98.00	53.43	7.57	1.17
Oct	18.65	36.50	27.57	86.16	35.28	6.26	0.45
Nov	16.26	34.29	25.27	82.58	37.38	5.62	0.41
Dec	12.70	31.02	21.86	78.99	37.31	5.74	0.47
Average	18.00	33.69	25.85	81.45	44.21	6.93	0.84

Table 16 Monthly average of weather parameters for Kalwan circle

Month	Temp_ Min	Temp_ Max	Temp_ Avg	RH_max	RH_min	Wind_Speed_ Max	Wind_Speed_ Avg
Jan	9.80	28.69	19.25	81.04	31.39	6.13	0.84
Feb	13.36	31.10	22.24	73.15	29.15	8.28	1.26
Mar	16.71	34.97	25.84	59.59	21.16	7.97	1.48
Jun	24.42	33.60	29.02	93.46	59.85	9.20	1.96
Jul	23.03	27.72	25.38	99.22	86.68	9.29	2.03
Aug	22.41	27.15	24.79	99.72	87.90	9.34	2.17
Sep	20.57	30.59	25.58	99.84	68.26	7.45	1.43
Oct	18.00	34.93	26.47	93.41	34.37	6.88	0.72
Nov	15.36	33.05	24.21	93.39	35.16	5.99	0.65
Dec	10.83	28.40	19.62	86.61	36.04	5.63	0.70
Average	17.46	31.01	24.24	88.01	49.14	7.61	1.32

Table 17 Monthly average of weather parameters for Kelzhar circle

Month	Temp_ Min	Temp_ Max	Temp_ Avg	RH_max	RH_min	Wind_Speed_ Max	Wind_Speed_ Avg
Jan	13.78	30.55	22.16	86.66	39.65	4.09	0.44
Feb	17.73	34.99	26.36	74.81	32.31	5.44	0.50
Mar	22.48	40.44	31.46	64.00	25.05	5.67	0.68
Jun	26.10	37.75	31.93	89.30	54.17	7.02	0.81
Jul	24.41	31.16	27.78	98.32	87.62	6.50	0.70
Aug	24.43	31.81	28.12	98.38	84.87	6.18	0.68
Sep	23.25	35.19	29.22	98.04	66.51	4.50	0.32
Oct	20.66	37.55	29.10	95.61	41.64	3.81	0.16
Nov	18.22	35.01	26.61	90.67	38.92	4.29	0.28
Dec	15.31	30.08	22.69	88.99	43.93	4.92	0.47
Average	20.65	34.43	27.54	88.57	51.64	5.24	0.50

Table 18 Monthly average of weather parameters for Mahora circle

Month	Temp_ Min	Temp_ Max	Temp_ Avg	RH_max	RH_min	Wind_Speed_ Max	Wind_Speed_ Avg
Jan	9.61	29.55	19.58	72.50	29.50	7.17	1.04
Feb	14.76	32.17	23.47	60.94	26.87	9.05	1.60
Mar	17.78	36.90	27.34	43.22	17.22	9.35	1.49
Jun	24.49	35.63	30.06	91.40	49.96	11.20	3.05
Jul	23.13	29.77	26.45	99.35	77.27	10.43	2.87
Aug	22.22	29.53	25.87	99.61	77.81	10.05	2.84
Sep	20.14	31.93	26.04	100.00	64.26	7.37	1.43
Oct	17.57	34.72	26.15	83.06	33.27	7.45	0.98
Nov	15.32	32.17	23.75	86.82	38.10	6.94	0.98
Dec	10.87	28.72	19.79	84.45	35.59	6.88	1.07
Average	17.59	32.10	24.85	82.24	45.11	8.58	1.74

Table 19 Monthly average of weather parameters for Midhala circle

Month	Temp_ Min	Temp_ Max	Temp_ Avg	RH_max	RH_min	Wind_Speed_ Max	Wind_Speed_ Avg
Jan	12.47	28.35	20.41	93.98	48.62	4.86	0.78
Feb	16.16	32.37	24.27	87.16	39.13	6.56	1.07
Mar	21.77	37.28	29.53	76.14	32.27	6.48	1.10
Jun	25.87	36.73	31.30	93.04	59.01	9.30	1.51
Jul	24.88	30.40	27.64	100.00	91.11	7.95	1.42
Aug	24.91	30.07	27.49	99.96	92.73	7.64	1.39
Sep	23.37	32.65	28.01	100.00	81.36	5.83	0.92
Oct	20.23	34.65	27.44	99.81	53.70	5.92	0.54
Nov	14.83	33.28	24.06	100.00	45.39	5.06	0.58
Dec	13.74	27.51	20.63	96.95	56.11	4.70	0.64
Average	19.84	32.31	26.08	94.75	60.13	6.43	0.99

Table 20 Monthly average of weather parameters for Modnimb circle

Month	Temp_ Min	Temp_ Max	Temp_ Avg	RH_max	RH_min	Wind_Speed_ Max	Wind_Speed_ Avg
Jan	12.15	31.17	21.66	78.90	33.67	4.99	0.64
Feb	16.13	33.95	25.04	73.83	30.20	5.39	0.73
Mar	20.50	38.83	29.67	57.81	20.14	6.58	1.19
Jun	23.74	35.60	29.67	96.22	56.16	8.52	1.18
Jul	22.85	32.42	27.63	97.95	68.41	8.86	1.15
Aug	22.37	31.95	27.16	97.84	69.31	9.20	1.23
Sep	21.84	34.91	28.37	97.95	52.73	7.98	1.03
Oct	21.09	35.79	28.44	86.84	37.08	8.03	0.94
Nov	18.80	33.65	26.23	83.88	41.03	7.19	0.82
Dec	15.27	30.50	22.89	86.59	44.88	6.33	0.71
Average	19.49	33.87	26.68	85.83	45.46	7.32	0.97

Table 21 Monthly average of weather parameters for Nagalgaon circle

Month	Temp_ Min	Temp_ Max	Temp_ Avg	RH_max	RH_min	Wind_Speed_ Max	Wind_Speed_ Avg
Jan	14.21	31.07	22.64	77.99	31.94	4.61	0.54
Feb	18.59	34.56	26.58	66.06	27.95	5.50	0.82
Mar	22.66	38.76	30.71	54.44	23.21	5.73	0.56
Jun	23.90	35.86	29.88	93.54	55.50	7.80	1.01
Jul	22.53	30.93	26.73	97.45	76.13	7.51	1.05
Aug	22.01	29.98	25.99	98.00	81.24	7.05	0.79
Sep	21.58	33.28	27.43	98.00	67.29	5.50	0.40
Oct	19.70	34.56	27.13	92.19	42.02	6.30	0.42
Nov	18.06	33.09	25.57	85.51	40.19	4.90	0.35
Dec	16.13	29.40	22.77	86.99	45.98	5.11	0.54
Average	19.94	33.12	26.53	85.13	49.30	6.01	0.65

Table 22 Monthly average of weather parameters for Rajura circle

Month	Temp_ Min	Temp_ Max	Temp_ Avg	RH_max	RH_min	Wind_Speed_ Max	Wind_Speed_ Avg
Jan	13.68	30.15	21.92	95.71	40.79	3.60	0.17
Feb	17.76	34.79	26.28	84.28	31.92	4.25	0.22
Mar	23.69	40.01	31.85	66.52	26.84	4.61	0.27
Jun	26.83	38.21	32.53	87.18	49.27	7.07	0.63
Jul	25.12	31.45	28.29	98.91	76.67	6.98	0.94
Aug	25.39	30.84	28.12	95.82	76.53	7.35	1.17
Sep	24.90	34.89	29.89	97.66	60.05	5.02	0.46
Oct	21.90	36.57	29.24	96.55	41.95	3.98	0.23
Nov	18.15	34.71	26.43	95.89	38.19	3.90	0.16
Dec	15.69	29.02	22.36	96.31	49.46	4.10	0.21
Average	21.33	34.04	27.69	91.53	49.34	5.09	0.45

Table 23 Monthly average of weather parameters for Wikharan circle

Month	Temp_ Min	Temp_ Max	Temp_ Avg	RH_max	RH_min	Wind_Speed_ Max	Wind_Speed_ Avg
Jan	11.65	30.26	20.95	67.91	30.20	5.72	0.93
Feb	16.18	33.18	24.68	61.14	29.14	4.98	0.73
Mar	19.53	37.51	28.52	51.35	21.50	6.08	1.17
Jun	26.95	37.50	32.23	90.84	54.78	13.14	3.81
Jul	25.08	31.58	28.33	97.58	80.35	9.98	2.31
Aug	24.20	30.99	27.60	97.88	79.61	7.77	1.53
Sep	22.74	33.81	28.27	96.63	61.20	6.08	1.10
Oct	21.43	37.82	29.62	73.15	30.84	6.43	0.76
Nov	18.04	35.70	26.87	71.23	33.18	5.06	0.78
Dec	12.85	30.38	21.62	73.00	34.86	4.41	0.64
Average	19.87	33.86	26.87	78.16	45.69	6.97	1.38

Annexure 2

FAO ETo Sensitivity to weather parameters for 16 circles

Table 24 FAO ETo Sensitivity to weather parameters for 16 circles.

Month	Default ETo	Temp_ max	Temp_ max	Temp_ min	Temp_ min	Wind speed	Rhmax	Rhmin
		+ 4 °C	- 4 °C	+ 4 °C	- 4 °C	+ 2 m/s	- 10%	+ 10%
Jan-19	3.08	3.51	2.67	2.95	3.18	4.80	3.08	3.09
Feb-19	4.07	4.63	3.54	3.87	4.22	6.01	4.08	4.07
Mar-19	5.25	5.90	4.63	4.99	5.47	7.85	5.24	5.27
Jun-18	5.32	6.34	4.28	4.66	5.78	6.19	5.40	5.17
Jul-18	3.79	4.79	2.62	2.84	4.34	3.92	3.87	3.65
Aug-18	3.63	4.60	2.51	2.72	4.16	3.76	3.71	3.50
Sep-18	4.13	4.97	3.27	3.57	4.50	4.72	4.16	4.07
Oct-18	4.07	4.71	3.46	3.79	4.28	5.66	4.06	4.09
Nov-18	3.32	3.82	2.84	3.13	3.45	4.96	3.31	3.34
Dec-18	2.79	3.23	2.39	2.64	2.90	4.18	2.80	2.79
Average	3.95	4.64	3.24	3.53	4.22	5.24	3.97	3.91

Table 25 FAO ETo Sensitivity to weather parameters for Arni circle.

Date	Default	Temp_ max	Temp_ max	Temp_ min	Temp_ min	Wind speed	Rhmax	Rhmin
		+ 4 °C	- 4 °C	+ 4 °C	- 4 °C	+ 2 m/s	-10 %	10 %
Jan-19	2.72	3.13	2.34	2.59	2.81	4.33	2.71	2.76
Feb-19	3.71	4.22	3.23	3.53	3.85	5.81	3.69	3.76
Mar-19	4.77	5.35	4.20	4.52	4.96	7.66	4.72	4.86
Jun-18	5.04	6.01	4.04	4.38	5.50	6.07	5.06	5.01
Jul-18	3.54	4.59	2.23	2.38	4.17	3.53	3.56	3.51
Aug-18	3.43	4.44	2.17	2.31	4.04	3.48	3.43	3.42
Sep-18	3.71	4.56	2.79	3.03	4.13	4.16	3.70	3.72
Oct-18	3.71	4.32	3.13	3.43	3.91	5.17	3.69	3.77
Nov-18	2.99	3.46	2.54	2.81	3.11	4.54	2.96	3.06
Dec-18	2.46	2.87	2.08	2.31	2.56	3.69	2.45	2.48
Average	3.61	4.28	2.90	3.16	3.89	4.89	3.60	3.64

Table 26 FAO ETo Sensitivity to weather parameters for Babalgaon circle.

Date	Default	Temp_ max	Temp_ max	Temp_ min	Temp_ min	Wind speed	Rhmax	Rhmin
		+ 4 °C	- 4 °C	+ 4 °C	- 4 °C	+ 2 m/s	-10 %	10 %
Jan-19	3.23	3.65	2.84	3.13	3.31	5.31	3.22	3.27
Feb-19	4.18	4.70	3.69	4.02	4.31	6.55	4.16	4.22
Mar-19	5.06	5.65	4.50	4.84	5.25	7.99	5.03	5.13
Jun-18	5.31	6.29	4.33	4.70	5.74	6.33	5.37	5.19
Jul-18	4.16	5.13	3.10	3.36	4.66	4.66	4.22	4.06
Aug-18	3.96	4.90	2.92	3.17	4.45	4.38	4.03	3.85
Sep-18	4.36	5.16	3.56	3.89	4.69	5.30	4.37	4.34
Oct-18	4.15	4.73	3.59	3.92	4.31	6.14	4.12	4.22
Nov-18	3.43	3.92	2.98	3.28	3.55	5.38	3.41	3.49
Dec-18	2.94	3.36	2.56	2.83	3.02	4.67	2.93	2.96
Average	4.07	4.74	3.41	3.71	4.33	5.67	4.08	4.07

Table 27 FAO ETo Sensitivity to weather parameters for Chandsar circle.

Date	Default	Temp_ max	Temp_ max	Temp_ min	Temp_ min	Wind speed	Rhmax	Rhmin
		+ 4 °C	- 4 °C	+ 4 °C	- 4 °C	+ 2 m/s	-10%	10%
Jan-19	3.02	3.45	2.63	2.93	3.09	4.64	3.02	3.03
Feb-19	3.96	4.51	3.44	3.78	4.09	5.73	3.96	3.96
Mar-19	5.12	5.76	4.51	4.90	5.30	7.59	5.10	5.16
Jun-18	6.23	7.34	5.13	5.58	6.70	7.23	6.33	6.01
Jul-18	3.99	5.05	2.75	2.97	4.58	4.09	4.03	3.91
Aug-18	3.64	4.65	2.49	2.69	4.20	3.65	3.70	3.53
Sep-18	4.31	5.17	3.46	3.79	4.67	4.94	4.35	4.24
Oct-18	4.31	4.95	3.70	4.08	4.48	6.06	4.29	4.35
Nov-18	3.36	3.86	2.90	3.22	3.46	5.11	3.34	3.42
Dec-18	2.76	3.17	2.38	2.66	2.83	4.23	2.75	2.77
Average	4.07	4.78	3.35	3.67	4.33	5.35	4.09	4.04

Table 28 FAO ETo Sensitivity to weather parameters for Chikhaldara circle.

Date	Default	Temp_ max	Temp_ max	Temp_ min	Temp_ min	Wind speed	Rhmax	Rhmin
		+ 4 °C	- 4 °C	+ 4 °C	- 4 °C	+ 2 m/s	-10%	10%
Jan-19	2.75	3.14	2.37	2.61	2.84	4.22	2.75	2.76
Feb-19	3.71	4.26	3.16	3.46	3.88	5.17	3.75	3.66
Mar-19	4.46	5.05	3.88	4.17	4.69	6.75	4.45	4.48
Jun-18	4.54	5.49	3.53	3.82	5.01	5.03	4.60	4.44
Jul-18	3.03	4.01	1.76	1.88	3.63	2.77	3.10	2.93
Aug-18	2.95	3.89	1.77	1.90	3.52	2.71	3.02	2.86
Sep-18	3.38	4.20	2.48	2.70	3.80	3.52	3.43	3.31
Oct-18	3.26	3.88	2.64	2.87	3.52	4.23	3.28	3.22
Nov-18	2.62	3.08	2.17	2.37	2.79	3.82	2.62	2.61
Dec-18	2.25	2.62	1.88	2.08	2.35	3.31	2.25	2.24
Average	3.31	3.96	2.61	2.84	3.60	4.24	3.34	3.27

Table 29 FAO ETo Sensitivity to weather parameters for Deolapar circle.

Date	Default	Temp_ max	Temp_ max	Temp_ min	Temp_ Min	Wind speed	Rhmax	Rhmin
		+ 4 °C	- 4 °C	+ 4 °C	- 4 °C	+ 2 m/s	-10%	10%
Jan-19	2.67	3.07	2.29	2.54	2.76	4.08	2.67	2.68
Feb-19	3.62	4.14	3.12	3.44	3.75	5.25	3.61	3.64
Mar-19	4.71	5.35	4.09	4.43	4.92	6.81	4.69	4.74
Jun-18	5.20	6.15	4.20	4.54	5.64	6.42	5.18	5.22
Jul-18	3.59	4.65	2.25	2.40	4.23	3.53	3.61	3.56
Aug-18	3.46	4.47	2.24	2.41	4.06	3.47	3.49	3.40
Sep-18	3.79	4.64	2.88	3.13	4.20	4.19	3.79	3.79
Oct-18	3.72	4.34	3.13	3.45	3.92	4.95	3.70	3.77
Nov-18	2.99	3.45	2.55	2.83	3.10	4.47	2.97	3.04
Dec-18	2.43	2.82	2.06	2.29	2.52	3.64	2.43	2.43
Average	3.61	4.30	2.89	3.15	3.90	4.70	3.61	3.62

Table 30 FAO ETo Sensitivity to weather parameters for Dev Daethan circle.

Date	Default	Temp_ max	Temp_ max	Temp_ min	Temp_ min	Wind speed	Rhmax	Rhmin
		+ 4 °C	- 4 °C	+ 4 °C	- 4 °C	+ 2 m/s	-10%	10%
Jan-19	3.54	4.02	3.09	3.41	3.64	5.27	3.55	3.52
Feb-19	4.42	5.00	3.87	4.24	4.57	6.37	4.43	4.41
Mar-19	5.72	6.37	5.09	5.50	5.91	8.40	5.71	5.74
Jun-18	4.93	5.91	3.91	4.25	5.39	5.63	5.00	4.78
Jul-18	3.50	4.49	2.33	2.52	4.06	3.63	3.60	3.35
Aug-18	3.52	4.46	2.46	2.67	4.03	3.65	3.62	3.37
Sep-18	4.44	5.26	3.62	3.96	4.77	5.18	4.49	4.34
Oct-18	4.43	5.09	3.79	4.13	4.65	6.14	4.45	4.39
Nov-18	3.65	4.20	3.13	3.44	3.80	5.22	3.66	3.61
Dec-18	3.12	3.58	2.70	2.99	3.23	4.65	3.13	3.11
Average	4.13	4.84	3.40	3.72	4.40	5.42	4.16	4.06

Table 31 FAO ETo Sensitivity to weather parameters for Itkal circle.

Date	Default	Temp_ max	Temp_ max	Temp_ min	Temp_ min	Wind speed	Rhmax	Rhmin
		+ 4 °C	- 4 °C	+ 4 °C	- 4 °C	+ 2 m/s	-10%	10%
Jan-19	3.43	3.91	2.97	3.26	3.56	5.27	3.43	3.42
Feb-19	4.63	5.25	4.05	4.40	4.82	6.70	4.65	4.60
Mar-19	6.07	6.78	5.38	5.79	6.31	8.76	6.08	6.04
Jun-18	5.11	6.14	4.06	4.45	5.55	5.68	5.26	4.82
Jul-18	3.98	4.94	2.94	3.22	4.44	4.21	4.13	3.73
Aug-18	3.78	4.70	2.76	3.02	4.24	4.00	3.88	3.61
Sep-18	4.20	5.05	3.35	3.67	4.57	4.80	4.26	4.10
Oct-18	4.50	5.22	3.80	4.16	4.75	5.91	4.53	4.41
Nov-18	3.74	4.33	3.18	3.49	3.93	5.27	3.77	3.69
Dec-18	3.20	3.72	2.70	2.99	3.34	4.47	3.22	3.16
Average	4.26	5.00	3.53	3.85	4.55	5.52	4.32	4.16

Table 32 FAO ETo Sensitivity to weather parameters for Kada circle.

Date	Default	Temp_ max	Temp_ max	Temp_ min	Temp_ min	Wind speed	Rhmax	Rhmin
		+ 4 °C	- 4 °C	+ 4 °C	- 4 °C	+ 2 m/s	-10%	10%
Jan-19	3.19	3.59	2.82	3.09	3.28	5.40	3.18	3.22
Feb-19	4.13	4.68	3.61	3.94	4.27	6.11	4.14	4.11
Mar-19	5.40	6.00	4.83	5.18	5.60	8.41	5.37	5.46
Jun-18	5.01	5.96	4.04	4.39	5.44	5.80	5.05	4.92
Jul-18	4.00	4.96	2.98	3.24	4.49	4.22	4.07	3.90
Aug-18	4.00	4.92	3.03	3.31	4.45	4.24	4.07	3.88
Sep-18	4.79	5.61	3.99	4.38	5.09	5.65	4.83	4.70
Oct-18	4.18	4.78	3.61	3.94	4.36	6.07	4.15	4.24
Nov-18	3.35	3.84	2.89	3.17	3.48	5.21	3.33	3.41
Dec-18	3.30	3.75	2.88	3.16	3.41	5.14	3.29	3.33
Average	4.13	4.80	3.47	3.78	4.38	5.64	4.15	4.12

Table 33 FAO ETo Sensitivity to weather parameters for Kalwan circle.

Date	Default	Temp_ max	Temp_ max	Temp_ min	Temp_ min	Wind speed	Rhmax	Rhmin
		+ 4 °C	- 4 °C	+ 4 °C	- 4 °C	+ 2 m/s	-10%	10%
Jan-19	3.17	3.61	2.76	3.05	3.26	4.85	3.18	3.15
Feb-19	4.32	4.91	3.76	4.13	4.47	6.06	4.35	4.27
Mar-19	5.69	6.39	5.02	5.44	5.90	7.94	5.72	5.63
Jun-18	4.88	5.92	3.77	4.10	5.38	5.49	5.01	4.66
Jul-18	3.35	4.35	2.13	2.30	3.92	3.41	3.50	3.14
Aug-18	2.92	3.88	1.71	1.84	3.47	2.87	3.08	2.70
Sep-18	3.76	4.58	2.90	3.17	4.13	4.15	3.84	3.62
Oct-18	4.18	4.80	3.60	3.93	4.37	5.85	4.18	4.18
Nov-18	3.39	3.88	2.93	3.23	3.51	5.06	3.39	3.39
Dec-18	2.82	3.23	2.45	2.71	2.91	4.32	2.83	2.81
Average	3.90	4.58	3.19	3.49	4.16	5.15	3.95	3.82

Table 34 FAO ETo Sensitivity to weather parameters for Kelzhar circle.

Date	Default	Temp_ max	Temp_ max	Temp_ min	Temp_ min	Wind speed	Rhmax	Rhmin
		+ 4 °C	- 4 °C	+ 4 °C	- 4 °C	+ 2 m/s	-10%	10%
Jan-19	2.79	3.21	2.39	2.64	2.89	4.43	2.78	2.81
Feb-19	3.77	4.29	3.27	3.58	3.92	5.85	3.75	3.80
Mar-19	5.07	5.72	4.45	4.80	5.29	7.84	5.04	5.14
Jun-18	5.24	6.24	4.22	4.57	5.71	6.35	5.26	5.21
Jul-18	3.87	4.91	2.71	2.92	4.45	3.87	3.91	3.82
Aug-18	3.71	4.73	2.57	2.77	4.28	3.75	3.75	3.66
Sep-18	4.22	5.07	3.37	3.68	4.58	4.93	4.20	4.27
Oct-18	3.89	4.49	3.31	3.64	4.06	5.57	3.84	4.01
Nov-18	3.10	3.58	2.66	2.94	3.22	4.90	3.07	3.18
Dec-18	2.62	3.05	2.22	2.45	2.73	4.02	2.62	2.63
Average	3.82	4.51	3.13	3.41	4.10	5.19	3.81	3.85

Table 35 FAO ETo Sensitivity to weather parameters for Mahora circle.

Date	Default	Temp_ max	Temp_ max	Temp_ min	Temp_ min	Wind speed	Rhmax	Rhmin
		+ 4 °C	- 4 °C	+ 4 °C	- 4 °C	+ 2 m/s	-10%	10%
Jan-19	3.48	3.95	3.05	3.36	3.58	5.30	3.50	3.44
Feb-19	4.87	5.51	4.27	4.68	5.02	6.75	4.91	4.78
Mar-19	6.09	6.77	5.44	5.86	6.29	8.77	6.10	6.05
Jun-18	6.26	7.39	5.13	5.62	6.71	7.07	6.45	5.89
Jul-18	3.72	4.73	2.54	2.78	4.24	3.85	3.93	3.40
Aug-18	3.74	4.70	2.68	2.96	4.20	3.84	3.93	3.43
Sep-18	4.13	4.95	3.31	3.65	4.46	4.59	4.20	3.99
Oct-18	4.45	5.09	3.85	4.21	4.64	6.20	4.47	4.40
Nov-18	3.53	4.06	3.03	3.34	3.68	5.07	3.56	3.47
Dec-18	3.18	3.65	2.75	3.06	3.28	4.63	3.21	3.13
Average	4.34	5.08	3.61	3.96	4.61	5.62	4.42	4.20

Table 36 FAO ETo Sensitivity to weather parameters for Midhala circle.

Date	Default	Temp_ max	Temp_ max	Temp_ min	Temp_ min	Wind speed	Rhmax	Rhmin
		+ 4 °C	- 4 °C	+ 4 °C	- 4 °C	+ 2 m/s	-10%	10%
Jan-19	2.83	3.30	2.39	2.66	2.95	3.94	2.85	2.81
Feb-19	4.05	4.67	3.47	3.82	4.23	5.51	4.08	4.01
Mar-19	5.19	5.94	4.47	4.85	5.45	7.18	5.21	5.16
Jun-18	5.43	6.49	4.33	4.70	5.92	6.28	5.51	5.27
Jul-18	3.41	4.47	2.12	2.28	4.03	3.30	3.52	3.26
Aug-18	3.13	4.17	1.81	1.93	3.76	2.99	3.25	2.98
Sep-18	3.86	4.75	2.96	3.24	4.28	4.01	3.90	3.80
Oct-18	3.81	4.49	3.15	3.47	4.04	4.81	3.81	3.81
Nov-18	3.35	3.88	2.87	3.19	3.47	4.70	3.35	3.36
Dec-18	2.50	2.95	2.08	2.33	2.62	3.37	2.52	2.49
Average	3.77	4.51	3.01	3.30	4.07	4.69	3.81	3.72

Table 37 FAO ETo Sensitivity to weather parameters for Modnimb circle.

Date	Default	Temp_ max	Temp_ max	Temp_ min	Temp_ min	Wind speed	Rhmax	Rhmin
		+ 4 °C	- 4 °C	+ 4 °C	- 4 °C	+ 2 m/s	-10%	10%
Jan-19	3.37	3.84	2.94	3.23	3.48	5.17	3.37	3.38
Feb-19	4.22	4.79	3.67	4.01	4.38	6.20	4.21	4.22
Mar-19	5.90	6.60	5.22	5.62	6.13	8.53	5.90	5.89
Jun-18	5.08	6.04	4.10	4.46	5.51	5.86	5.13	4.97
Jul-18	4.32	5.28	3.32	3.61	4.79	4.70	4.38	4.21
Aug-18	4.28	5.21	3.31	3.61	4.72	4.66	4.34	4.16
Sep-18	4.73	5.58	3.89	4.25	5.07	5.60	4.77	4.65
Oct-18	4.49	5.20	3.81	4.15	4.75	6.11	4.51	4.45
Nov-18	3.69	4.27	3.13	3.43	3.88	5.22	3.70	3.66
Dec-18	3.13	3.63	2.66	2.94	3.27	4.42	3.15	3.12
Average	4.32	5.04	3.61	3.93	4.60	5.65	4.35	4.27

Table 38 FAO ETo Sensitivity to weather parameters for Nagalgaon circle.

Date	Default	Temp_ max	Temp_ max	Temp_ min	Temp_ min	Wind speed	Rhmax	Rhmin
		+ 4 °C	- 4 °C	+ 4 °C	- 4 °C	+ 2 m/s	-10%	10%
Jan-19	3.14	3.58	2.72	2.98	3.26	5.01	3.13	3.16
Feb-19	4.20	4.76	3.65	3.97	4.37	6.35	4.19	4.20
Mar-19	4.79	5.40	4.19	4.49	5.02	7.54	4.75	4.84
Jun-18	5.09	6.04	4.13	4.48	5.52	5.96	5.13	5.02
Jul-18	3.98	4.93	2.95	3.20	4.47	4.19	4.04	3.88
Aug-18	3.72	4.65	2.70	2.93	4.22	3.80	3.76	3.66
Sep-18	4.13	4.96	3.31	3.61	4.50	4.62	4.13	4.15
Oct-18	3.92	4.55	3.31	3.62	4.14	5.35	3.90	3.96
Nov-18	3.20	3.70	2.72	2.98	3.35	4.79	3.18	3.25
Dec-18	2.75	3.21	2.31	2.54	2.89	4.00	2.75	2.75
Average	3.89	4.57	3.20	3.48	4.17	5.17	3.89	3.88

Table 39 FAO ETo Sensitivity to weather parameters for Rajura circle.

Date	Default	Temp_ max	Temp_ max	Temp_ min	Temp_ min	Wind speed	Rhmax	Rhmin
		+ 4 °C	- 4 °C	+ 4 °C	- 4 °C	+ 2 m/s	-10%	10%
Jan-19	2.65	3.05	2.27	2.51	2.74	4.24	2.63	2.70
Feb-19	3.53	4.03	3.05	3.33	3.67	5.61	3.49	3.60
Mar-19	4.47	5.08	3.86	4.16	4.69	7.19	4.40	4.56
Jun-18	5.08	6.04	4.09	4.41	5.54	6.42	5.08	5.08
Jul-18	3.80	4.84	2.56	2.75	4.40	4.14	3.86	3.72
Aug-18	3.64	4.66	2.38	2.55	4.24	4.08	3.72	3.52
Sep-18	3.94	4.81	3.01	3.27	4.37	4.73	3.94	3.94
Oct-18	3.78	4.41	3.17	3.48	3.99	5.35	3.75	3.87
Nov-18	3.05	3.52	2.60	2.88	3.16	4.81	3.01	3.14
Dec-18	2.39	2.81	1.98	2.20	2.50	3.56	2.37	2.41
Average	3.63	4.31	2.92	3.18	3.92	5.06	3.62	3.66

Table 40 FAO ETo Sensitivity to weather parameters for Wikharan circle.

Date	Default	Temp_ max	Temp_ max	Temp_ min	Temp_ min	Wind speed	Rhmax	Rhmin
		+ 4 °C	- 4 °C	+ 4 °C	- 4 °C	+ 2 m/s	-10%	10%
Jan-19	3.26	3.70	2.86	3.15	3.35	5.23	3.28	3.24
Feb-19	3.84	4.35	3.36	3.66	3.98	6.05	3.84	3.85
Mar-19	5.52	6.18	4.89	5.27	5.73	8.21	5.53	5.51
Jun-18	6.74	8.00	5.50	6.05	7.24	7.48	7.01	6.26
Jul-18	3.98	5.04	2.77	3.01	4.53	4.16	4.17	3.70
Aug-18	3.60	4.60	2.47	2.67	4.15	3.74	3.72	3.43
Sep-18	4.17	5.03	3.29	3.60	4.55	4.86	4.22	4.07
Oct-18	4.34	4.95	3.75	4.09	4.53	6.60	4.33	4.35
Nov-18	3.65	4.15	3.18	3.49	3.77	5.82	3.65	3.65
Dec-18	2.81	3.21	2.45	2.71	2.89	4.66	2.82	2.81
Average	4.20	4.92	3.47	3.79	4.47	5.72	4.26	4.10

Annexure 3

Hargreaves and Jensen Haise ETo Sensitivity to weather parameters for 16 circles

Table 41 Hargreaves and Jensen Haise ETo Sensitivity to weather parameters for 16 circles

Date	HS	JH	HS_Temp_max	JH_Temp_max	HS_Temp_max	JH_Temp_max	HS_Temp_min	JH_Temp_min	HS_Temp_min	JH_Temp_min
			+ 4°C	+ 4°C	- 4 °C	- 4 °C	+ 4°C	+ 4°C	- 4 °C	- 4 °C
Jan-19	4.22	2.80	4.91	4.21	3.52	1.72	3.91	2.39	4.43	3.08
Feb-19	5.08	3.88	5.91	5.77	4.23	2.38	4.65	3.21	5.37	4.36
Mar-19	6.50	6.27	7.49	8.98	5.48	4.02	5.97	5.25	6.88	7.02
Jun-18	5.97	4.40	7.25	7.20	4.55	2.23	4.94	2.93	6.67	5.60
Jul-18	4.55	2.12	5.89	4.17	2.87	0.72	3.13	0.98	5.39	3.14
Aug-18	4.39	1.97	5.69	3.93	2.77	0.65	3.03	0.89	5.20	2.94
Sep-18	5.11	3.33	6.22	5.52	3.89	1.66	4.25	2.23	5.69	4.21
Oct-18	5.29	4.28	6.19	6.45	4.34	2.54	4.74	3.38	5.67	4.96
Nov-18	4.53	3.41	5.29	5.13	3.74	2.04	4.11	2.76	4.82	3.88
Dec-18	3.79	2.31	4.47	3.60	3.09	1.33	3.43	1.85	4.04	2.63
Average	4.95	3.51	5.93	5.53	3.88	1.96	4.25	2.63	5.42	4.21

Table 42 Hargreaves and Jensen Haise ETo Sensitivity to weather parameters for Arni circle.

Date	HS	JH	HS_Temp_max	JH_Temp_max	HS_Temp_max	JH_Temp_max	HS_Temp_min	JH_Temp_min	HS_Temp_min	JH_Temp_min
			+ 4 °C	+ 4 °C	- 4 °C	- 4 °C	+ 4 °C	+ 4 °C	- 4 °C	- 4 °C
Jan-19	4.14	2.62	4.84	3.98	3.43	1.58	3.80	2.20	4.36	2.91
Feb-19	5.28	4.23	6.12	6.21	4.44	2.64	4.87	3.54	5.58	4.73
Mar-19	6.78	6.91	7.79	9.74	5.75	4.52	6.25	5.84	7.17	7.69
Jun-18	6.16	4.75	7.45	7.63	4.75	2.48	5.15	3.24	6.87	5.97
Jul-18	4.36	1.86	5.76	3.87	2.52	0.54	2.75	0.73	5.28	2.92
Aug-18	4.23	1.76	5.58	3.70	2.44	0.49	2.67	0.67	5.11	2.77
Sep-18	4.73	2.66	5.88	4.73	3.41	1.14	3.72	1.54	5.39	3.59
Oct-18	5.13	3.85	6.03	5.91	4.18	2.21	4.57	2.95	5.52	4.52
Nov-18	4.44	3.18	5.21	4.85	3.66	1.87	4.01	2.54	4.74	3.66
Dec-18	3.64	2.04	4.32	3.25	2.94	1.13	3.26	1.59	3.90	2.36
Average	4.91	3.45	5.90	5.45	3.80	1.91	4.16	2.56	5.40	4.16

Table 43 Hargreaves and Jensen Haise ETo Sensitivity to weather parameters for Babalgaon circle.

Date	HS	JH	HS Temp_ max	JH Temp_ max	HS Temp_ max	JH Temp_ max	HS Temp_ min	JH Temp_ min	HS Temp_ min	JH Temp_ min
			+ 4 °C	+ 4 °C	- 4 °C	- 4 °C	+ 4 °C	+ 4 °C	- 4 °C	- 4 °C
Jan-19	4.71	3.58	5.39	5.15	4.02	2.33	4.46	3.22	4.87	3.80
Feb-19	5.69	5.02	6.51	7.13	4.87	3.29	5.35	4.40	5.93	5.43
Mar-19	6.84	6.91	7.82	9.68	5.85	4.58	6.37	5.97	7.17	7.58
Jun-18	6.06	4.46	7.31	7.23	4.69	2.29	5.10	3.03	6.73	5.61
Jul-18	4.92	2.58	6.22	4.79	3.39	1.02	3.70	1.37	5.70	3.63
Aug-18	4.68	2.34	5.95	4.40	3.17	0.89	3.47	1.21	5.44	3.31
Sep-18	5.48	3.88	6.56	6.21	4.32	2.08	4.72	2.78	6.01	4.75
Oct-18	5.73	5.07	6.61	7.36	4.82	3.19	5.27	4.22	6.05	5.68
Nov-18	4.92	4.07	5.67	5.93	4.15	2.58	4.56	3.46	5.17	4.50
Dec-18	4.25	3.00	4.91	4.43	3.59	1.87	3.98	2.58	4.44	3.27
Average	5.33	4.10	6.30	6.24	4.29	2.42	4.70	3.23	5.75	4.76

Table 44 Hargreaves and Jensen Haise ETo Sensitivity to weather parameters for Chandsar circle.

Date	HS	JH	HS Temp_ max	JH Temp_ max	HS Temp_ max	JH Temp_ max	HS Temp_ min	JH Temp_ min	HS Temp_ min	JH Temp_ min
			+ 4 °C	+ 4 °C	- 4 °C	- 4 °C	+ 4 °C	+ 4 °C	- 4 °C	- 4 °C
Jan-19	4.36	2.94	5.00	4.28	3.72	1.89	4.14	2.65	4.49	3.11
Feb-19	5.18	3.95	5.97	5.75	4.38	2.51	4.83	3.41	5.42	4.32
Mar-19	6.68	6.45	7.63	8.97	5.74	4.33	6.27	5.67	6.98	6.98
Jun-18	6.56	5.44	7.87	8.53	5.15	2.94	5.58	3.82	7.27	6.74
Jul-18	4.84	2.49	6.22	4.73	3.13	0.92	3.41	1.23	5.71	3.61
Aug-18	4.50	2.07	5.83	4.10	2.86	0.67	3.12	0.91	5.34	3.10
Sep-18	5.39	3.78	6.49	6.07	4.19	1.99	4.57	2.65	5.96	4.67
Oct-18	5.77	5.25	6.64	7.51	4.88	3.37	5.33	4.44	6.09	5.83
Nov-18	4.88	4.11	5.61	5.90	4.15	2.66	4.55	3.56	5.11	4.50
Dec-18	4.01	2.63	4.64	3.91	3.39	1.63	3.76	2.28	4.18	2.85
Average	5.22	3.94	6.19	6.00	4.18	2.32	4.57	3.09	5.65	4.59

Table 45 Hargreaves and Jensen Haise ETo Sensitivity to weather parameters for Chikhaldara circle.

Date	HS	JH	HS Temp_ max	JH Temp_ max	HS Temp_ max	JH Temp_ max	HS Temp_ min	JH Temp_ min	HS Temp_ min	JH Temp_ min
			+ 4 °C	+ 4 °C	- 4 °C	- 4 °C	+ 4 °C	+ 4 °C	- 4 °C	- 4 °C
Jan-19	3.77	2.36	4.43	3.66	3.09	1.38	3.44	1.94	3.98	2.65
Feb-19	3.95	2.16	4.78	3.66	3.07	1.08	3.39	1.50	4.33	2.68
Mar-19	5.52	4.45	6.51	6.90	4.48	2.54	4.90	3.38	5.95	5.28
Jun-18	5.30	3.33	6.54	5.75	3.87	1.56	4.23	2.10	5.98	4.36
Jul-18	3.73	1.19	5.08	2.79	1.89	0.24	2.08	0.34	4.61	2.03
Aug-18	3.63	1.15	4.92	2.70	1.89	0.23	2.08	0.32	4.47	1.97
Sep-18	4.15	2.01	5.26	3.81	2.83	0.78	3.11	1.07	4.79	2.83
Oct-18	3.92	2.06	4.84	3.69	2.90	0.89	3.19	1.23	4.40	2.73
Nov-18	3.40	1.73	4.16	3.04	2.57	0.80	2.84	1.11	3.77	2.22
Dec-18	2.98	1.32	3.63	2.31	2.29	0.63	2.55	0.90	3.26	1.64
Average	4.06	2.24	5.02	3.90	2.95	1.07	3.25	1.46	4.56	2.90

Table 46 Hargreaves and Jensen Haise ETo Sensitivity to weather parameters for Deolapar circle.

Date	HS	JH	HS Temp_ max	JH Temp_ max	HS Temp_ max	JH Temp_ max	HS Temp_ min	JH Temp_ min	HS Temp_ min	JH Temp_ min
			+ 4 °C	+ 4 °C	- 4 °C	- 4 °C	+ 4 °C	+ 4 °C	- 4 °C	- 4 °C
Jan-19	3.82	2.22	4.48	3.43	3.14	1.31	3.49	1.85	4.02	2.47
Feb-19	4.89	3.54	5.68	5.28	4.09	2.16	4.50	2.95	5.16	3.95
Mar-19	6.21	5.63	7.19	8.16	5.21	3.56	5.69	4.67	6.59	6.34
Jun-18	6.55	5.59	7.84	8.70	5.13	3.09	5.55	4.01	7.24	6.86
Jul-18	4.43	1.95	5.83	4.01	2.55	0.59	2.79	0.81	5.34	3.02
Aug-18	4.24	1.76	5.59	3.73	2.51	0.47	2.75	0.64	5.12	2.80
Sep-18	4.83	2.96	5.96	5.05	3.53	1.40	3.85	1.89	5.46	3.85
Oct-18	5.09	3.93	5.97	5.99	4.18	2.30	4.57	3.08	5.46	4.58
Nov-18	4.31	3.08	5.04	4.67	3.57	1.82	3.92	2.48	4.58	3.51
Dec-18	3.41	1.79	4.05	2.88	2.75	0.98	3.05	1.40	3.64	2.07
Average	4.78	3.27	5.76	5.21	3.68	1.79	4.04	2.41	5.26	3.96

Table 47 Hargreaves and Jensen Haise ET. Sensitivity to weather parameters for Dev Daethan circle.

Date	HS	JH	HS Temp_ max	JH Temp_ max	HS Temp_ max	JH Temp_ max	HS Temp_ min	JH Temp_ min	HS Temp_ min	JH Temp_ min
			+ 4 °C	+ 4 °C	- 4 °C	- 4 °C	+ 4 °C	+ 4 °C	- 4 °C	- 4 °C
Jan-19	4.51	3.18	5.20	4.68	3.83	2.01	4.26	2.81	4.68	3.41
Feb-19	5.42	4.41	6.22	6.37	4.61	2.84	5.09	3.86	5.64	4.78
Mar-19	6.98	7.25	7.91	10.00	6.04	4.96	6.60	6.50	7.24	7.77
Jun-18	5.62	3.73	6.88	6.32	4.21	1.77	4.59	2.36	6.32	4.85
Jul-18	4.17	1.65	5.52	3.49	2.45	0.46	2.68	0.63	5.04	2.60
Aug-18	4.20	1.70	5.48	3.51	2.64	0.51	2.90	0.70	5.00	2.60
Sep-18	5.29	3.52	6.36	5.74	4.15	1.83	4.54	2.47	5.81	4.35
Oct-18	5.33	4.33	6.25	6.56	4.38	2.55	4.78	3.40	5.73	5.04
Nov-18	4.58	3.44	5.36	5.21	3.79	2.06	4.16	2.79	4.88	3.92
Dec-18	4.08	2.69	4.75	4.10	3.40	1.61	3.76	2.24	4.29	3.01
Average	5.02	3.60	5.99	5.61	3.96	2.07	4.34	2.79	5.46	4.24

Table 48 Hargreaves and Jensen Haise ET. Sensitivity to weather parameters for Itkal circle.

Date	HS	JH	HS Temp_ max	JH Temp_ max	HS Temp_ max	JH Temp_ max	HS Temp_ min	JH Temp_ min	HS Temp_ min	JH Temp_ min
			+ 4 °C	+ 4 °C	- 4 °C	- 4 °C	+ 4 °C	+ 4 °C	- 4 °C	- 4 °C
Jan-19	4.41	3.01	5.16	4.60	3.64	1.79	4.01	2.45	4.68	3.42
Feb-19	5.22	4.06	6.12	6.16	4.31	2.40	4.71	3.21	5.59	4.70
Mar-19	6.52	6.27	7.56	9.15	5.44	3.88	5.91	5.06	6.96	7.18
Jun-18	5.47	3.51	6.73	6.01	4.07	1.64	4.43	2.19	6.18	4.61
Jul-18	4.52	2.01	5.80	3.96	3.02	0.68	3.30	0.94	5.30	2.95
Aug-18	4.48	2.04	5.72	3.94	3.00	0.73	3.29	1.00	5.22	2.94
Sep-18	5.05	3.13	6.15	5.27	3.84	1.53	4.20	2.06	5.62	3.99
Oct-18	5.16	3.89	6.10	6.03	4.17	2.20	4.56	2.95	5.58	4.61
Nov-18	4.51	3.26	5.33	5.06	3.66	1.85	4.01	2.50	4.87	3.83
Dec-18	3.90	2.39	4.65	3.83	3.13	1.29	3.44	1.78	4.22	2.84
Average	4.93	3.37	5.93	5.42	3.83	1.81	4.20	2.43	5.42	4.12

Table 49 Hargreaves and Jensen Haise ETo Sensitivity to weather parameters for Kada circle.

Date	HS	JH	HS Temp_ max	JH Temp_ max	HS_ Temp_ max	JH Temp_ max	HS Temp_ min	JH Temp_ min	HS Temp_ min	JH Temp_ min
			+ 4 °C	+ 4 °C	- 4 °C	- 4 °C	+ 4 °C	+ 4 °C	- 4 °C	- 4 °C
Jan-19	4.49	3.28	5.17	4.82	3.81	2.07	4.22	2.87	4.67	3.55
Feb-19	4.96	3.72	5.76	5.55	4.14	2.29	4.56	3.11	5.23	4.16
Mar-19	6.94	7.36	7.91	10.24	5.96	4.95	6.50	6.43	7.26	8.03
Jun-18	5.92	4.23	7.15	6.92	4.58	2.16	4.99	2.87	6.56	5.33
Jul-18	4.83	2.45	6.09	4.55	3.37	0.97	3.68	1.32	5.57	3.42
Aug-18	4.85	2.53	6.07	4.63	3.47	1.03	3.80	1.41	5.54	3.47
Sep-18	5.79	4.44	6.83	6.87	4.70	2.53	5.14	3.38	6.25	5.26
Oct-18	5.72	5.16	6.61	7.51	4.81	3.24	5.25	4.28	6.06	5.80
Nov-18	4.80	3.90	5.57	5.77	4.01	2.42	4.40	3.25	5.07	4.37
Dec-18	4.59	3.49	5.32	5.16	3.86	2.18	4.26	2.96	4.82	3.86
Average	5.30	4.08	6.25	6.23	4.28	2.40	4.69	3.21	5.71	4.74

Table 50 Hargreaves and Jensen Haise ETo Sensitivity to weather parameters for Kalwan circle.

Date	HS	JH	HS Temp_ max	JH Temp_ max	HS Temp_ max	JH Temp_ max	HS Temp_ min	JH Temp_ min	HS Temp_ min	JH Temp_ min
			+ 4 °C	+ 4 °C	- 4 °C	- 4 °C	+ 4 °C	+ 4 °C	- 4 °C	- 4 °C
Jan-19	4.06	2.56	4.71	3.87	3.39	1.57	3.78	2.21	4.23	2.79
Feb-19	4.82	3.44	5.62	5.16	4.01	2.10	4.44	2.88	5.08	3.83
Mar-19	6.07	5.27	7.02	7.67	5.11	3.33	5.60	4.44	6.41	5.87
Jun-18	5.25	3.13	6.58	5.63	3.70	1.31	4.03	1.75	6.04	4.31
Jul-18	4.02	1.46	5.41	3.28	2.16	0.32	2.37	0.45	4.94	2.44
Aug-18	3.58	1.06	4.94	2.64	1.69	0.15	1.86	0.20	4.50	1.93
Sep-18	4.57	2.51	5.67	4.41	3.30	1.15	3.62	1.56	5.17	3.30
Oct-18	5.32	4.38	6.20	6.54	4.43	2.66	4.85	3.55	5.66	5.00
Nov-18	4.53	3.47	5.26	5.18	3.79	2.11	4.16	2.87	4.78	3.89
Dec-18	3.73	2.26	4.36	3.47	3.10	1.34	3.45	1.89	3.92	2.50
Average	4.66	3.09	5.60	4.93	3.59	1.72	3.95	2.33	5.10	3.70

Table 51 Hargreaves and Jensen Haise ET_o Sensitivity to weather parameters for Kelzhar circle.

Date	HS	JH	HS Temp_ max	JH Temp_ max	HS Temp_ max	JH Temp_ max	HS Temp_ min	JH Temp_ min	HS Temp_ min	JH Temp_ min
			+4 °C	+4 °C	-4 °C	-4 °C	+4 °C	+4 °C	-4 °C	-4 °C
Jan-19	4.06	2.60	4.76	3.97	3.34	1.54	3.69	2.14	4.31	2.92
Feb-19	5.20	4.17	6.03	6.15	4.35	2.58	4.76	3.45	5.51	4.69
Mar-19	6.79	7.12	7.82	10.04	5.74	4.66	6.22	5.97	7.21	7.99
Jun-18	6.31	5.04	7.62	8.05	4.87	2.65	5.27	3.45	7.03	6.33
Jul-18	4.84	2.43	6.19	4.64	3.21	0.88	3.49	1.18	5.67	3.51
Aug-18	4.62	2.29	5.95	4.42	3.01	0.81	3.28	1.09	5.46	3.35
Sep-18	5.54	4.19	6.65	6.62	4.33	2.27	4.71	2.99	6.11	5.14
Oct-18	5.62	5.03	6.52	7.35	4.70	3.12	5.11	4.09	5.99	5.72
Nov-18	4.63	3.66	5.39	5.46	3.85	2.22	4.21	2.97	4.92	4.17
Dec-18	3.69	2.21	4.39	3.51	2.96	1.22	3.27	1.69	3.98	2.59
Average	5.14	3.92	6.13	6.06	4.06	2.24	4.43	2.96	5.61	4.68

Table 52 Hargreaves and Jensen Haise ET_o Sensitivity to weather parameters for Mahora circle.

Date	HS	JH	HS Temp_ max	JH Temp_ max	HS Temp_ max	JH Temp_ max	HS Temp_ min	JH Temp_ min	HS Temp_ min	JH Temp_ min
			+4 °C	+4 °C	-4 °C	-4 °C	+4 °C	+4 °C	-4 °C	-4 °C
Jan-19	4.22	2.79	4.88	4.15	3.56	1.74	3.96	2.45	4.38	3.01
Feb-19	4.95	3.62	5.76	5.44	4.12	2.19	4.54	2.99	5.23	4.07
Mar-19	6.45	6.12	7.41	8.74	5.48	3.97	5.99	5.23	6.78	6.77
Jun-18	5.91	4.26	7.19	7.05	4.50	2.10	4.90	2.78	6.62	5.46
Jul-18	4.28	1.79	5.65	3.72	2.50	0.53	2.74	0.73	5.16	2.78
Aug-18	4.32	1.87	5.59	3.74	2.76	0.60	3.03	0.83	5.11	2.79
Sep-18	5.00	3.05	6.06	5.10	3.85	1.52	4.22	2.06	5.53	3.84
Oct-18	5.35	4.36	6.21	6.48	4.47	2.66	4.89	3.56	5.67	4.94
Nov-18	4.36	3.10	5.10	4.72	3.61	1.84	3.97	2.52	4.63	3.52
Dec-18	3.79	2.29	4.42	3.51	3.15	1.35	3.50	1.91	3.97	2.53
Average	4.87	3.34	5.83	5.28	3.81	1.87	4.18	2.52	5.31	3.98

Table 53 Hargreaves and Jensen Haise ET_o Sensitivity to weather parameters for Midhala circle.

Date	HS	JH	HS Temp_ max	JH Temp_ max	HS Temp_ max	JH Temp_ max	HS Temp_ min	JH Temp_ min	HS Temp_ min	JH Temp_ min
			+ 4 °C	+ 4 °C	- 4 °C	- 4 °C	+ 4 °C	+ 4 °C	- 4 °C	- 4 °C
Jan-19	3.80	2.12	4.50	3.32	3.08	1.22	3.42	1.72	4.05	2.40
Feb-19	4.85	3.38	5.68	5.14	4.00	2.00	4.40	2.72	5.17	3.86
Mar-19	6.07	5.24	7.10	7.80	5.00	3.16	5.44	4.13	6.53	6.09
Jun-18	6.10	4.63	7.41	7.52	4.60	2.36	4.99	3.08	6.84	5.89
Jul-18	4.30	1.77	5.73	3.78	2.43	0.46	2.65	0.62	5.25	2.85
Aug-18	3.98	1.49	5.40	3.37	2.03	0.30	2.21	0.41	4.95	2.53
Sep-18	4.90	2.93	6.04	5.07	3.64	1.32	3.96	1.77	5.54	3.87
Oct-18	4.99	3.62	5.91	5.64	4.02	2.03	4.40	2.72	5.41	4.31
Nov-18	4.60	3.44	5.32	5.08	3.87	2.13	4.25	2.90	4.84	3.81
Dec-18	3.42	1.75	4.09	2.85	2.72	0.94	3.01	1.33	3.69	2.05
Average	4.72	3.11	5.72	5.02	3.60	1.66	3.94	2.23	5.22	3.81

Table 54 Hargreaves and Jensen Haise ET_o Sensitivity to weather parameters for Modnimb circle.

Date	HS	JH	HS Temp_ max	JH Temp_ max	HS Temp_ max	JH Temp_ max	HS Temp_ min	JH Temp_ min	HS Temp_ min	JH Temp_ min
			+ 4 °C	+ 4 °C	- 4 °C	- 4 °C	+ 4 °C	+ 4 °C	- 4 °C	- 4 °C
Jan-19	4.55	3.23	5.27	4.80	3.83	2.00	4.24	2.76	4.76	3.54
Feb-19	5.37	4.32	6.23	6.39	4.50	2.66	4.94	3.59	5.67	4.84
Mar-19	6.73	6.80	7.75	9.72	5.69	4.38	6.19	5.69	7.12	7.63
Jun-18	5.95	4.42	7.18	7.17	4.61	2.27	5.02	3.01	6.60	5.55
Jul-18	5.15	2.97	6.39	5.27	3.74	1.28	4.08	1.73	5.86	4.00
Aug-18	5.09	2.93	6.30	5.18	3.73	1.29	4.08	1.74	5.77	3.92
Sep-18	5.65	4.17	6.74	6.65	4.49	2.24	4.90	2.98	6.18	5.10
Oct-18	5.38	4.36	6.35	6.70	4.37	2.51	4.77	3.33	5.82	5.16
Nov-18	4.59	3.37	5.43	5.24	3.72	1.92	4.07	2.58	4.95	3.98
Dec-18	4.04	2.54	4.78	4.01	3.28	1.42	3.62	1.97	4.33	2.96
Average	5.25	3.92	6.24	6.12	4.20	2.20	4.59	2.95	5.70	4.67

Table 55 Hargreaves and Jensen Haise ET. Sensitivity to weather parameters for Nagalgaon circle.

Date	HS	JH	HS Temp_ max	JH Temp_ max	HS Temp_ max	JH Temp_ max	HS Temp_ min	JH Temp_ min	HS Temp_ min	JH Temp_ min
			+ 4 °C	+ 4 °C	- 4 °C	- 4 °C	+ 4 °C	+ 4 °C	- 4 °C	- 4 °C
Jan-19	4.35	2.99	5.09	4.54	3.60	1.78	3.97	2.45	4.61	3.37
Feb-19	5.25	4.20	6.14	6.33	4.34	2.50	4.75	3.34	5.61	4.84
Mar-19	6.44	6.20	7.50	9.12	5.35	3.79	5.81	4.93	6.90	7.17
Jun-18	6.06	4.57	7.30	7.40	4.73	2.36	5.14	3.12	6.71	5.73
Jul-18	4.83	2.48	6.10	4.61	3.36	0.97	3.67	1.31	5.58	3.47
Aug-18	4.59	2.21	5.83	4.20	3.14	0.82	3.44	1.13	5.33	3.14
Sep-18	5.27	3.49	6.36	5.76	4.10	1.75	4.48	2.36	5.82	4.38
Oct-18	5.20	4.00	6.13	6.17	4.24	2.29	4.64	3.06	5.61	4.71
Nov-18	4.47	3.21	5.28	4.99	3.64	1.82	4.00	2.47	4.81	3.76
Dec-18	3.68	2.14	4.42	3.48	2.90	1.13	3.20	1.56	4.00	2.57
Average	5.01	3.56	6.01	5.67	3.94	1.93	4.31	2.59	5.49	4.32

Table 56 Hargreaves and Jensen Haise ET. Sensitivity to weather parameters for Rajura circle.

Date	HS	JH	HS Temp_ max	JH Temp_ max	HS Temp_ max	JH Temp_ max	HS Temp_ min	JH Temp_ min	HS Temp_ min	JH Temp_ min
			+ 4 °C	+ 4 °C	- 4 °C	- 4 °C	+ 4 °C	+ 4 °C	- 4 °C	- 4 °C
Jan-19	4.16	2.62	4.87	4.00	3.43	1.56	3.79	2.16	4.41	2.94
Feb-19	5.26	4.17	6.12	6.16	4.38	2.56	4.80	3.42	5.59	4.71
Mar-19	6.57	6.44	7.63	9.31	5.47	4.03	5.93	5.19	7.04	7.39
Jun-18	6.28	4.92	7.60	7.95	4.83	2.51	5.23	3.27	7.02	6.26
Jul-18	4.61	2.21	6.02	4.38	2.82	0.73	3.07	0.98	5.52	3.33
Aug-18	4.25	1.80	5.66	3.85	2.40	0.45	2.61	0.61	5.20	2.91
Sep-18	5.01	3.17	6.20	5.47	3.65	1.45	3.97	1.92	5.70	4.21
Oct-18	5.31	4.25	6.26	6.48	4.33	2.45	4.71	3.24	5.75	5.02
Nov-18	4.67	3.58	5.45	5.36	3.87	2.15	4.24	2.89	4.97	4.09
Dec-18	3.58	1.94	4.28	3.16	2.83	1.03	3.13	1.43	3.88	2.31
Average	5.00	3.59	6.02	5.70	3.86	1.96	4.22	2.60	5.52	4.39

Table 57 Hargreaves and Jensen Haise ETo Sensitivity to weather parameters for Wikharan circle.

Date	HS	JH	HS Temp_ max	JH Temp_ max	HS Temp_ max	JH Temp_ max	HS Temp_ min	JH Temp_ min	HS Temp_ min	JH Temp_ min
			+4 °C	+4 °C	- 4 °C	- 4 °C	+4 °C	+4 °C	- 4 °C	- 4 °C
Jan-19	4.15	2.68	4.82	4.00	3.48	1.65	3.86	2.30	4.35	2.93
Feb-19	4.96	3.64	5.78	5.44	4.12	2.21	4.53	2.99	5.26	4.11
Mar-19	6.36	5.84	7.35	8.37	5.36	3.74	5.84	4.89	6.74	6.53
Jun-18	6.04	4.44	7.40	7.38	4.54	2.14	4.91	2.80	6.83	5.78
Jul-18	4.61	2.15	6.02	4.30	2.82	0.69	3.07	0.93	5.52	3.26
Aug-18	4.33	1.83	5.66	3.78	2.66	0.52	2.90	0.70	5.19	2.84
Sep-18	5.04	3.18	6.16	5.32	3.79	1.56	4.13	2.08	5.64	4.07
Oct-18	5.56	4.90	6.47	7.21	4.62	3.00	5.03	3.93	5.95	5.62
Nov-18	4.74	3.89	5.49	5.71	3.97	2.42	4.34	3.23	5.02	4.38
Dec-18	3.86	2.42	4.50	3.68	3.21	1.44	3.55	2.01	4.06	2.70
Average	4.97	3.53	5.96	5.55	3.88	1.97	4.24	2.63	5.45	4.25

Annexure 4

Daily ETo comparison between different methods for 16 circles

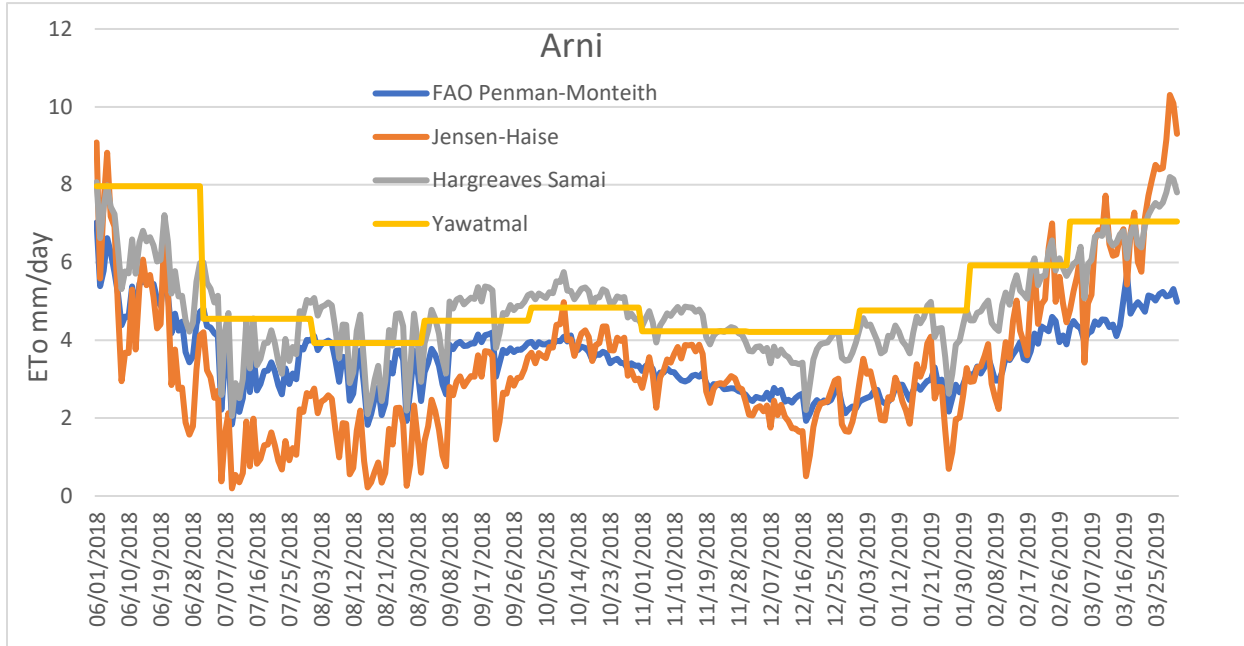


Fig 7 Variation in ETo from different methods for Arni circle

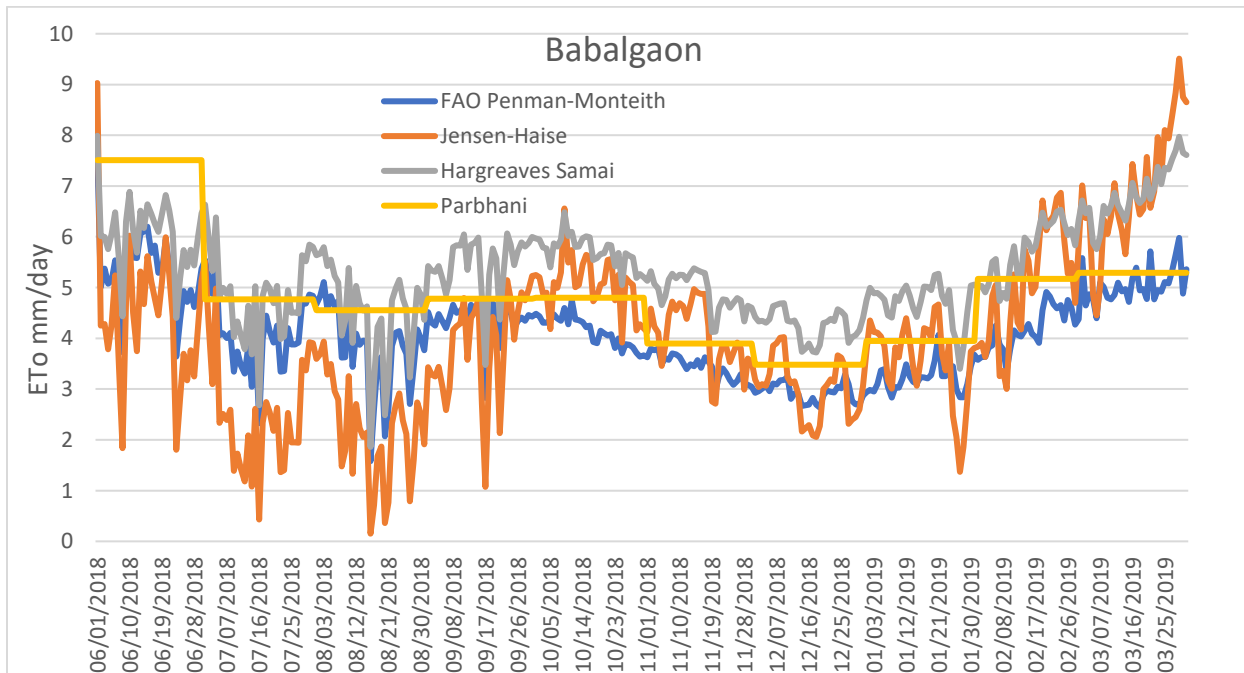


Fig 8 Variation in ETo from different methods for Babalgaon circle

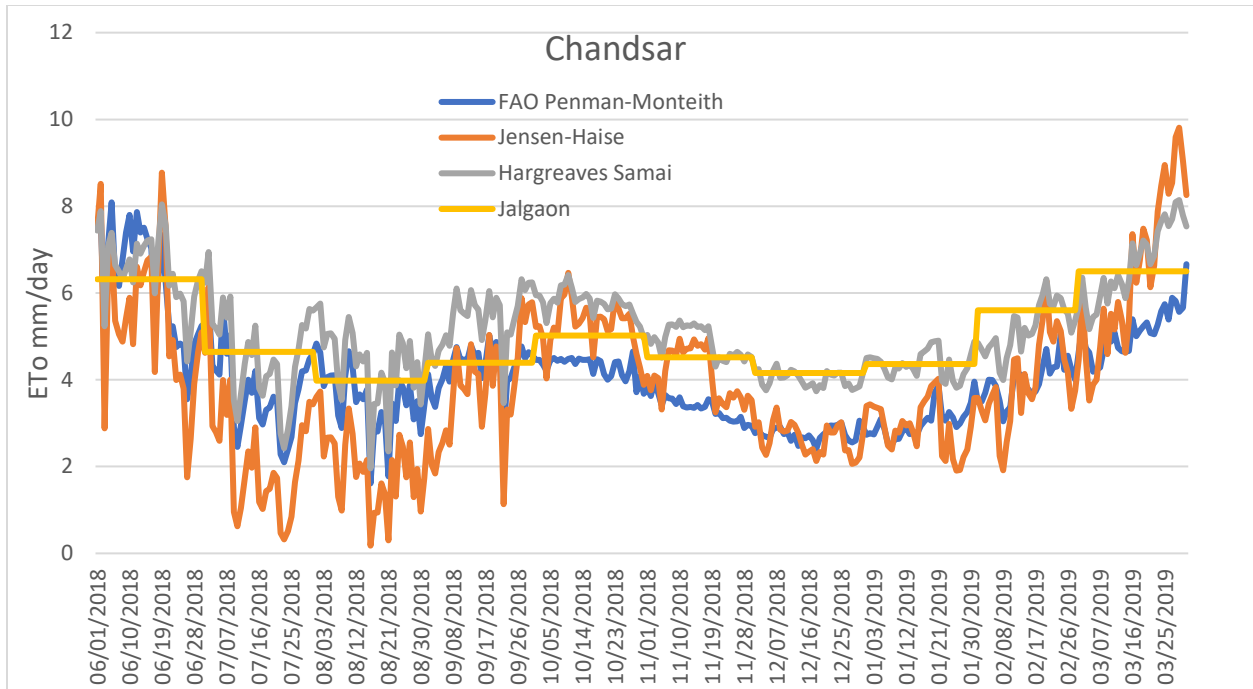


Fig 9 Variation in ETo from different methods for Chandsar circle

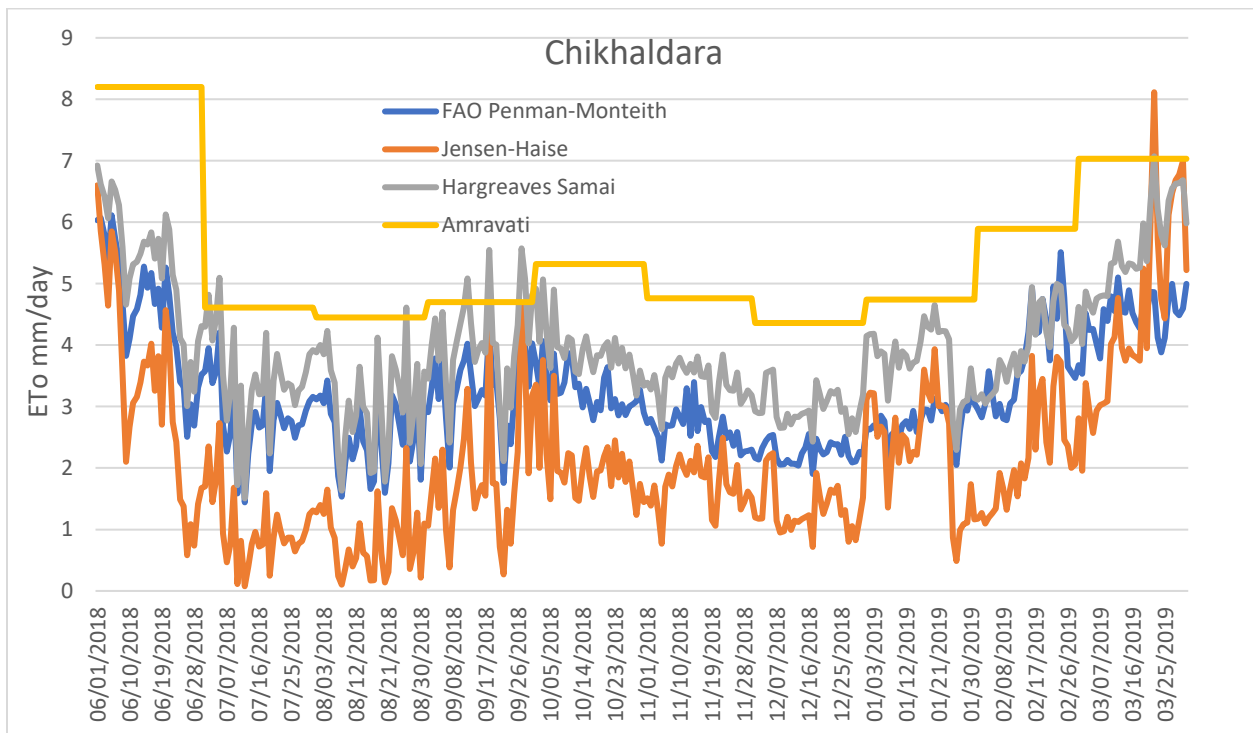


Fig 10 Variation in ETo from different methods for Chikhaldara circle

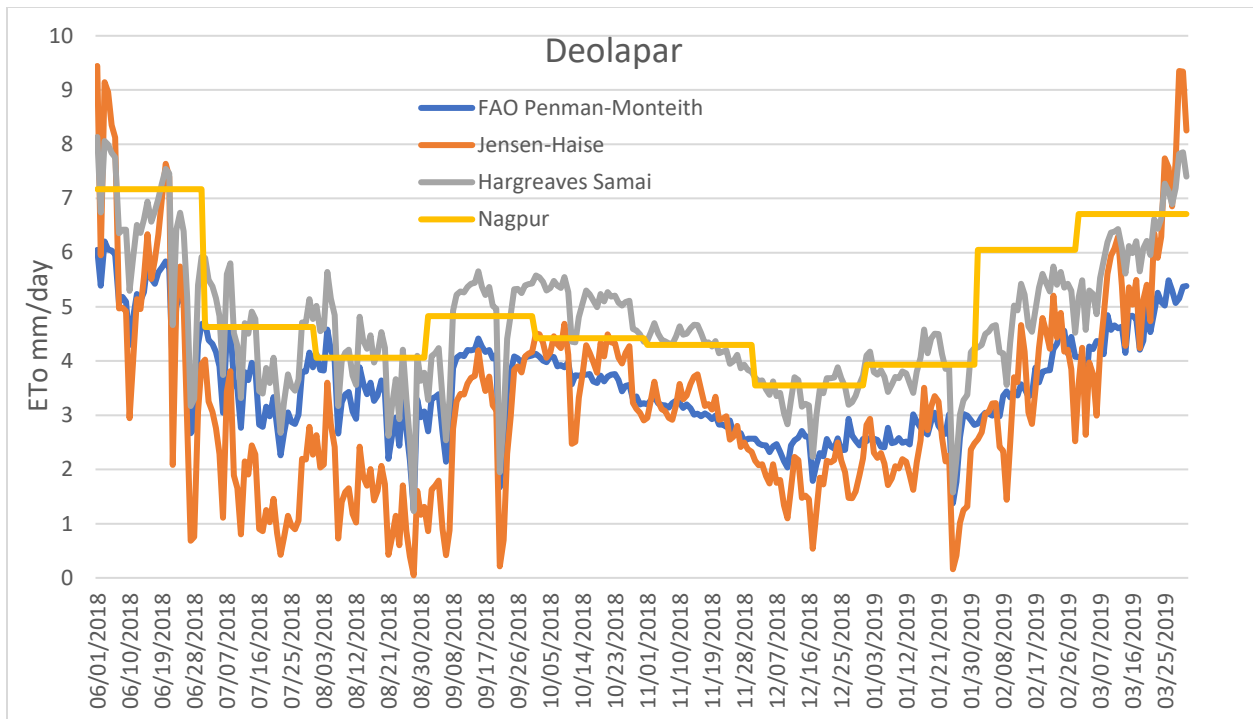


Fig 11 Variation in ETo from different methods for Deolapar circle

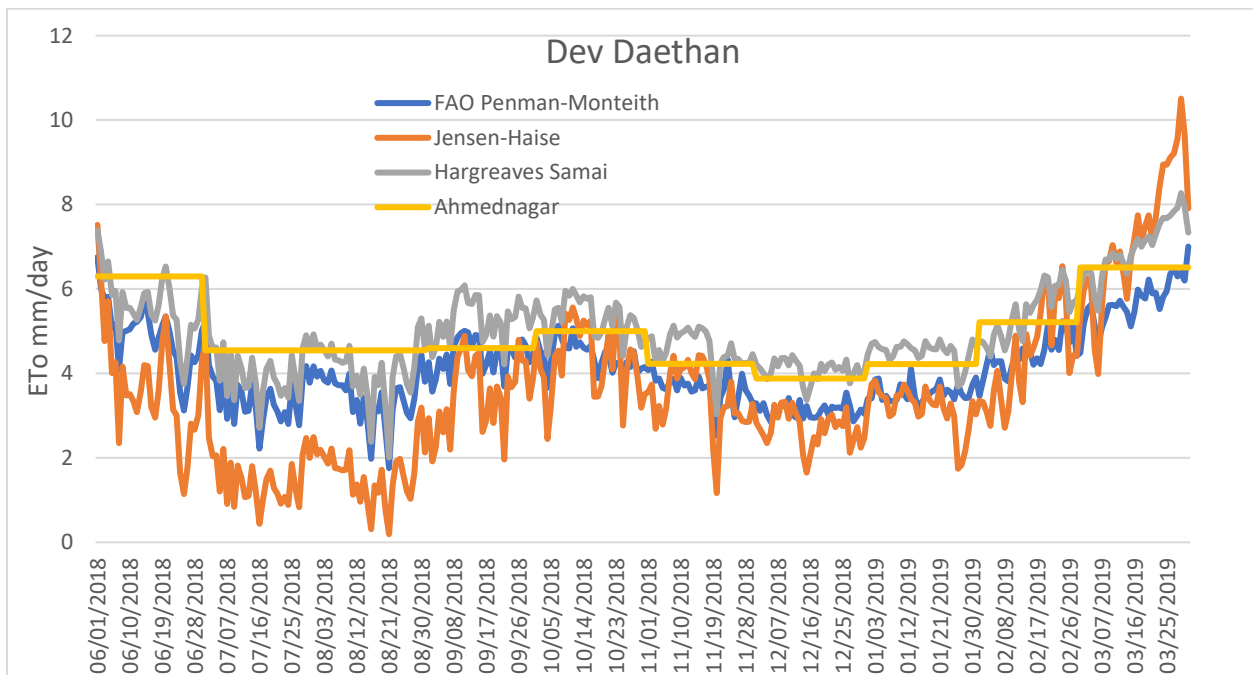


Fig 12 Variation in ETo from different methods for Dev Daethan circle

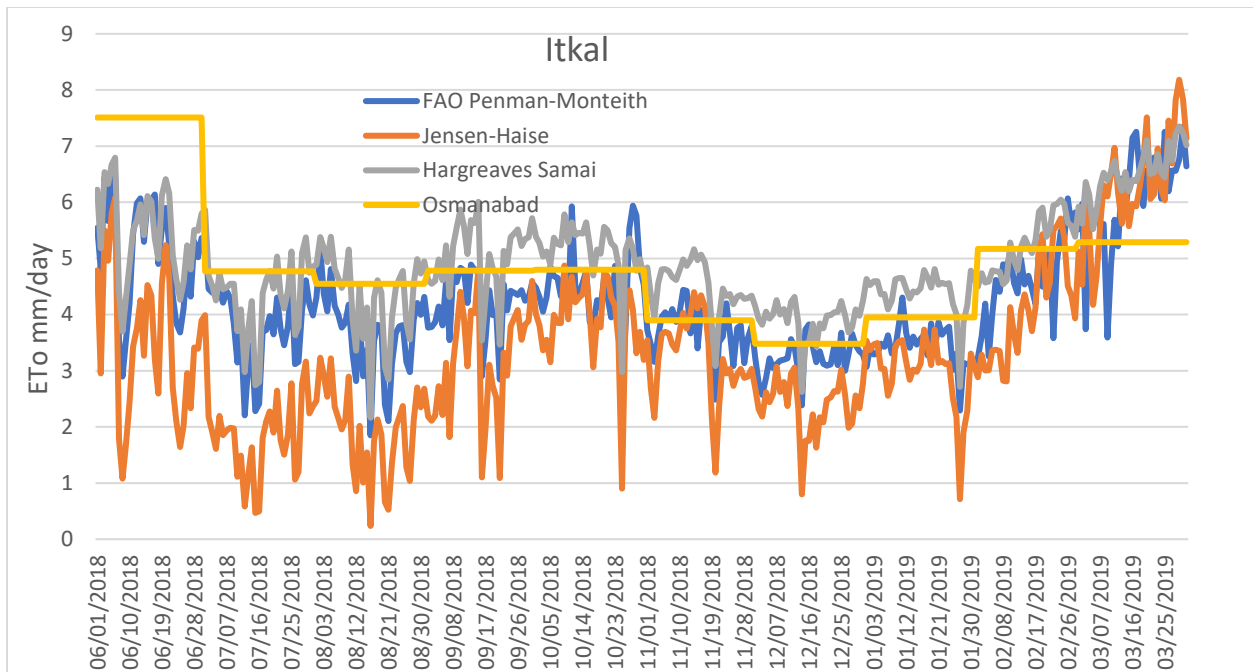


Fig 13 Variation in ETo from different methods for Itkal circle

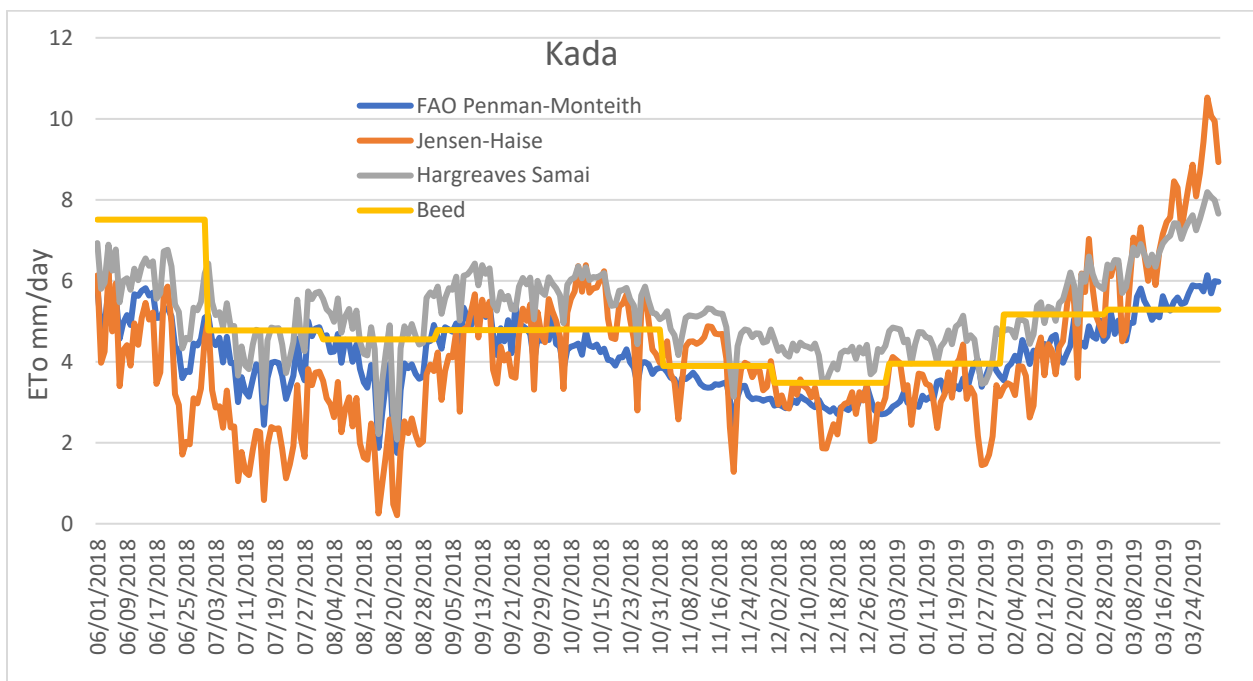


Fig 14 Variation in ETo from different methods for Kada circle

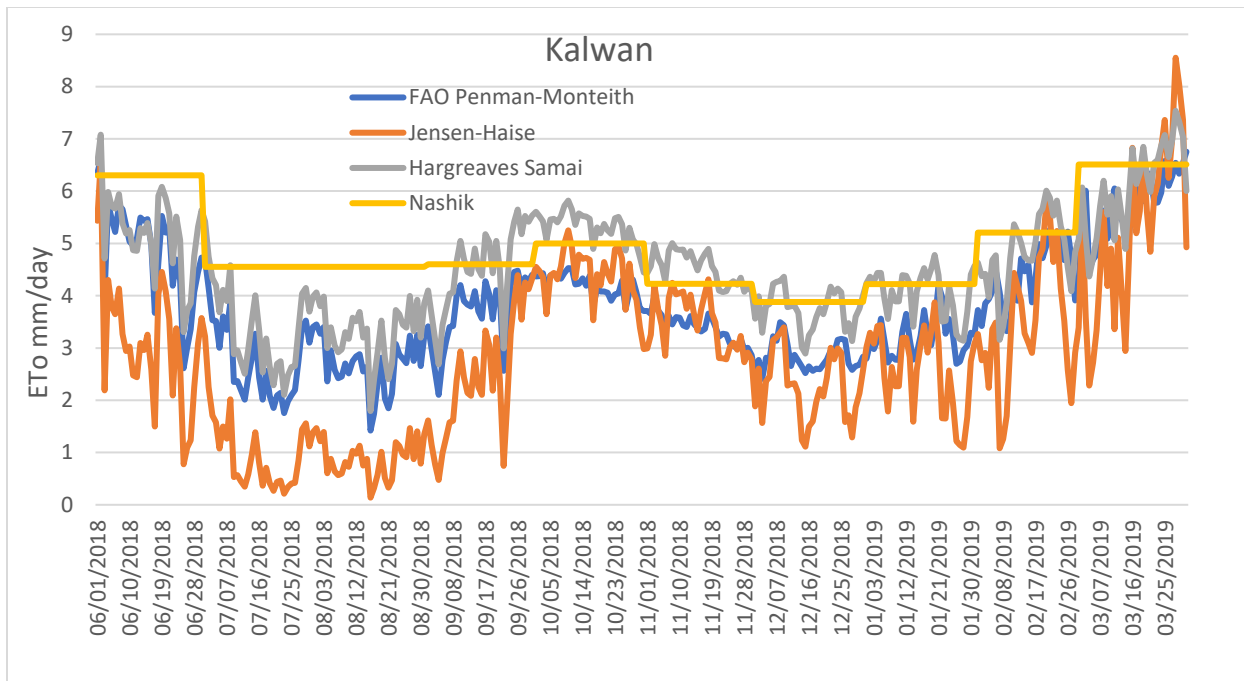


Fig 15 Variation in ETo from different methods for Kalwan circle

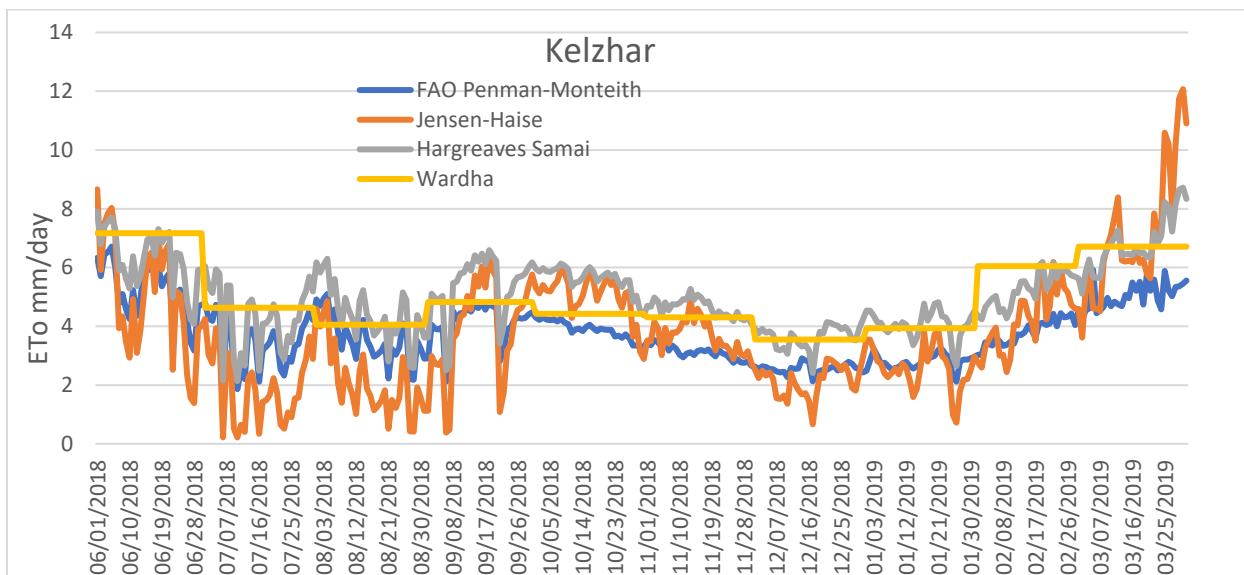


Fig 16 Variation in ETo from different methods for Kelzhar circle

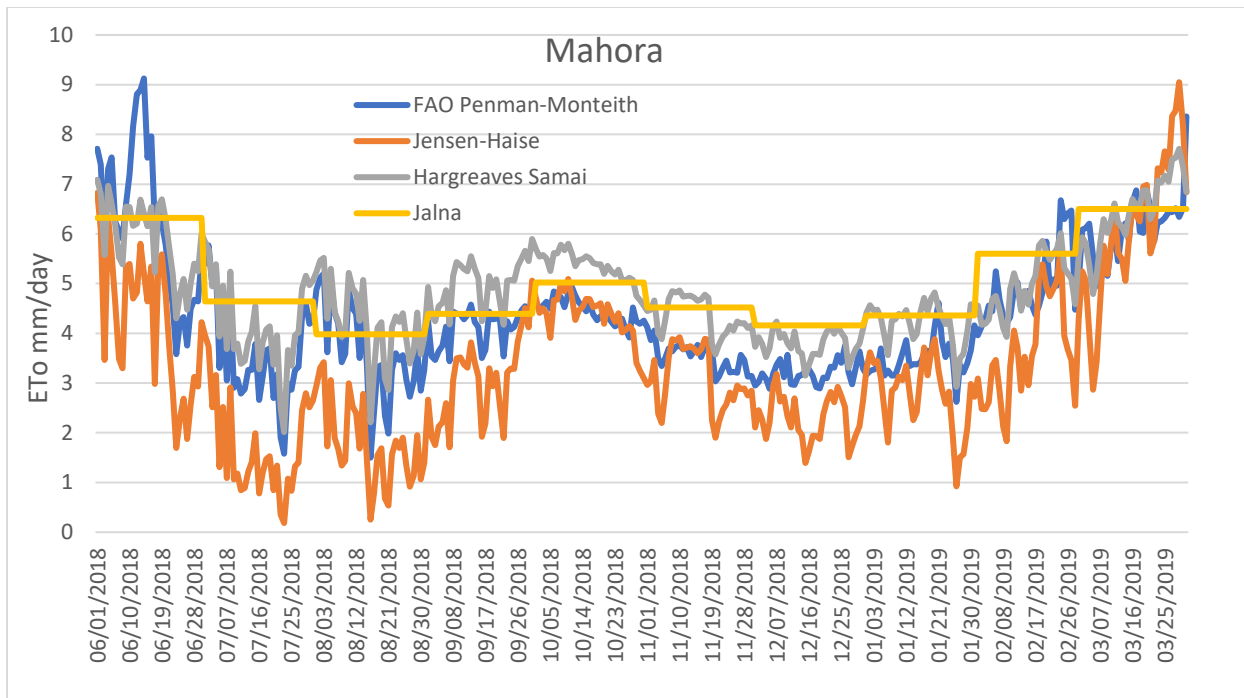


Fig 17 Variation in ETo from different methods for Mahora circle

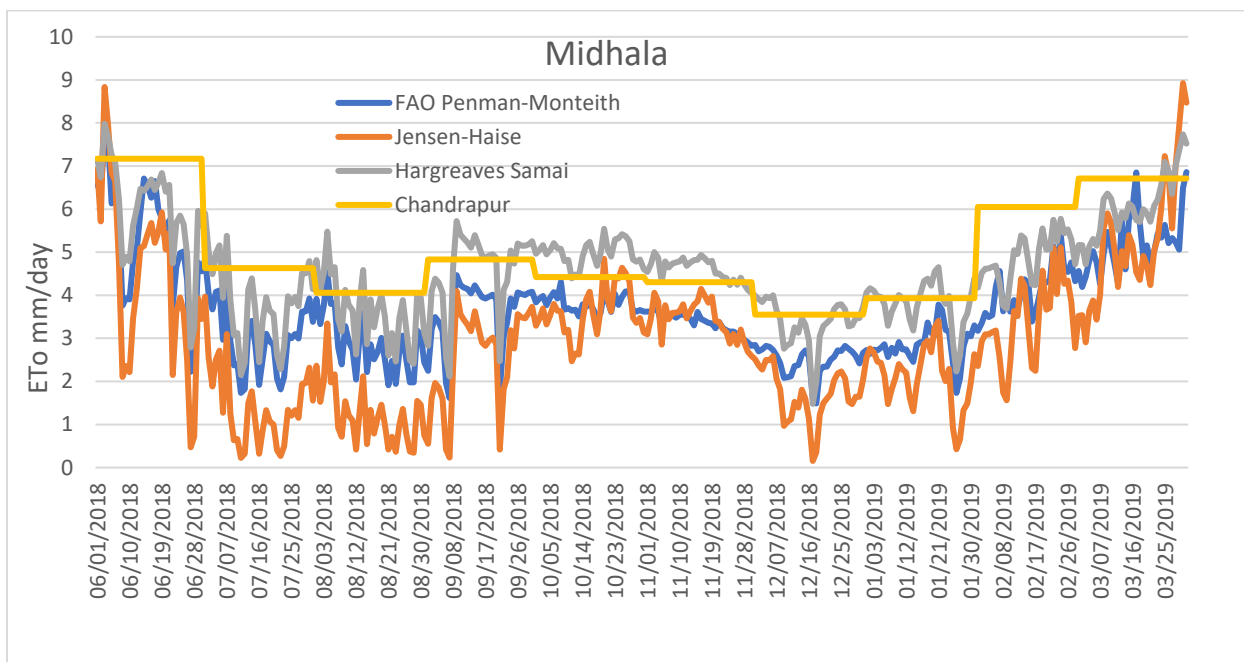


Fig 18 Variation in ETo from different methods for Midhala circle

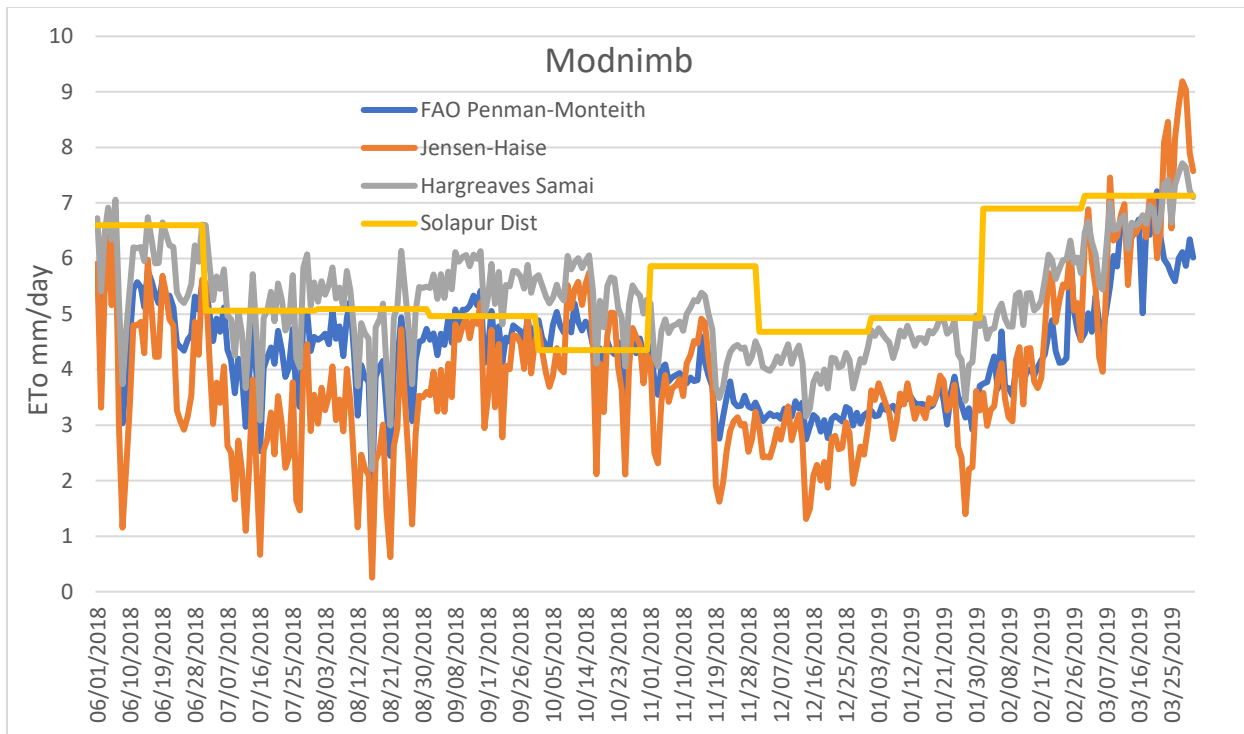


Fig 19 Variation in ETo from different methods for Modnimb circle

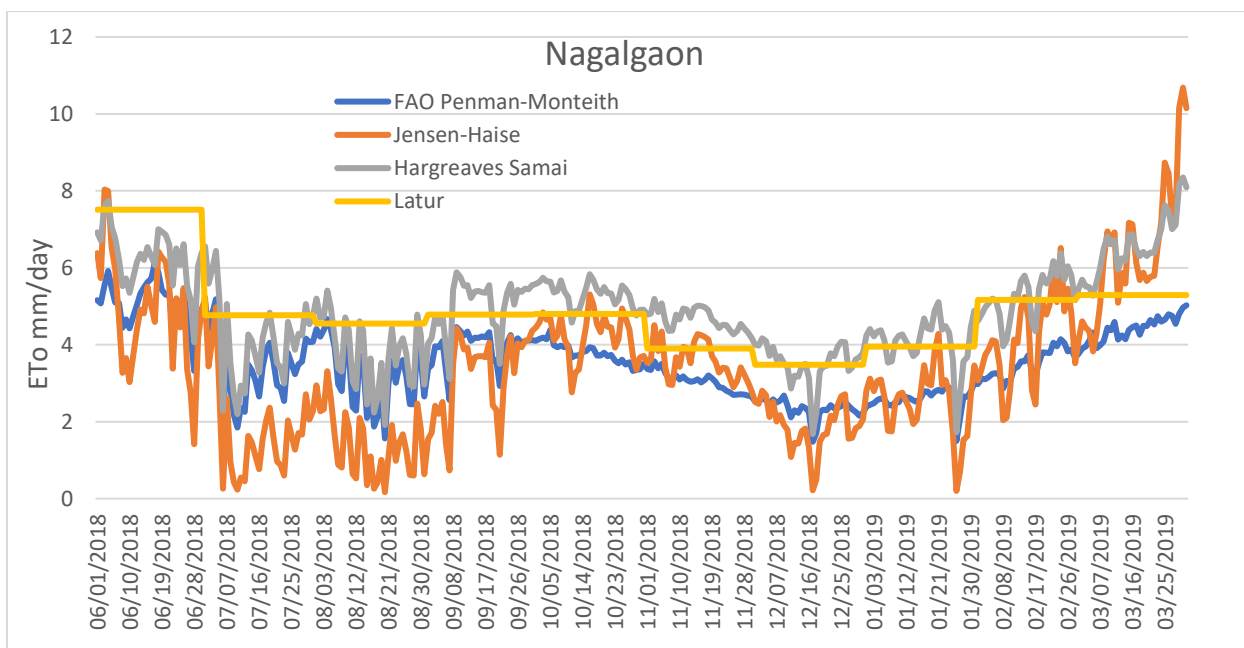


Fig 20 Variation in ETo from different methods for Nagalgaon circle

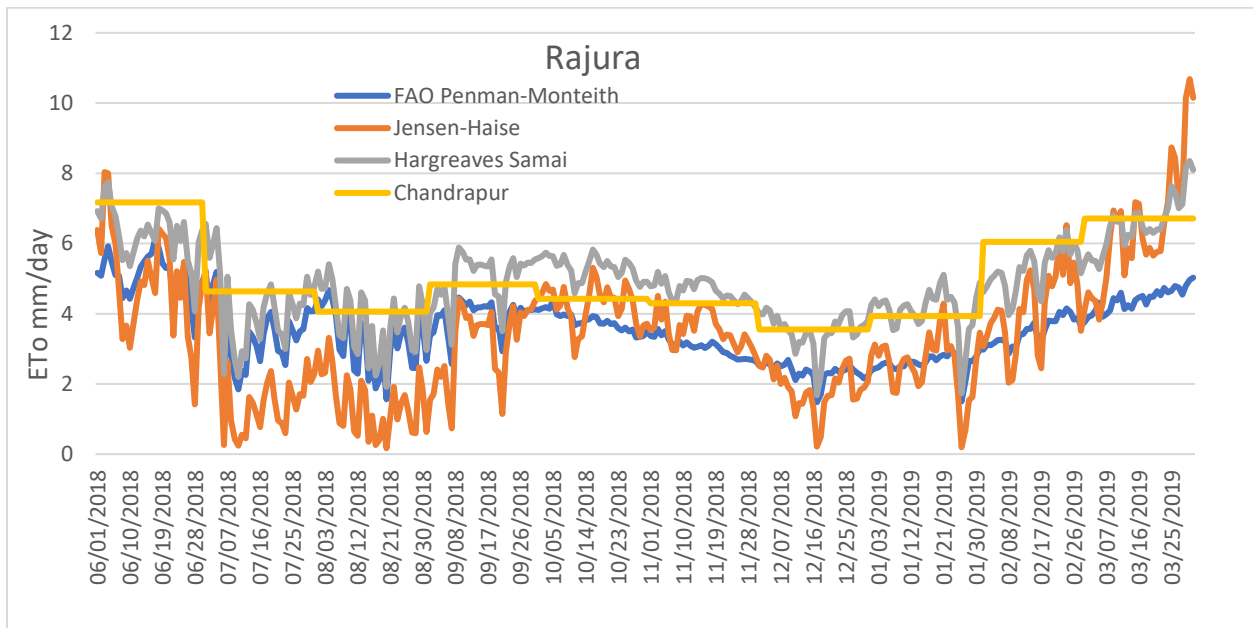


Fig 21 Variation in ETo from different methods for Rajura circle

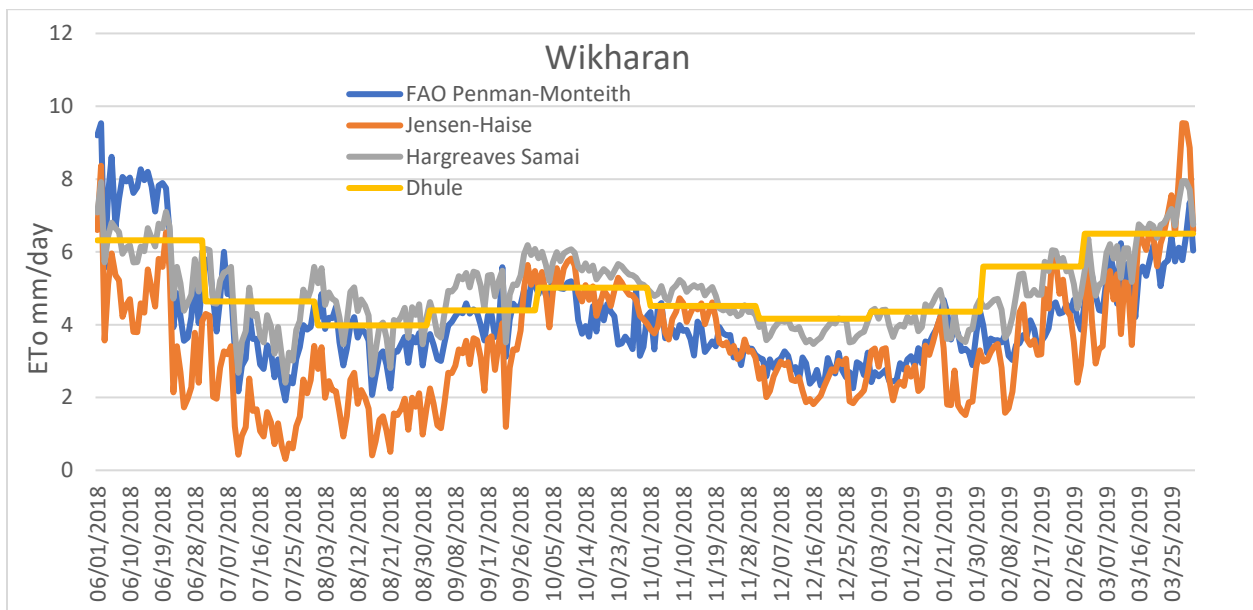


Fig 22 Variation in ETo from different methods for Wikharan circle