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Spatial Distribution of Reference Evapotranspiration for Aurangabad District

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A B S T R A C T

Evapotranspiration estimation is required for effective water management and crop planning. So that reference evapotranspiration was calculated using Hargreaves Samani and Penman Monteith method for Aurangabad district. The primary objective of this study is to investigate the possibility for application of the Hargreaves-Samani equation in Aurangabad district for computing daily reference evapotranspiration. An evaluation of the Hargreaves-Samani equation and its modifications proposed in literature is made by comparing daily estimates with Penman-Monteith results DSS_ET software was used to calculate reference evapotranspiration. Annual Average reference evapotranspiration for Aurangabad district was found to be 5.13 and 5.25 mm/day for Hargreaves and Penman method respectively. Statistical analysis was made to evaluate the performance of reference evapotranspiration methods by using standard deviation, was found 0.33 to 1.81 mm/day for Penman method and 0.24 to 0.89 mm/day for Hargreaves method. For Aurangabad district, its skewness coefficient value ranges between -1.30 to 1.64 during various meteorological weeks for Penman method and -2.05 to 1.07 for Hargreaves method.

Introduction

Reference evapotranspiration is a biometeorological element depicting in practical terms atmosphere evaporative demand with the aim of defining the ideal amount of water irrigation to be adopted at the right time throughout the crop growing season at a given site, conducting prediction studies of crop production and water balance. It is defined as the amount of water lost from the surface grown with grass or alfalfa fully covering the soil at an active development stage, with a uniform height, leaf area index of roughly 3 exposed to the prevailing atmospheric conditions under no water restriction and with a fetch sufficiently large and well irrigated to minimize advection towards the experimental area. As we know, water is basis of life. Also water has been labeled ‘blue gold’ and it is destined to be critical issue of 21^{st} century. Globally irrigation is responsible for 75-80% of the world wide spending of water (Steve *et al.,* 2006). In the modern world, the demand of water is increasing because of the growing population as well as the increased urbanization and industrialization. So for that development of sustainable irrigation practices requires better understanding of biophysical processes of root water uptake in soil and transpiration from plant canopies. As a result, water for agriculture becoming limited. For this reason, accurate estimation of crop water requirement is very important. The problem of over irrigation or under irrigation will be minimized if we are able to accurately estimate the reference crop evapotranspiration (Chen, *et al.*, 2005; Subedi and Chavez, 2015). Accurate estimation of reference evapotranspiration is investigated due to its critical role in determination of crop water requirement and optimum water scheduling. Spatially calculating ET_c is very necessary because it is a major component in qualifying a water budget scheme and the maps provide the spatial ability to display the distribution. ET helps in determining when and how much irrigation water is needed and for designing and management of irrigation system (Poyen *et al.*, 2016; Gupta *et al.*, 2016).

For water resource management, irrigation scheduling, and environmental assessment, an accurate prediction of ET_0 is critical. Farmers, irrigation planners, hydrologists, and policymakers will benefit from this knowledge since it will help them make more informed decisions about how to use water more effectively and efficiently. A spatially distributed measure of ET_0 is required by many hydrological, agricultural, and environmental models. Furthermore, the spatial distribution of ET0 provides useful data and information for regional hydrological research as well as water resource planning and management. Climate variables, on the other hand, are frequently characterised by high spatial variability, which is obtained by a complex interaction between topographical features and the nature of the climatic factors. As a result, a concentrated network of weather stations recording the full weather data should be developed for accurate estimation of ET_0's spatial distribution. To solve this problem, different statistical methods have been developed to forecast the spatial distribution of climatic variables in areas without weather stations. The geographical information system (GIS) has provided an interesting solution for this problem since it allows one to combine a digital elevation model (DEM) (Ghobari, 2000; Tabari *et al.*, 2013).

FAO Penman-Monteith method is preferred as the standard and accurate method for daily ET_0 estimation. However, the major constrains of this method is requirement of extensive weather data such as air temperature, relative humidity, wind speed, solar radiation which could not be easily available at many places.

In addition to the use of complicated unit conversations and lengthy calculations, the reliable quality data and difficulties in data collection present other serious limitations for this method. Hargreaves requires only temperature and incident solar radiation. Also it was found that Hargreaves was found that nearly accurate estimates as that PM method.

Although many approaches have been developed and applied for various applications based on available input data, there is still remarkable range of uncertainity related to which method to be adopted for ET_0 estimation. Therefore main aim of this study was to estimate reference evapotranspiration for Aurangabad district and spatial mapping for development of hydrologic design.

Materials and Methods

Location of Study area and data

Aurangabad district was part of the Marathwada region and latitude and longitude is $19^0 89'$ N and $75^0 15'$ E. The district has an area of $10000 km^2$. Aurangabad district is located mainly between Godavari River. Aurangabad district lies on the

Deccan plateau and covered by the Deccan Traps. The rainy season lasts from the June through September and average rainfall is 734 mm. The temperature ranges between 14 to 40 degrees Celsius on average. The winter season is from October to February and summer season is from March to May.

Daily data on temperature (maximum and minimum temperature), RH, wind speed and solar radiation for period of 31 years from 1990-2020 was collected from NASA website.

This collected data is measured from satellite analysis. The data is used for estimation of reference crop evapotranspiration by Penman Monteith and Hargreaves Samani method.

Evaluation of Et_0 Estimation Methods

Several approaches for estimating reference crop evapotranspiration from climatological data have been developed, including equations ranging from the most sophisticated energy balance methods that require thorough climatological data to simpler methods that require less data.

Some of these methods require a large number of meteorological characteristics, while others require only limited data. Some strategies for estimating reference evapotranspiration have been developed in response to the availability of data (Allen *et al.*, 1989).

The FAO Penman-Monteith (F-PM) method is preferred as the standard and most accurate method for estimating daily ETo. The main limitation of this method is the demand for extensive weather data such as air temperature, relative humidity, wind speed, and sun radiation, which may not be clearly available in many places (Jensen *et al.*, 1990).

In constrast, Hargreaves- Samani method requires only temperature data which is easily available. So for that we used Hargreaves- Samani method to estimate the reference evapotranspiration.

Hargreaves – Samani method

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

$$ETo = 0.0023\ R_a Td0.5\ (Tm + 17.8)$$

Where, ETo is reference evapotranspiration (mm day-1); R_a is extra-terrestrial radiation (mm day^{-1}); T_d is difference between maximum and minimum temperature (^oC); T_m is mean temperature (^oC).

Penman-Monteith Method

Reference crop evapotranspiration (ETo) is the rate of evapotranspiration from a hypothetical reference with assumed crop height at 0.12m.

The FAO -56 PM Method, which is considered the most accurate method to estimate ETo under different climatic condition, was employed to estimate the daily values of ETo in this study.

Monthly and annual values of ETo where obtained by adding of the daily values. The equation of the FAO-56 P-M method is as follows:

$$ETo = [0.408\ \Delta\ (Rn\text{-}G) + \boldsymbol{\gamma}(900\backslash T+273)\boldsymbol{u}2\ (es - ea)]\backslash\Delta + \boldsymbol{\gamma}(1 + 0.34\ \boldsymbol{u2})$$

Where, ET_o is Reference evapotranspiration (mm/day); R_n is Net radiation at the crop surface(MJ m^{-2} day^{-1}); G= soil heat flux density(MJ m^{-2} day^{-1}); T is Mean daily air temperature at 2m height(^0C); u2 is Wind speed at 2m height(m s^{-1}); e_s is Saturation vapors pressure(kPa); e_a is Actual vapor pressure(kPa); (es-ea) is Saturation vapors pressure deficit(kPa); Δ = Slope of vapour pressure curve(kPa ^0C); γ is Psychometric constant(kPa ^0C) (Chavan *et al.*, 2009).

The equation uses standard climatologically records of solar radiation (sunshine), air temperature, humidity and wind speed.

Statistical analysis

The performance of ET_0 estimated by Hargreaves-Samani method was compared with ET_0 estimates of Penman-Monteith for their accuracy using standard deviation, coefficient of variation (Cv), Skewness coefficient (C_k) and Kurtosis coefficient (Ck).

Standard deviation

Standard deviation is a measure of the amount of variation or dispersion of set of values. A low standard deviation indicates that the values tend to be close to the mean of the set, while a high standard deviation indicates that the values are spread out over a wider range. The formula for standard deviation is given as follows;

$$\sigma = \sqrt{\frac{\sum (x_i - \mu)^2}{N}}$$

Where, σ is standard deviation; N is number of observations; x_i is each value from observation and µ is mean.

Coefficient of Variation (C_v)

The coefficient of variation (C_v) is ratio of the standard deviation to the mean. The higher the coefficient of variation, the greater the level of dispersion around the mean. It is generally expressed in percentage.

$$Cv = \frac{\sigma}{\bar{x}}$$

Where C_v is coefficient of variation; σ is standard deviation

Coefficient Skewness

The coefficient of skewness is a measure of asymmetry in the distribution. The skewness value can be positive, zero, negative or undefined. A perfectively symmetric distribution like the normal distribution has a skew equal to zero.

$$\text{Coefficient of skewness} = \frac{\text{Mean} - \text{Mode}}{\text{Standard deviation}}$$

Coefficient of Kurtosis

The coefficient of kurtosis is used to measure the peakness or flatness of a curve.

$$\text{Kurtosis} = \frac{\sum_i^n (X_i - \bar{X} / N}{S^4}$$

Where, S is standard deviation; N is number of observations.

Spatial Mapping of reference evapotranspiration

For generation of spatial map of reference evapotranspiration, IDW method is used to generate the spatial map which is simple and easily available method. Accurate generation of spatial maps was done using this method. Spatial map of Parbhani district for both Hargreaves and Penman Monteith method.

Results and Discussion

Average weekly reference evapotranspiration for Aurangabad district

The average weekly reference evapotranspiration was estimated for Aurangabad district by using Hargreaves–Samani and FAO-56 Penman-Monteith method. The estimated values are tabulated in Table.3.1 and compared the methods in Fig.3.1. The overall average weekly reference evapotranspiration for Aurangabad district was found to be 5.1 and 5.3 mm/day for HS and PM method respectively. The average weekly ET_0 is calculated during year 1990-2020. From the Table 3.1 and Fig.3.1, it was seen that the reference evapotranspiration rate was highest (7.8 mm/day) for the HS method during 18^{th} standard meteorological week (SMW) whereas it is lowest (3.9 mm/day) during 32^{th}, 37^{th}, 46^{th}, 47^{th}, 51^{th} and 52^{th} standard meteorological week (SMW) respectively due to decrease in temperature whereas for PM method, average weekly ET_0 value was highest (9.6 mm/day) in month of may during 21^{st} standard meteorological week (SMW) due to increase in relative humidity and lowest value (3.5 mm/day) in month of September during 35^{th} standard meteorological week (SMW).

Maximum evapotranspiration rate in May mainly because of the local climatic characteristic of the study area. Since the month of May stands for the maximum temperature compared to other months of the year, evapotranspiration in this particular month was recorded highest. So that it is necessary to reduce the use of water resource and develop precise irrigation management. From the fig.3.8, it was observed that reference evapotranspiration values deplete gradually during 23^{th} standard meteorological week (SMW) which is due to change in local climatic parameters for both HS and PM method for year 1990-2020.

From the Table 3.1, it was found that mean weekly ETo values estimated by methods like Hargreaves Samani and Penman Monteith, lies in the close proximity. However, sometimes reference evapotranspiration rate calculated by HS and PM method are same.

It was also seen that prepared graph follows similar trend for ET_0 values calculate by both HS and PM method. Fig. 3.8 shows average weekly ET_0 trend in Aurangabad district.

Statistical analysis of average weekly ET_0 for Aurangabad district

For Aurangabad district, the standard deviation varies between 0.33 to 1.81 mm/day for Penman method and 0.24 to 0.89 mm/day for Hargreaves method. The lowest value of standard deviation for Hargreaves method was found during 7^{th} standard meteorological week and highest value during 23^{th} meteorological week. However for Penman method, it was found during 5^{th} and 23^{rd} meteorological week. The coefficient of variation (C_v) shows the extent of variability of data and it is unitless. For Aurangabad district, the lowest and highest value of C_v for Hargreaves method was found to be 4.63 and 14.72 during 7^{th} and 23^{th} meteorological week. However for Penman method, lowest and highest value of C_v is 6.58 and 26.07 during 8^{th} and 24^{th} meteorological week. The skewness coefficient is a characterization of degree of asymmetry of distribution around its mean. For Aurangabad district, its value ranges between -1.30 to 1.64 during various meteorological weeks for Penman method and -2.05 to 1.07 for Hargreaves method.

For Aurangabad district, results indicate for Penman method that Kurtosis ranged between -1.36 to 3.49 during 39^{th} and 25^{th} meteorological week. Results indicate for Hargreaves method that Kurtosis ranged between -1.16 to 5.39 during 49^{th} and 17^{th} meteorological week.

Spatial distribution mapping of reference evapotranspiration

Spatial continuous data (or spatial continuous surfaces) play a significant role in planning, risk assessment, and decision making inirrigation management. They are, however, as geographic information systems (GIS) and modelling techniques are becoming powerful tools in natural resource management and biological conservation, spatial continuous data of environmental variables are increasingly required.

Since ET_0 plays an important role in the distributed hydrological modeling. In this study, the two approaches made for preparation of spatial distribution maps of ET_0 were compared. In the first approaches, reference evapotranspiration on daily basis was computed using Hargreaves-Samani and Penman-Monteith for marathwada region for 31 years. In the second approach, results of ET_0 obtained by Hargreaves-Samani and Penman-Monteith method were interpolated by using inverse distance weight method. However, the ET_0 maps were prepared by applying suitable methods in Arc GIS.

Table.1 Average weekly ET_0 for Aurangabad district

Standard Meteorological week	Dates	Reference evapotranspiration (ET_0), mm/day	
		PM	HS
1	1-7 Jan	4.4	5.2
2	8-14	4.4	4.8
3	15-21	4.4	4.3
4	22-28	4.6	4.5
5	29-4 Feb	4.9	4.9
6	5-11	5.6	6.0
7	12-18	5.4	5.1
8	19-25	5.6	5.5
9	26-4 Mar	5.8	5.6
10	5-11	6.4	6.5
11	12-18	6.4	6.1
12	19-25	7.1	6.7
13	26-1 Apr	7.3	6.7
14	2-8	7.3	7.0
15	9-15	7.4	6.6
16	16-22	8.3	7.4
17	23-29	8.7	7.6
18	30-6 May	8.7	7.8
19	7-13	8.9	6.7
20	14-20	9.5	7.5
21	21-27	9.6	7.5
22	28-3 Jun	8.6	6.3
23	4-10	7.2	6.0
24	11-17	5.8	5.1
25	18-24	5.4	5.2
26	25-1 July	4.8	4.7
27	2-8	4.5	4.5
28	9-15	4.2	4.2
29	16-22	4.0	4.5
30	23-29	3.9	4.5
31	30-5 Aug	3.7	4.0
32	6-12	3.6	3.9
33	13-19	3.9	4.5
34	20-26	3.7	4.4
35	27-2 Sep	3.5	4.0
36	3-9	3.7	4.4
37	10-16	3.7	3.9
38	17-23	3.7	4.2
39	24-30	3.9	4.2

40	**1-7 Oct**	4.0	4.5
41	**8-14**	4.0	4.2
42	**15-21**	4.0	4.2
43	**22-28**	4.0	4.2
44	**29-4 Nov**	4.1	4.4
45	**5-11**	4.2	5.2
46	**12-18**	3.8	3.9
47	**19-25**	3.7	3.9
48	**26-2 Dec**	3.7	4.0
49	**3-9**	4.4	5.6
50	**10-16**	3.8	4.0
51	**17-23**	3.8	3.9
52	**24-31**	3.8	3.9

Fig.1 Average weekly reference evapotranspiration trends for Aurangabad district (1990-2020)

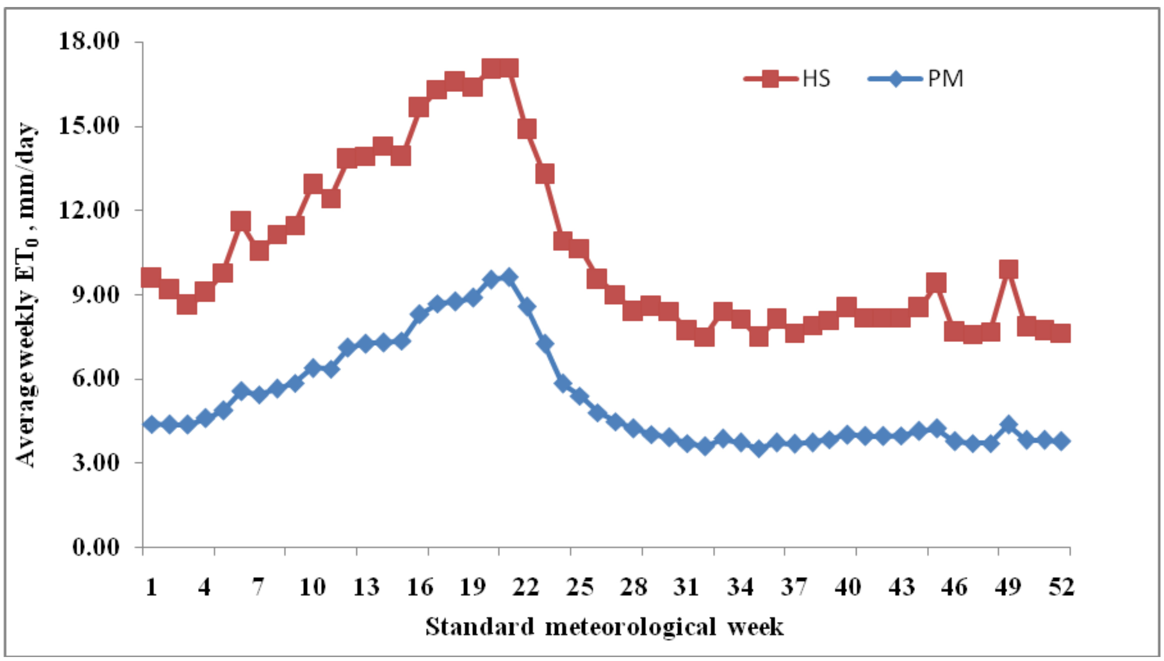


Table.2 Statistical characteristics of weekly ET_0 at Aurangabad district

Met.Week	Standard deviation mm/day		Coefficient of variation (C_v)		Skewness coefficient (C_s)		Kurtosis	
	PM	HS	PM	HS	PM	HS	PM	HS
1	0.46	0.29	10.41	5.62	-0.09	0.00	-0.64	-0.45
2	0.39	0.29	8.92	5.99	-0.11	-0.33	0.20	-0.44
3	0.43	0.25	9.92	5.88	0.10	-0.54	-0.50	0.23
4	0.36	0.27	7.89	6.14	0.28	-0.28	-1.07	0.24
5	0.33	0.26	6.79	5.23	0.11	0.10	0.06	-1.02
6	0.43	0.35	7.77	5.91	-0.25	-0.75	1.71	1.93
7	0.39	0.24	7.13	4.63	0.15	-0.79	-0.96	0.69
8	0.37	0.29	6.58	5.22	-0.76	-0.49	0.08	-0.19
9	0.45	0.34	7.76	5.98	0.16	-1.14	-0.48	1.36
10	0.65	0.42	10.12	6.50	-0.87	-1.63	0.42	3.24
11	0.58	0.41	9.16	6.70	-1.14	-0.56	0.82	0.09
12	0.62	0.33	8.75	4.85	-0.51	-0.41	-0.48	0.68
13	0.73	0.36	10.04	5.36	-0.43	-1.32	1.41	2.10
14	0.70	0.41	9.63	5.87	-0.59	-1.42	0.79	3.20
15	1.00	0.43	13.53	6.53	-0.26	-1.41	0.64	2.93
16	1.06	0.45	12.81	6.14	0.23	-0.31	-0.42	-0.96
17	1.04	0.43	11.94	5.68	0.13	-2.05	0.31	5.39
18	1.15	0.42	13.16	5.34	-0.47	-0.99	-0.49	0.42
19	1.12	0.39	12.61	5.19	-0.23	-1.32	-1.01	1.25
20	1.20	0.61	12.56	8.14	-1.03	-1.25	0.34	1.29
21	1.33	0.62	13.87	8.27	-1.30	-1.27	1.57	1.28
22	1.65	0.77	19.26	12.30	-1.12	-1.17	1.01	0.70
23	1.81	0.89	25.06	14.72	0.22	-0.02	-0.82	-1.33
24	1.52	0.72	26.07	14.24	0.77	0.63	0.44	0.11
25	0.99	0.56	18.30	10.66	0.31	-0.49	-0.21	-0.06
26	1.14	0.59	23.69	12.45	1.64	0.94	3.49	1.73
27	0.83	0.46	18.44	10.23	0.77	0.70	-0.34	-0.44
28	0.78	0.42	18.52	10.05	0.60	0.69	0.09	0.18
29	0.65	0.38	16.16	8.46	0.12	0.27	1.04	-0.37
30	0.63	0.40	16.26	8.88	0.20	0.50	-0.30	-0.17
31	0.69	0.48	18.57	11.94	0.88	1.00	0.47	0.05
32	0.54	0.38	15.13	9.80	0.06	-0.02	-0.59	-0.39
33	0.68	0.52	17.65	11.46	-0.09	-0.09	0.46	-0.79
34	0.56	0.45	15.08	10.17	1.12	1.07	1.16	1.86
35	0.55	0.42	15.75	10.53	0.56	0.62	0.37	-0.58
36	0.51	0.43	13.59	9.83	-0.21	-0.17	-0.74	-0.13
37	0.52	0.40	14.09	10.26	-0.17	0.38	-0.80	-0.16
38	0.61	0.47	16.25	11.20	-0.59	-0.34	-0.63	-0.69

39	0.51	0.44	13.17	10.49	0.10	0.53	-1.36	-0.70
40	0.69	0.63	17.26	13.91	0.35	0.55	-0.44	-0.71
41	0.68	0.56	17.07	13.27	-0.21	0.44	1.28	-0.47
42	0.55	0.52	13.76	12.26	-0.06	0.05	-0.08	-0.32
43	0.75	0.57	18.74	13.69	0.00	0.01	-0.37	-0.73
44	0.71	0.55	17.13	12.63	0.33	-0.19	-0.16	-0.74
45	0.71	0.61	16.78	11.86	0.26	-0.56	-0.57	-0.76
46	0.70	0.48	18.67	12.21	0.19	-0.01	-1.07	-0.97
47	0.56	0.43	15.13	11.20	0.41	-0.04	-0.08	-0.10
48	0.55	0.43	14.85	10.73	0.25	-0.28	-0.57	-1.12
49	0.69	0.58	15.91	10.39	-0.04	-0.36	-1.05	-1.16
50	0.59	0.39	15.51	9.79	-0.05	-0.51	-1.03	-0.91
51	0.51	0.28	13.22	7.25	-0.17	-0.30	-1.10	-0.82
52	0.50	0.29	13.26	7.40	-0.36	-0.96	0.05	2.79

Fig.2 Reference evapotranspiration map for Aurangabad district using Hargreaves-Samani method

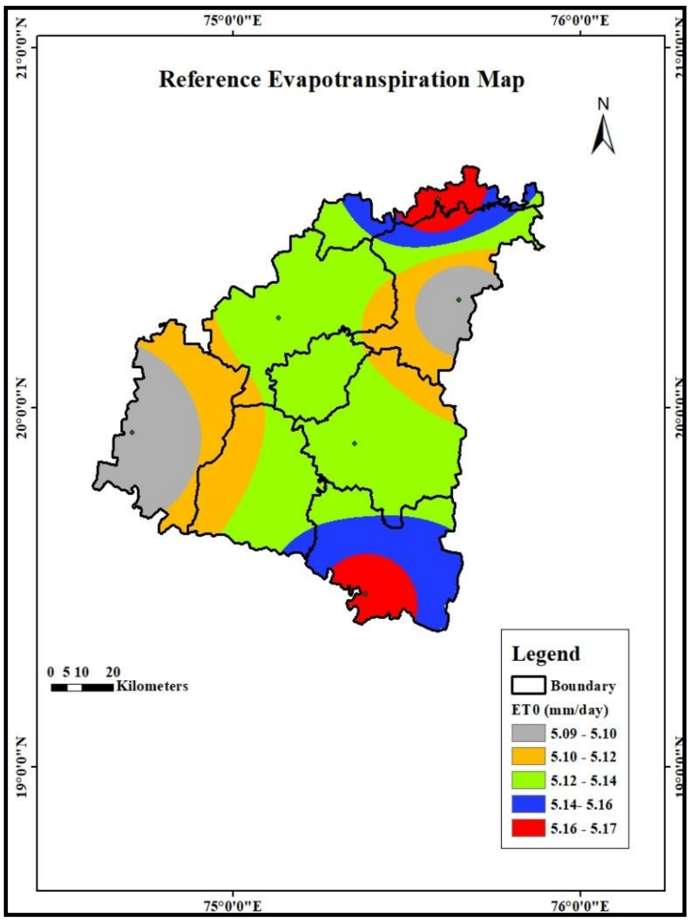
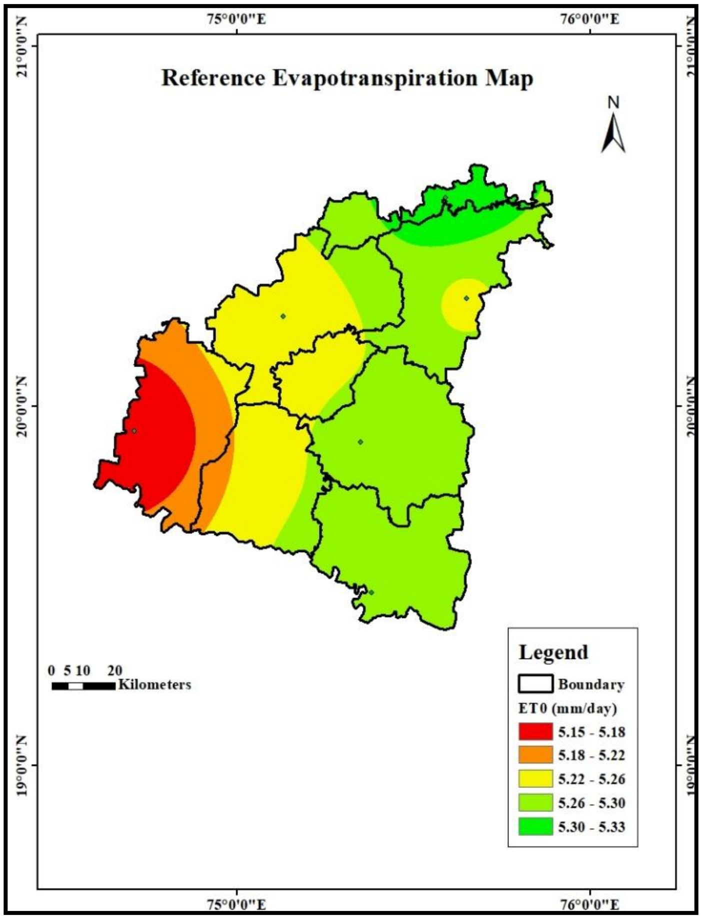


Fig.3 Reference evapotranspiration map for Aurangabad district using Penman-Monteith method



The FAO-56 PM equation is recommended as the standard for computing ET0, although its use is limited by the availability of necessary meteorological data. In these cases, the HS equation based on minimum and maximum air temperature is regarded a good alternative, however empirical coefficients must often be adjusted to local climatic conditions, using FAO-56 PM as a benchmark.

The results of HS equation was compared with Penman Monteith method for Aurangabad district. Results shows that there is close relationship between these two methods. Whereas using ET_0 maps, it was concluded that east part of Aurangabad district comes under low evapotranspiration and south part has high evapotranspiration rate.

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