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Anjana Chettri
Department of Agricultural Meteorology, IGKV, Raipur, Chhattisgarh, India

JL Chaudhary
Sr. Scientist, Department of Agricultural Meteorology, IGKV, Raipur, Chhattisgarh, India

Corresponding Author:
Anjana Chettri
Department of Agricultural Meteorology, IGKV, Raipur, Chhattisgarh, India

Variability in reference evapotranspiration in different districts of Chhattisgarh, India

Anjana Chettri and JL Chaudhary

Abstract
A research study was undertaken to evaluate reference evapotranspiration (ET_o) along with their trends in different districts of Chhattisgarh, India using 28 years (1991-2019) long term data during 2021-2022. Bastar district observed highest annual ET_o while lowest in Mungeli district. *kharif* and *rabi* ET_o was observed to be highest in Bilaspur and Balodabazar districts, respectively while lowest in Kanker and Koriya districts, respectively. Highest ET_o variability recorded was during kharif season as 4.3%. The results also showed that the magnitude of negative trends in the annual ET_o series ranged from (-) 1.469 to (-) 2.852 mm year^{-1} while positive trends ranged between (+) 2.670 to (+) 2.143 mm year^{-1}. The analysis also revealed that *kharif* ET_o in Chhattisgarh decreased at an average rate of (-) 0.510 to (-) 0.490 mm year^{-1}. ET_o values during the *rabi* season decreased at a rate of (-) 0.948 to (-) 0.368 mm year^{-1}, respectively.

Keywords: Reference evapotranspiration, trends, Chhattisgarh.

1. Introduction
In the context of world's economy, water is a limiting factor due to its change in distribution and decreasing quality and quantity (Paltineanu *et al.,* 2007) [5]. Evapotranspiration is significant in terms of hydrological water balance, irrigation system design and management, water resources planning and management, ground water recharge, predicting crop yield etc. (Zhan and Feng, 2003) [3]. It is often regarded as best indication of water requirement. A large uniform grass (or alfalfa) field is considered worldwide as the reference surface and is assumed to be free of water, stress and disease.

The concept of the reference evapotranspiration was introduced to study the evaporative demand of the atmosphere which had least involvement in the crop type, crop development and management practices. In reference evapotranspiration surface, water is freely available that is why ET is not affected by soil factors but is affected by climatic factors. The adoption of a reference crop (grass) has made consistent crop coefficient selection much easier and more practical (Djaman, 2013) [2]. The output of this adoption has resulted in a more reliable estimation of actual crop evapotranspiration (Eta) in new areas. For better understanding of climate change and its effect on hydrology, analysis of trend and variation of ET_o is of utmost importance (Chakraborty *et al.,* 2013) [4]. Climate change and global warming are directly affecting the availability and quality of water for the agricultural use, therefore monitoring the level is much more necessary. Keeping this fact in view the current research was taken to understand the water availability for agricultural purposes of the state.

2. Materials and Methods
2.1 Data collection
The long term (1991-2019) gridded data were collected from India Meteorological Department (IMD), New Delhi and actual weather data were collected from department of agrometeorology, IGKV, Raipur. The daily weather parameters are gridded air temperature (maximum and minimum), actual relative humidity, actual wind speed, actual rainfall and actual sunshine hours collected for 27 districts of Chhattisgarh.

2.2 Methods
2.2.1 FAO-56 Penman-Monteith
FAO-56 Penman-Monteith method is the standardized method used for the estimation of reference evapotranspiration using daily climatological data in this study.

The equation of this method is given as follows (Allen *et al.*, 1998) [1];

$$ET_o = \frac{0.408\,\Delta\,(Rn-G) + \gamma\,\frac{900}{\overline{T}+273} u2\,(es-ea)}{\Delta + \gamma\,(1+0.34\,u2)} \;\ldots\ldots\,(1)$$

Where, ET_o = Reference evapotranspiration (mm day^{-1}), R_n = Net radiation at the crop surface (MJ m^{-2} day^{-1}), G = Soil heat flux density (MJ m^{-2} day^{-1}), $\overline{T}$ = Mean daily air temperature (°C), u_2 = Wind speed at a 2 m height above the ground (ms^{-1}), e_s= Saturation vapour pressure (kPa), e_a = Actual vapour pressure (kPa), e_s-e_a = Saturation VPD (kPa), Δ = Slope of vapour pressure curve (kPa °C^{-1}) and γ = Psychrometric constant (kPa °C^{-1}).

2.2.2 FAO-24 Epan

Evaporation from pan (USWB Class A Pan evaporimeter) is due to the combined effect of temperature, relative humidity, wind speed and duration of sunshine. It is used in case there is lack of weather data availability. The estimation of reference evapotranspiration as given by FAO-24 Epan method is as follows;

$$ET_o = Epan.Kp \;\ldots\ldots\,(2)$$

Where, ET_o= Reference evapotranspiration, Epan = Pan evapotranspiration (mm day^{-1}) and Kp = Pan coefficient (0.7).

2.3 Trend analysis

Trend analysis in ETo for 27 district was studied by conducting regression analysis and using Mann Kendall test for a period of 28 years (1991-2019).

3. Result and Discussion

3.1 Variations in annual reference evapotranspiration

Annual ET_o observed in 27 districts were found between 1200 mm and 1100 mm. Among 27 districts, annual ET_o observed were such that Bastar (1224.4±42.9 mm) district showed the highest value while the lowest value was recorded in Mungeli (1135.5±37.1 mm) district The variability in annual ET_o was found highest in three districts namely; Jashpur (4.4%), Koriya (4.4%) and Surguja (4.4%) and three districts showed similar variability; Balrampur (4.3%), Surajpur (4.2%) and Gariaband (4.1%). The lowest variability was found in six districts namely; Balod (2.2%), Bemetara (2.2%), Durg (2.2%), Janjgir-Champa (2.2%), Mahasamund (2.2%) and Raipur (2.2%). Average annual ET_o for 27 districts were recorded as 1176.1±36.82 mm and variability were 3.1% which was lower than that observed during *kharif* and *rabi* seasons (Table 1).

Out of 27 districts, Balrampur, Gariaband, Jashpur, Surajpur and Surguja showed significant increasing trend at 5% level of significance. Bijapur, Dhamtari, Kondagaon, Mungeli and Narayanpur districts showed significant decreasing trend at 5% level while Bastar, Bilaspur, Dantewada, Sukma and Kanker districts showed significant decreasing trend at 1% level of significance. The result also indicated that the magnitude of negative trends in annual ET_o series ranged at an average rate of (-) 1.469 to (-) 2.852 mm year^{-1}. Moreover, annual ET_o of Balrampur, Gariaband, Jashpur, Surajpur and Surguja increased by (+) 2.268, (+) 2.181, (+) 2.670, (+) 2.143 and (+) 2.306 mm year^{-1}, respectively. Mann Kendall test depicted that ET_o for 8 districts viz., Bastar, Dantewada, Dhamtari, Kanker, Kondagaon, Mungeli, Narayanpur and Sukma were significantly decreasing at 5% level. Jashpur district showed significant increasing while Bijapur district showed significant decreasing trend at 10% level of significance. Bilaspur district showed significant decreasing trend at 1% level of significance. The remaining districts did not show any significant changes (Table 1).

Table 1: Average annual ET_o in different districts of Chhattisgarh (1991-2019)

S.N.	Districts	Mean±SD (mm)	CV (%)	r	Rate of Change (mm/year)	Linear Regression	Mann Kendall
				Annual ETo			
1	Balod	1181.1±26.0	2.2	-0.27	-0.826	NS	NS
2	Balodabazar	1172.1±26.9	2.3	-0.163	-0.514	NS	NS
3	Balrampur	1144.3±49.2	4.3	0.392	2.268	S*	NS
4	Bastar	1224.4±42.9	3.5	-0.472	-2.38	S**	S**
5	Bemetara	1161.5±25.5	2.2	-0.205	-0.615	NS	NS
6	Bijapur	1216.8±43.0	3.5	-0.425	-2.15	S*	S*
7	Bilaspur	1189.7±40.3	3.4	-0.603	-2.852	S**	S***
8	Dantewada	1214.1±42.4	3.5	-0.471	-2.347	S**	S**
9	Dhamtari	1178.4±28.4	2.4	-0.44	-1.469	S*	S**
10	Durg	1165.3±25.7	2.2	-0.207	-0.624	NS	NS
11	Gariaband	1186.3±48.5	4.1	0.383	2.181	S*	NS
12	Janjgir-Champa	1155.9±25.6	2.2	0.174	0.524	NS	NS
13	Jashpur	1167.2±51.5	4.4	0.441	2.67	S*	S*
14	Kanker	1188.8±42.2	3.6	0.03	0.097	NS	NS
15	Kabirdham	1153.9±27.9	2.4	-0.48	-2.382	S**	S**
16	Kondagaon	1220.4±43.1	3.5	-0.462	-2.335	S*	S**
17	Korba	1150.3±26.6	2.3	-0.222	-0.652	NS	NS
18	Koriya	1143.6±50.6	4.4	0.354	2.107	NS	NS
19	Mahasamund	1166.3±25.9	2.2	-0.176	-0.536	NS	NS
20	Mungeli	1135.5±37.1	3.3	-0.427	-1.861	S*	S**
21	Narayanpur	1214.5±42.9	3.5	-0.463	-2.314	S*	S**
22	Raigarh	1158.8±27.5	2.4	-0.133	-0.43	NS	NS
23	Raipur	1161.2±25.6	2.2	-0.214	-0.642	NS	NS
24	Rajnandgaon	1185.4±27.2	2.3	-0.258	-0.825	NS	NS
25	Sukma	1219.3±42.8	3.5	-0.479	-2.408	S**	S**
26	Surajpur	1145.3±48.5	4.2	0.376	2.143	S*	NS

27	Surguja	1153.4±50.2	4.4	0.391	2.306	S*	NS
	Mean	1176.1±36.82	3.1	-0.149	-0.514	S	NS

Note: *** Significant at 1% level, ** Significant at 5% level, * Significant at 10% level,
** Significant at 1%, *Significant at 5% level (Linear regression), NS (Non-Significant).

Table 2: Average *kharif* ET_o in different districts of Chhattisgarh (1991-2019)

S.N.	Districts	Mean±SD (mm)	CV (%)	r	Rate of Change (mm/year)	Linear Regression	Mann Kendall
				***Kharif* ETo**			
1	Balod	505.0±19.5	3.9	-0.041	-0.095	NS	NS
2	Balodabazar	506.6±20.4	4	0.035	0.083	NS	NS
3	Balrampur	507.3±22.2	4.4	0.225	0.588	NS	NS
4	Bastar	498.2±20.4	4.1	-0.507	-1.217	S**	S***
5	Bemetara	502.6±19.5	3.9	0	0.002	NS	NS
6	Bijapur	495.0±20.7	4.2	-0.485	-1.178	S**	S***
7	Bilaspur	520.5±24.0	4.6	-0.49	-1.378	S**	S***
8	Dantewada	496.2±20.2	4.1	-0.506	-1.203	S**	S***
9	Dhamtari	503.7±19.9	4	-0.142	-0.332	NS	NS
10	Durg	503.1±19.6	3.9	0	0.001	NS	NS
11	Gariaband	506.2±21.0	4.2	0.219	0.542	NS	NS
12	Janjgir-Champa	502.4±19.5	3.9	0.026	0.06	NS	NS
13	Jashpur	519.7±24.4	4.7	0.428	1.229	S*	S**
14	Kanker	493.2±20.6	4.2	0	0.011	NS	NS
15	Kabirdham	501.3±19.7	3.9	-0.504	-1.222	S**	S**
16	Kondagaon	496.2±20.5	4.1	-0.508	-1.222	S**	S***
17	Korba	501.6±20.4	4.1	-0.055	-0.132	NS	NS
18	Koriya	512.4±24.7	4.8	0.288	0.835	NS	NS
19	Mahasamund	503.8±19.5	3.9	0.022	0.053	NS	NS
20	Mungeli	495.4±23.6	4.8	-0.263	-0.727	NS	NS
21	Narayanpur	495.1±20.4	4.1	-0.51	-1.223	S**	S***
22	Raigarh	501.7±19.7	3.9	-0.074	-0.171	NS	NS
23	Raipur	502.7±19.7	3.9	0.014	0.033	NS	NS
24	Rajnandgaon	506.9±20.2	4	-0.026	-0.063	NS	NS
25	Sukma	495.9±20.2	4.1	-0.503	-1.19	S**	S***
26	Surajpur	509.3±22.3	4.4	0.212	0.556	NS	NS
27	Surguja	508.6±22.6	4.5	0.245	0.065	NS	NS
	Mean	503.35±20.95	4.2	-0.107	-0.270	NS	NS

Note: *** Significant at 1% level, ** Significant at 5% level, * Significant at 10% level,
** Significant at 1%, *Significant at 5% level (Linear regression), NS (Non-Significant)

3.2 Variations in kharif reference evapotranspiration

During *kharif* season, highest *kharif* ET_o was observed in Bilaspur (520.5±24.0 mm) district, while the lowest ET_o was recorded in Kanker (493.2±20.6 mm) district. The variability in *kharif* ET_o was found highest in two districts; Koriya (4.8%) and Mungeli (4.8%) while the lowest was found in eight districts; Balod (3.9%), Bemetara (3.9%), Durg (3.9%), Janjgir-Champa (3.9%), Kabirdham (3.9%), Mahasamund (3.9%), Raigarh (3.9%) and Raipur (3.9%). Average *kharif* ET_o for 27 districts was observed as 503.35±20.95 mm and variability during *kharif* season for the 27 districts for a period of 28 years were recorded as 4.2% (Table 2).

Bijapur and Jashpur showed significant increasing trend at 5% and 1% level of significance while 7 districts namely; Bastar, Bilaspur, Dantewada, Kanker, Kondagaon, Narayanpur and Sukma showed significant decreasing trend at 1% level. The analysis also indicated that *kharif* ET_o of Chhattisgarh decreased at the average rate of (-) 0.510 to (-) 0.490 while in Jashpur and Bijapur districts increased at the rate of (+) 0.428 to (+) 0.485 mm year^{-1}, respectively.

The remaining districts did not show any significant changes (Table 2).

3.3 Variations in rabi reference evapotranspiration

During *rabi* season, highest *rabi* ET_o was observed in Balodabazar (506.6±20.4mm) district while the lowest was recorded in Koriya (370.9±23.8mm) district. The variability in *rabi* ET_o was found highest in three districts; Balrampur (6.5%), Jashpur (6.5%) and Surguja (6.5%) and similar variability was observed in two districts; Surajpur (6.4%) and Koriya (6.4%) while the lowest was found in two districts; Janjgir-Champa (2.6%) and Korba (2.6%). Average *rabi* ET_o for a period of 28 years for 27 districts observed was 408.2±16.17 mm and the variability were found to be 4.1% (Table 3). Out of 27 districts, Balod, Balodabazar, Bemetara, Bilaspur, Dhamtari, Durg, Janjgir-Champa, Korba, Mahasamund, Mungeli, Raigarh, Rajnandgaon and Raipur i.e., a total of 13 districts showed significant decreasing trend at 1% level while Kanker indicated significant decreasing trend at 5% level of significance, respectively. During *rabi* season, ET_o values did not show any increase but decreased at the average rate of (-) 0.948 to (-) 0.368 mm year^{-1}, respectively. According to Mann Kendall test, Balod, Balodabazar, Bemetara, Bilaspur, Dhamtari, Durg, Janjgir-Champa, Korba, Mahasamund, Mungeli, Raigarh, Raipur and Rajnandgaon districts showed significant decreasing trend at 1% level of significance. However, Bastar, Dantewada, Kabirdham, Kanker and Sukma districts showed significant decreasing trend at 10% level of significance (Table 3).

3.4 Comparison between FAO-56 PM and FAO-24 Epan method for Raipur district

The comparison between FAO-56 PM and FAO-24 Epan method was done for Raipur district only due to the lack of

Epan data for all the 27 districts. Raipur district is taken so to understand the efficiency between the two different methods.FAO-56 PM considers the climatic parameters while FAO-24 Epan neglects climatic parameters rather it considers the evaporation measured through evaporimeter. FAO-56 and FAO-24 methods for ET_o estimation for Raipur district clearly showed difference of approx. 200 mm in annual ET_o. Here, FAO-24 Epan showed higher ET_o than that observed when estimated using FAO-56 PM method. The difference observed in the above two methods may be due to the fact that FAO-56 PM method considered the climatic parameters while FAO-24 Epan directly estimates ET_o considering only pan coefficient and pan evaporation. From the point of irrigation scheduling, FAO-56 PM method can be considered accurate as it being the sole standard method as well it considers the climatic parameters too but before irrigation scheduling it is better advised to consider both the methods for higher accuracy. The value obtained from pan evaporimeter is sometimes affected by the area of installation while on the other hand the climatic data gives more accurate results (Table 4).

Table 3: Average *rabi* ET_o in different districts of Chhattisgarh (1991-2019)

S.N.	Districts	Mean±SD (mm)	CV (%)	r	Rate of Change (mm/year)	Linear Regression	Mann Kendall
***Rabi* ETo**							
1	Balod	409.2±11.5	2.8	-0.662	-0.89	S**	S***
2	Balodabazar	506.6±20.4	4	-0.629	-0.772	S**	S***
3	Balrampur	371.6±24.3	6.5	0.327	0.933	NS	NS
4	Bastar	451.3±20.5	4.6	-0.35	-0.844	NS	S*
5	Bemetara	392.8±10.6	2.7	-0.624	-0.78	S**	S***
6	Bijapur	447.2±20.5	4.6	-0.294	-0.709	NS	NS
7	Bilaspur	394.8±16.2	4.1	-0.579	-1.1	S**	S***
8	Dantewada	448.3±20.5	4.6	-0.345	-0.829	NS	S*
9	Dhamtari	408.3±14.2	3.5	-0.709	-1.183	S**	S***
10	Durg	396.1±10.8	2.7	-0.622	-0.787	S**	S***
11	Gariaband	406.5±15.2	3.7	0.126	0.226	NS	NS
12	Janjgir-Champa	387.6±10.2	2.6	-0.633	-0.759	S**	S***
13	Jashpur	381.9±24.7	6.5	0.254	0.736	NS	NS
14	Kanker	420.1±19.2	4.6	-0.362	-0.45	NS	S*
15	Kabirdham	385.4±10.6	2.7	-0.368	-0.831	S*	S*
16	Kondagaon	445.4±20.5	4.6	-0.335	-0.807	NS	NS
17	Korba	384.3±9.9	2.6	-0.514	-0.599	S**	S***
18	Koriya	370.9±23.8	6.4	0.225	0.629	NS	NS
19	Mahasamund	396.6±10.5	2.7	-0.629	-0.776	S**	S***
20	Mungeli	377.3±13.7	3.6	-0.631	-1.015	S**	S***
21	Narayanpur	441.0±20.3	4.6	-0.328	-0.782	NS	NS
22	Raigarh	391.7±10.6	2.7	-0.509	-0.632	S**	S***
23	Raipur	393.5±11.0	2.8	-0.645	-0.833	S**	S***
24	Rajnandgaon	408.3±11.9	2.9	-0.676	-0.948	S**	S***
25	Sukma	455.2±20.8	4.6	-0.365	-0.889	NS	S*
26	Surajpur	371.1±23.8	6.4	0.297	0.832	NS	NS
27	Surguja	378.8±24.8	6.5	0.324	0.942	NS	NS
	Mean	408.2±16.17	4.1	-0.343	-0.478	S	S

Note: *** Significant at 1% level, ** Significant at 5% level, * Significant at 10% level,
** Significant at 1%, *Significant at 5% level (Linear regression), NS (Non-Significant).

Table 4: Comparison between FAO-56 PM and FAO-24 Epan method.

RAIPUR	Annual ET_o		*Kharif* ET_o		*Rabi* ET_o	
Method	**Mean±SD (mm)**	**CV (%)**	**Mean±SD (mm)**	**CV (%)**	**Mean±SD (mm)**	**CV (%)**
FAO-56 ET_o	1161.2±25.6	2.2	502.7±19.7	3.9	393.5±11.0	2.8
FAO-24 Epan	1378.5±94.3	6.8	502.2±43.0	8.6	506.3±36.8	7.3

4. Conclusion

The study concluded that only few districts can meet the water demand of the crop. As more than half of the state showed larger variability in ET_o which warns about the critical situation of water availability in the state. The study further suggests a proper and immediate management of water for future water availability for agricultural purposes.

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