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Research Article

DISTRIBUTION OF REFERENCE EVAPOTRANSPIRATION IN MADHYA PRADESH, INDIA

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ABSTRACT
Various meteorological parameters like temperature, wind speed, radiation, humidity etc. have considerable impact on the water resources. Variation in reference evapotranspiration (ET_0) can have impact on the crop of the area. Thus it is extremely necessary to understand the ET of the region before planning and management. Landuse type, soil type etc also have strong effect on ET of a river basin. In the present study FAO56 Penman-Monteith method has been used for estimating ET_0 for entire Madhya Pradesh from 1971 to 2000. The results indicate higher ET_0 during the month of May with highest being found in Indore (11.77 mm day^{-1}). The months from April to June have considerably high ET_0 while other months have low ET_0. Minimum rate of evapotranspiration is observed in Jabalpur during the month of December. Among the 13 stations, Pachmarhi has the lowest ET_0 even in May (6.07 mm day^{-1}). Thus wide variation in ET_0 distribution is observed in MP which is due to the effect of other climate parameters.

Key Words: *Meteorological Parameters, Reference Evapotranspiration (Et$_0$), Fao56 Penman-Monteith Method, Madhya Pradesh, Climate*

INTRODUCTION
Evaporation comprises an important part of the thermal balance occurring on the earth surface. It is also a part of water budget and the surface heat and water conditions are the determinant of formation of the surface ecological environment. Thus the study of evaporative capacity of the land is always one of the major problems in hydrology and geosciences (Ping *et al.*, 2009). The rate of reference evapotranspiration is generally calculated from a reference surface where it is denoted as ET_0 but adequate amount of water is required there. Reference surface for the purpose is a hypothetical grass which is a reference crop with specific characteristics. With the help of ET_0, many research have been done like aridity/humidity conditions (Wu *et al.*, 2006), ecosystem models (Fisher *et al.*, 2005), estimation of rainfall-runoff and water use in agriculture (Allen, 2000; Hunsaker *et al.*, 2002). The evapotranspiration of reference crop is found on the basis of the meteorological data and the calculation is given by FAO depending on the meteorological parameters and meteorological data. Thus it is difficult to apply the method in the areas where there is lack of meteorological observation data, and recommended the use of evaporating pan observation data for determining the reference crop evapotranspiration by FAO (Allen *et al.*, 1998). Various methods for empirical estimation of ET_0 requires proper and accurate measurements of different parameters like temperature, humidity, wind speed, sunshine, solar radiation etc. But measurement of all these parameters in a place is quite few particularly in any developing country. There are also local changes in ET_0 on the basis of distance from the weather station (Hubbard, 1994; Pielke *et al.*, 2000) and proper integration of different climatic parameters are required which also affect the accuracy of ET_0 (Meek and Hatfield, 1994; Allen, 1996). Various methods for calculations are there among which pan evaporimeter and some ET models use only temperature and thus are less complex (Magliulo *et al.*, 2003). The Hargreaves equation also needs only minimum and maximum temperature (Hargreaves and Samani, 1985) and extraterrestrial radiation (Droogers and Allen, 2002). Thus ET_0 can be measured by various models and methods by different weather parameters (Thornthwaite, 1948; Penman, 1948;

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Priestley and Taylor, 1972; Hargreaves, 1994; Hargreaves and Allen, 2003). Allen *et al.*, (1998) developed a model for ET_0 which was published by the Food and Agriculture Organization of the United Nations as Penman–Monteith (FAO56-PM) by using a hypothetic reference crop which is approved for the arid and humid climatic conditions.

Present study involves the ET_0 computation and analysis of variation for whole Madhya Pradesh with parameters like minimum and maximum temperature, humidity, wind speed, sunshine and solar radiation for 30 years (1971 to 2000).

Study Area

The study area lies in Madhya Pradesh which extends from 21°17´ to 26°36´ N latitude and from 74°02´ to 82°26´E longitude with an area of 443,000 km^2. Thirteen stations taken for the study are Khandwa, Nimach, Guna, Satna, Nowgong, Bhopal-Bairagarh, Hoshngabad, Pachmarhi, Sagar, Seoni, Jabalpur, and Umaria. The state of Madhya Pradesh has subtropical type of climate. It has a dry and hot summer and a cool winter. The average rainfall is nearly 1025 mm which decreases from east to west (Figure1).

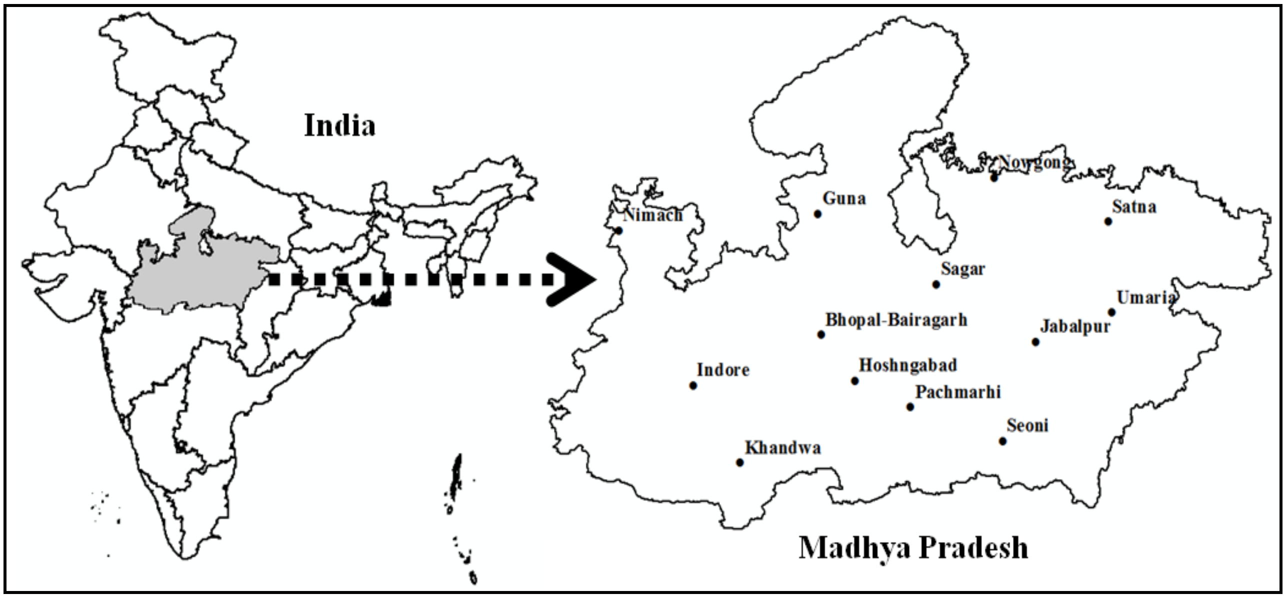


Figure 1: Study area

1. Data and Methodology

1.1 Estimation of ET_0 with Penman-Monteith

For calculating the ET_0, some climatic station datasets were used in the study. Different climatic variables like minimum and maximum air temperature, relative humidity, wind speed and sunshine duration of 30 years (1971 to 2000) were considered. Average monthly datasets have been used for estimating the average monthly ET_0 taken from the Water Development and Management Unit and the Climate Change and Bio-energy Unit of FAO, 2006.

The Penman-Monteith model was formulated on the basis of hypothetical green grass reference surface in which case the height of the grass is presumed to be 0.12m with a surface resistance of 70s m^{-1} and with an albedo of 0.23 (Allen *et al.*, 1998). It has been approved by Food and Agriculture Organization (FAO-56). Penman-Monteith equations are given below in sequence:

$$ET_0 = \frac{0.408 \times \Delta \times (R_n - G) + \gamma \times (\frac{900}{T + 273}) \times u_2 (e_s - e_a)}{\Delta + \gamma (1 + 0.34 u_2)} \quad (1)$$

Where,

ET_0 = reference evapotranspiration (mmd^{-1});

R_n = net radiation at the crop surface (MJm^{-2}d^{-1});

G = soil heat flux density (MJm^{-2}d^{-1});

γ = psychometric constant (KPa°C^{-1});

T = the mean of the monthly maximum and minimum air temperatures (°C);

u_2 = wind speed at 2 m height (ms^{-1});

e_s = saturated vapour pressure (KPa);

e_a = actual vapour pressure (KPa);

Δ = slope vapour pressure curve (KPa°C^{-1})

1.1.1 Slope of saturation vapour pressure (Δ)

The slope of the relation between saturation vapour pressure and temperature D is required for calculating reference evapotranspiration. At a given temperature, the slope is given by:

$$\Delta = \frac{4098\left[0.6108\exp\left(\frac{17.27T}{T+237.3}\right)\right]}{(T+237.3)^2} \tag{2}$$

1.1.2 Atmospheric Parameters

$$P = 101.3\left(\frac{293-0.0065z}{293}\right)^{5.26} \tag{3}$$

Where,

P = atmospheric pressure (KPa),

Z = elevation above sea level (m)

$$\gamma = \frac{c_p P}{\varepsilon\lambda} = 0.664742x10^{-3} P \tag{4}$$

Where,

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

λ = latent heat of vaporization, 2.45 (MJ kg^{-1})

ε = ratio molecular weight of water vapour/ day air = 0.622

1.1.3 Air Humidity

$$e°(T) = 0.6108\exp\left(\frac{17.27T}{T+237.3}\right) \tag{5}$$

Where,

$e°(T)$ Stands for the saturation vapour pressure at the air temperature T [kPa]

1.1.4 Actual vapour pressure

$$e_a = \frac{e^o(T_{\min})\frac{RH_{\max}}{100} + e^o(T_{\max})\frac{RH_{\min}}{100}}{2} \quad (6)$$

Where,
$e^o(T_{\min})$ = saturation vapour pressure at daily minimum temperature [kPa],
$e^o(T_{\max})$ = saturation vapour pressure at daily maximum temperature [kPa],
$RH_{\max}$ = maximum relative humidity [%],
$RH_{\min}$ = minimum relative humidity [%].

1.1.5 Net radiation (Rn)

$$R_n = R_{ns} - R_{nl} \quad (7)$$

Where,
R_{ns} = incoming net shortwave radiation and R_{nl} is the outgoing net longwave radiation.

$$R_{ns} = (1-\alpha)R_s \quad (8)$$

α = albedo or canopy reflection coefficient for the reference crop [dimensionless],
R_s = the incoming solar radiation ($MJm^{-2}d^{-1}$); in case net solar radiation is required to be calculated while computing ET_0, fixed value of 0.23 is considered for the albedo.

$$R_s = \left(a_s + b_s\frac{n}{N}\right)R_a \quad (9)$$

Where,
a_s, b_s = the fraction of extraterrestrial radiation reaching the earth on clear days (n = N),
R_a = extraterrestrial radiation ($MJm^{-2}d^{-1}$);
$\frac{n}{N}$ = relative sunshine duration,

$$R_a = \frac{24(60)}{\pi} G_{sc} d_r \left[\omega_s \sin(\phi)\sin(\delta) + \cos(\delta)\sin\omega_s)\right] \quad (10)$$

Where,
G_{sc} = solar constant = 0.0820 MJ m^{-2} min^{-1},
d_r = inverse relative distance of Earth and Sun,
ω_s = sunset hour angle (rad),
ϕ = latitude (rad),
δ = solar declination (rad);

$$R_{nl} = \sigma\left[\frac{(T_{\max})^4 + (T_{\min})^4}{2}\right]\left(0.34 - 0.14\sqrt{e_a}\right)\left(1.35\frac{R_s}{R_{so}} - 0.35\right) \quad (11)$$

Where,
σ = Stefan-Boltzmann constant [4.903 10^{-9} MJ K^{-4} m^{-2} day^{-1}],
$T_{\max}$ = maximum absolute temperature [K = °C+ 273.16],
$T_{\min}$ = minimum absolute temperature [K = °C+ 273.16],
$\frac{R_s}{R_{so}}$ = relative shortwave radiation (limited to ≤ 1.0),

1.1.6 Wind speed

For the adjustment of the wind speed data obtained from instrument which is placed at elevations other than the standard height of 2 m, following calculation is done:

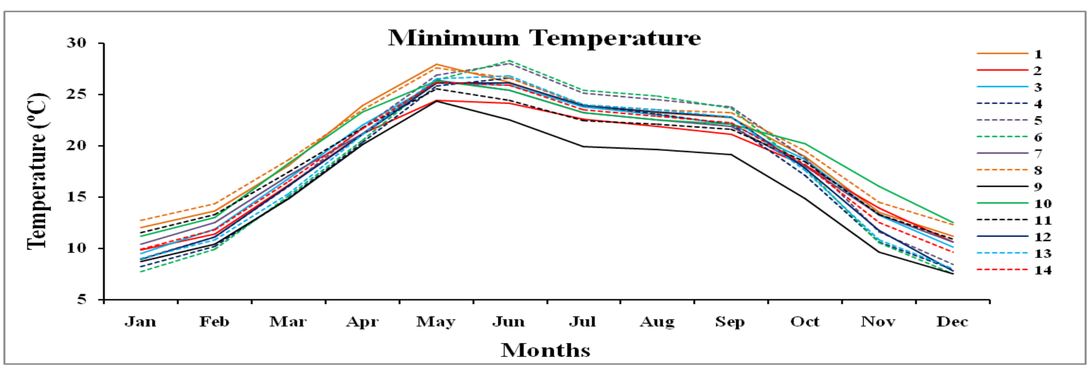
$$u_2 = u_z \frac{4.87}{\ln(67.8z - 5.42)} \quad (12)$$

Where,
u_z = measured wind speed at z m above ground surface [m s^{-1}],
z = height of measurement above ground surface [m].

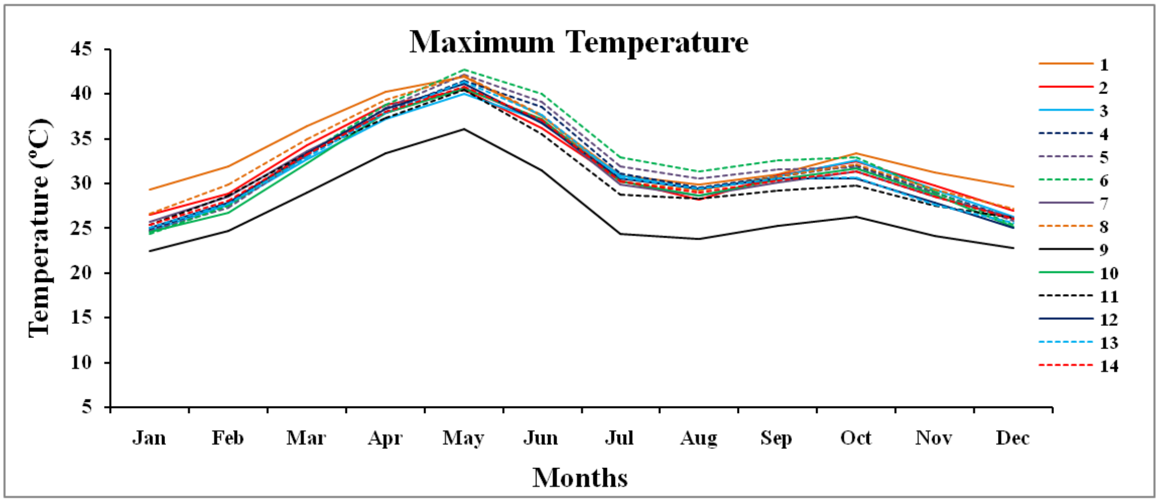
RESULTS

Different climatic variables of minimum and maximum temperature, humidity, wind speed, sunshine duration and radiation have been shown for 30 years from 1971 to 2000. The minimum temperature is highest in May-June up to September after which it started to decrease. The minimum temperature varies from 28.3°C in June (Nowgong) to 7.5°C in December (Nowgong and Pachmarhi). The average monthly maximum temperature is highest in the month of May with more than 40°C and little down from June to August and again a little peak in September up to 35°C and lowest in January (22.4°C) in Pachmarhi. Khandwa is showing highest maximum temperature. The relative humidity is highest or maximum from June to September of nearly 95% in June, with Jabalpur having the highest while lowest humidity is found from March to April with Indore having the lowest (13.3% in April). Wind speed is maximum from April to August. It varies from 50 km/day in November-December to 455km/day during June-July with Indore having distinctively the highest wind speed (458 km/day). The maximum and minimum sunshine hours varies from 10.2hr/day in February when sky remains very clear to less than 5hr/day during the monsoon period (minimum of 1.34 hr/day in July) of overcast sky respectively. The solar radiation is highest in May of around 25 $MJm^{-2}d^{-1}$ in Nimach to around 12 $MJm^{-2}d^{-1}$ in Umaria during July-August (Figure 2 a-f).

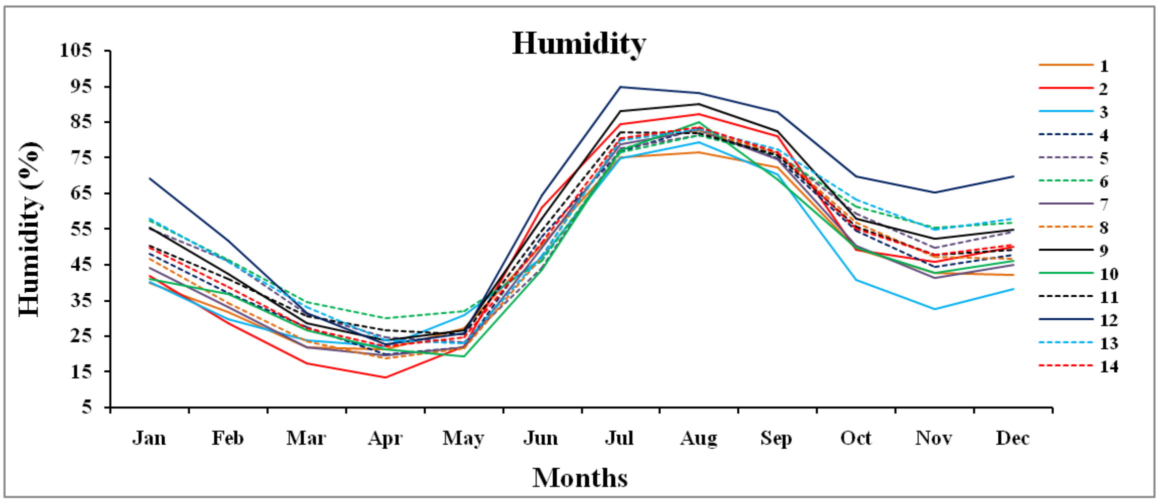
(a)



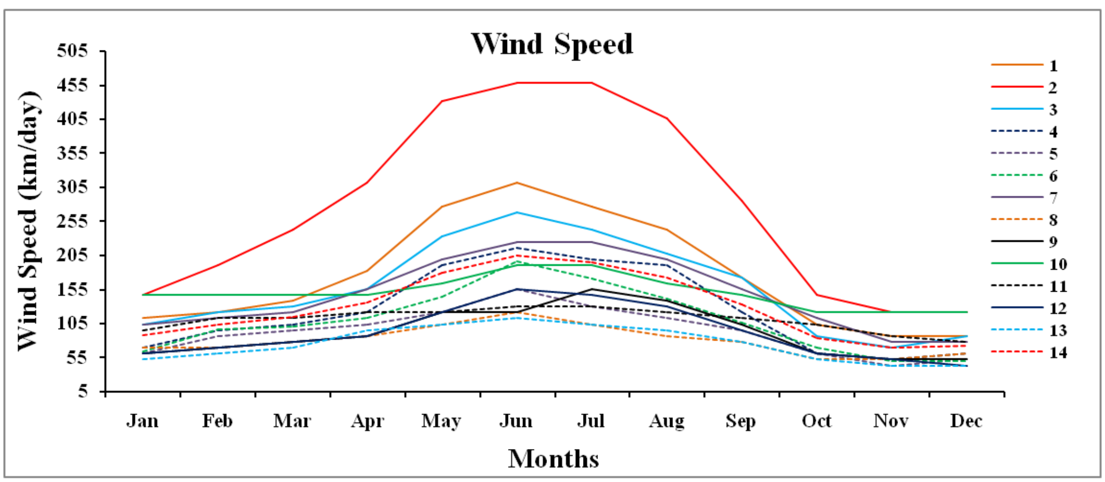
(b)


Maximum Temperature
Temperature (°C)
Months
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
45 40 35 30 25 20 15 10 5
1 2 3 4 5 6 7 8 9 10 11 12 13 14

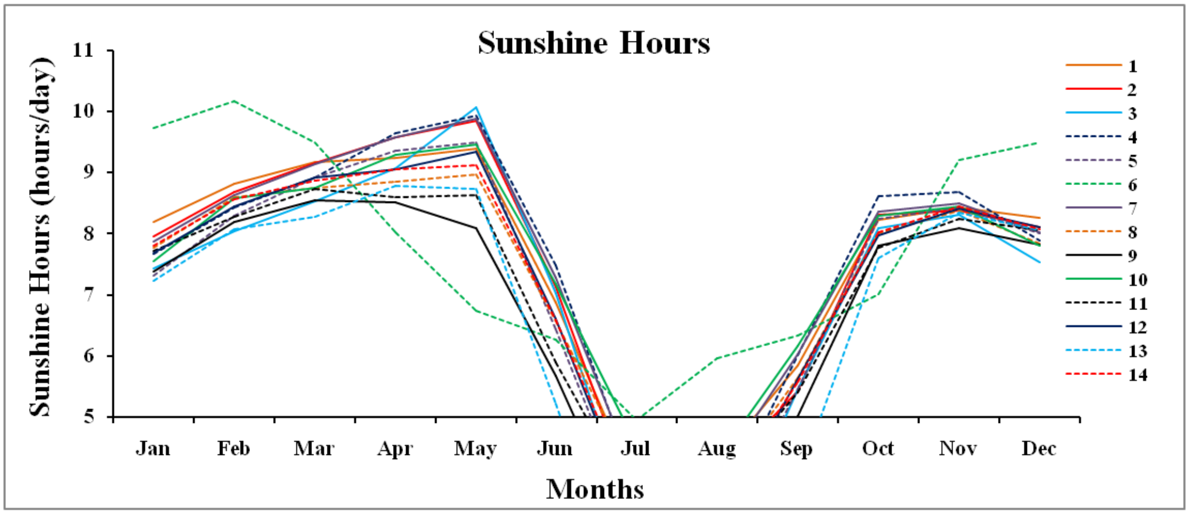
(c)


Humidity
Humidity (%)
Months
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
105 95 85 75 65 55 45 35 25 15 5
1 2 3 4 5 6 7 8 9 10 11 12 13 14

(d)


Wind Speed
Wind Speed (km/day)
Months
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
505 455 405 355 305 255 205 155 105 55 5
1 2 3 4 5 6 7 8 9 10 11 12 13 14

(e)



(f)

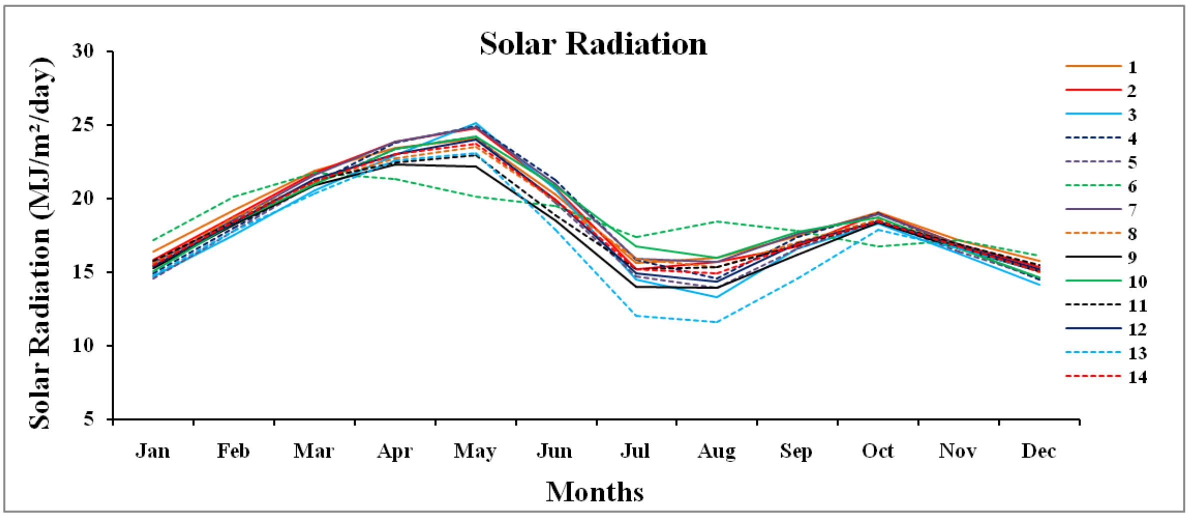


Figure 2: (a-f): Average monthly climatic variables from 1971 to 2000 Khandwa=1, Indore=2, Nimach=3, Guna=4, Satna=5, Nowgong=6, Bhopal-Bairagarh=7, Hoshngabad=8, Pachmarhi=9, Sagar=10, Seoni=11, Jabalpur=12, Umaria=13 and Mean of all stations=14.

The mean monthly ET_0 was calculated with help of FAO 56 Penman-Monteith method with 13 stations of entire Madhya Pradesh to show the variation of ET_0 throughout the state which is an extremely important variable to be considered for agriculture purpose. The result indicates that ET is highest in the month of May (11.77 mm day^{-1}) in Indore to lowest in the month of December (2.2 mm day^{-1}) in Jabalpur. May is the month of highest rate of ET for all the 13 stations which in descending order are 11.77 mm day^{-1} in Indore, 9.64 mm day^{-1} in Khandwa, 8.54 mm day^{-1} in Nimach, 8.32 mm day^{-1} in Bhopal-Bairagarh, 8.2 mm day^{-1} in Guna, 7.62 mm day^{-1} in Sagar, 6.87 mm day^{-1} in Satna, 6.76 mm day^{-1} in Jabalpur, 6.67 mm day^{-1} in Nowgong, 6.56 mm day^{-1} in Seoni, 6.46 mm day^{-1} in Hoshngabad, 6.32 mm day^{-1} in Umaria and 6.07 mm day^{-1} in Pachmarhi. The mean of all 13 stations for the May month is 7.68 mm day^{-1}. The rate of evapotranspiration is observed to be highest in the months of April to June in Madhya Pradesh. Thus water requirement for crops are more during this period (Table1).

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Table1: Average monthly ET_0 (mm day^{-1})

Sl no.	Station name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	**Khandwa**	3.5	4.36	5.73	7.48	9.64	7.68	4.46	4.13	4.13	4.25	4.44	3.56
2	**Indore**	3.57	4.95	7.17	9.68	11.77	7.65	4.01	3.23	4.04	4.76	3.79	3.17
3	**Nimach**	2.87	3.8	5.04	6.57	8.54	7.43	4.18	3.46	4.15	4.08	3.09	2.74
4	**Guna**	2.42	3.41	4.62	6.04	8.2	7.02	4.23	3.46	3.95	3.76	2.81	2.34
5	**Satna**	2.28	3.2	4.48	5.73	6.87	6.5	4.66	3.39	3.2	3.29	2.71	2.27
6	**Nowgong**	2.41	3.44	4.6	5.61	6.67	6.65	4.52	4.2	4.07	3.64	2.85	2.25
7	**Bhopal-Bairagarh**	2.98	3.84	5.13	6.74	8.32	5.93	3.85	3.61	4.06	4.39	3.23	2.69
8	**Hoshngabd**	2.7	3.38	4.42	5.42	6.46	5.87	3.76	3.38	3.7	3.7	2.96	2.55
9	**Pachmarhi**	2.35	3.05	4.04	4.97	6.07	4.87	2.97	2.74	3.22	3.39	2.67	2.24
10	**Sagar**	3.35	4.03	5.29	6.55	7.62	6.8	4.22	3.5	4.16	4.47	3.76	3.05
11	**Seoni**	2.9	3.81	4.9	5.88	6.56	5.39	3.54	3.4	3.69	4.01	3.26	2.74
12	**Jabalpur**	2.34	3.11	4.3	5.35	6.76	5.67	3.23	3.03	3.57	3.63	2.84	2.2
13	**Umaria**	2.27	2.99	4.01	5.43	6.32	5.42	3.15	2.79	3.32	3.52	2.71	2.21
14	**Mean**	2.76	3.64	4.90	6.27	7.68	6.38	3.91	3.41	3.79	3.91	3.16	2.62

Conclusion

The study involves the computation and analysis of one of the most important climatic variable, i.e. evapotranspiration for entire Madhya Pradesh. This study shows the monthly ET variation which is very useful for analysis of various irrigation plans, crop water requirements etc. The disparity of ET in different parts of the state needs different quantity of water supply according to the demand of the area. The region of Indore requires greater supply of water to the nearby agricultural fields during May as ET is highest there. While Pachmarhi being the hilly area, have lowest ET and needs less water supply to the crops during this month. FAO-56 Penman-Monteith method is a globally accepted and extremely important empirical model to calculate ET_0 which is also an important climatic parameter. This result can give an overall picture of ET_0 of the state of Madhya Pradesh for further water resource and management plans.

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