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Spatial variability of annual and monthly Potential Evapotranspiration (PET) over India

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सार – इस अध्ययन में पेनमेन मॉनटियथ समीकरण द्वारा संभाव्य वाष्पन वाष्पोत्सर्जन (पी. ई. टी.) का आकलन करने के लिए वर्ष 1971–2005 की अवधि में भारत के सुवितरित 140 स्थानों के लिए मौसम विज्ञान की आँकड़ों का उपयोग किया गया है।

जलगाँव में वार्षिक पी. ई. टी. का अधिकतम औसत 2342 मि. मी. था और गिंज में न्यूनतम 921 मि. मी. था। भारत के सभी स्टेशनों में माध्य वार्षिक पी. ई. टी. का औसत शीत ऋतु में 12 प्रतिशत, मानसून पूर्व ऋतु में 34 प्रतिशत, मानसून ऋतु में 35 प्रतिशत और मानसूनोत्तर ऋतु मे 19 प्रतिशत के योगदान सहित 1547 मि. मी. रहा। 1400 मि. मी. से कम वार्षिक पी. ई. टी. के न्यूनतम केन्द्र मुख्यतः 30 डिग्री उत्तरी अक्षांश के ऊपर स्थित है। 1800 मि. मी. से अधिक वार्षिक पी. ई. टी. के उच्च केन्द्र रेगिस्तानी इलाकों और मध्य भारत में स्थित है यहाँ पर अधिकाँश महीनों में पहाड़ी स्थानों में मान सबसे कम होते है। 200 मि. मी. से अधिक के उच्चतर मासिक पी. ई. टी. मान सामान्यतः पश्चिमी और मध्य भारत के मानसून पूर्व ऋतु और मानसून ऋतु में देखे गए है। जैसे जैसे मानसून आगे बढ़ता है, पश्चिमी भारत में पी. ई. टी. के मान धीरे धीरे कम होते है। शीत और मानसूनोत्तर ऋतु में न्यूनतम पी. ई. टी. मान देखे गए हैं। 82.1 मि. मी. के न्यूनतम माध्य मासिक पी. ई. टी. दिसंबर माह में और 199.6 मि. मी. के उच्चतम माध्य मासिक पी. ई. टी. मई माह में देखे गए हैं (2° × 2°) अक्षांश/देशांतर ग्रेडों पर माध्य वार्षिक और मासिक पी. ई. टी. विकसित किए गए और इस शोध पत्र में प्रस्तुत किए गए है।

ABSTRACT. In this study, meteorological data for well distributed 140 locations in India for the period (1971-2005) have been utilized for estimation of potential evapotranspiration (PET) by Penman-Monteith equation.

The highest average annual PET of 2342 mm was at Jalgaon and lowest of 921 mm at Ging. Range of average annual PET is 1421 mm. The mean annual PET averaged for all stations over India is 1547 mm with 12% contribution in winter, 34% in pre-monsoon, 35% in monsoon and 19% in post-monsoon seasons. The lowest centers with annual PET less than 1400 mm are mainly located above 30 degree N latitude. The high centers with annual PET more than 1800 mm are located in desert area and central India, with lowest values at hill stations during most of the months. The higher monthly PET values in excess of 200 mm are normally observed during pre-monsoon and monsoon over western and Central India. As the monsoon advances, the PET values over western India decrease gradually. The lower PET values are observed during winter and post-monsoon season. The lowest mean monthly PET of 82.1 mm is in December and highest mean monthly PET of 199.6 mm is in May. Mean annual and monthly PET over (2° × 2°) latitude/longitude grids have been developed and presented.

Key words – Potential evapotranspiration, Monthly PET, Annual PET.

1. Introduction

The values of PET closely resembles with evapotranspiration rates from a reference surface, *viz*., "A hypothetical reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 s m^{-1} and an albedo of 0.23″. A large number of more or less empirical methods have been developed over the last 100 years worldwide to estimate evapotranspiration from different climatic variables. Evapotranspiration data are frequently

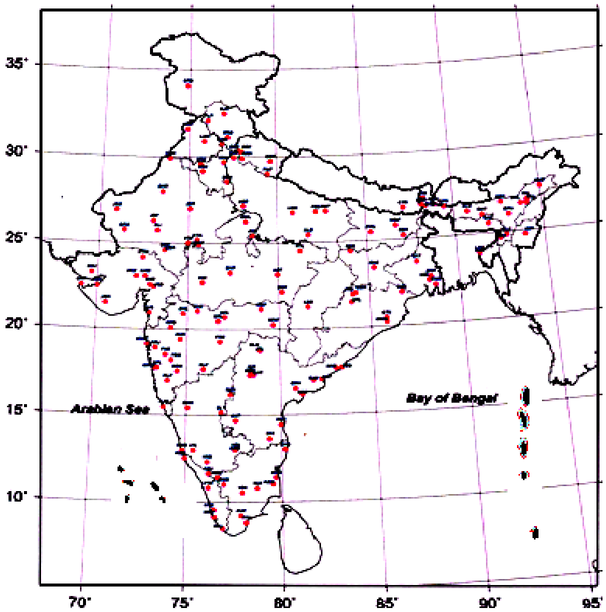

Fig.1. Locator map of 140 locations selected for the study

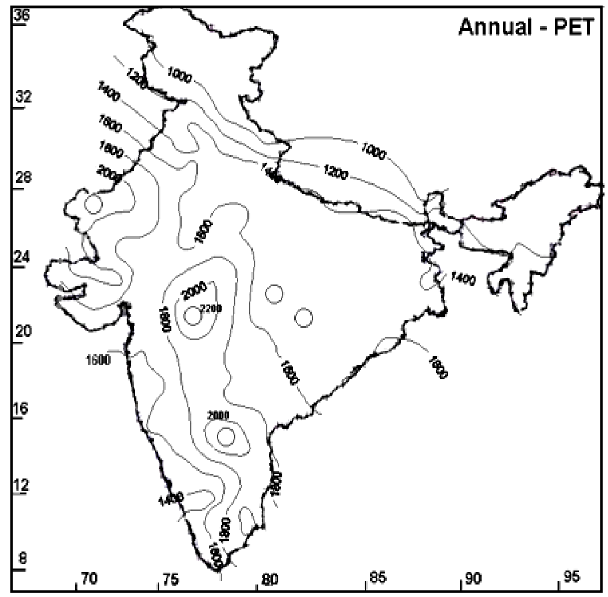

Fig. 2. Spatial variability of annual potential evapotranspiration (PET) over India

needed at short notice for project planning or irrigation scheduling design. To accommodate users with different data availability, four different methods are used to calculate PET; namely, the Blaney-Criddle, radiation, modified Penman and Pan evaporation methods. FAO (1998) has recommended Penman-Monteith equation as a suitable method for computing PET. This method has been found to offer the best possible results with minimum possible error (FAO, 1998). PET plays a major role in the redistribution of energy between the soil plant continuum and the atmosphere and is an essential part of the hydrological cycle.

Evapotranspiration is widely used in guiding agricultural irrigation schedule through the quantitative estimation of the crop water requirement for achieving the aims of water saving and increasing agricultural yield. This information is also essential for understanding land surface processes in climatology (Chen *et al.*, 2005). Research studies relating to potential evapotranspiration (PET), its temporal variability, estimation through remote sensing data and various applications to agriculture as well as hydrology have been reported (Adhikari *et al.*, 2004; Arora, 2002; Debnath, 1996; Hulme *et al.*, 1992 ; Patil and Puttanna, 2009; Patil, 2010a & 2010b; Jat, *et al.*, 2004; Kingra *et al.*, 2004; Mehta *et al.*, 2006; Pascua, 2000; Samui *et al.* 2008; Singh *et al.*, 2003; Varshneya and Pillai , 2004; Verma *et al.* 2004; Verma *et al.* 2008; WMO, 1997; Xueqin Zhang *et al.* 2009). In this paper, the spatial variability of annual and monthly PET (January through December) over India are discussed.

2. Data and methodology

Meteorological data for well distributed 140 locations in India (Fig. 1) obtained from National Data Centre, Pune on maximum and minimum temperature, morning and afternoon relative humidity, wind speed and bright sunshine hours for the period (1971-2005) have been utilized for estimation of monthly potential evapotranspiration (PET) by Penman-Monteith equation (FAO, 1998) given below;

$$\mathrm{ET}_0 = \frac{0.408\Delta(R_n - G) + \frac{900}{T+273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

where,

$\mathrm{ET_o}$ - Potential/reference evapotranspiration (mm day^{-1}),

R_n - Net radiation at the crop surface (MJm^{-2}day^{-1}),

G - Soil heat flux density (MJ m^{-2} day^{-1}),

T - Mean daily air temperature at 2 m height (°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),

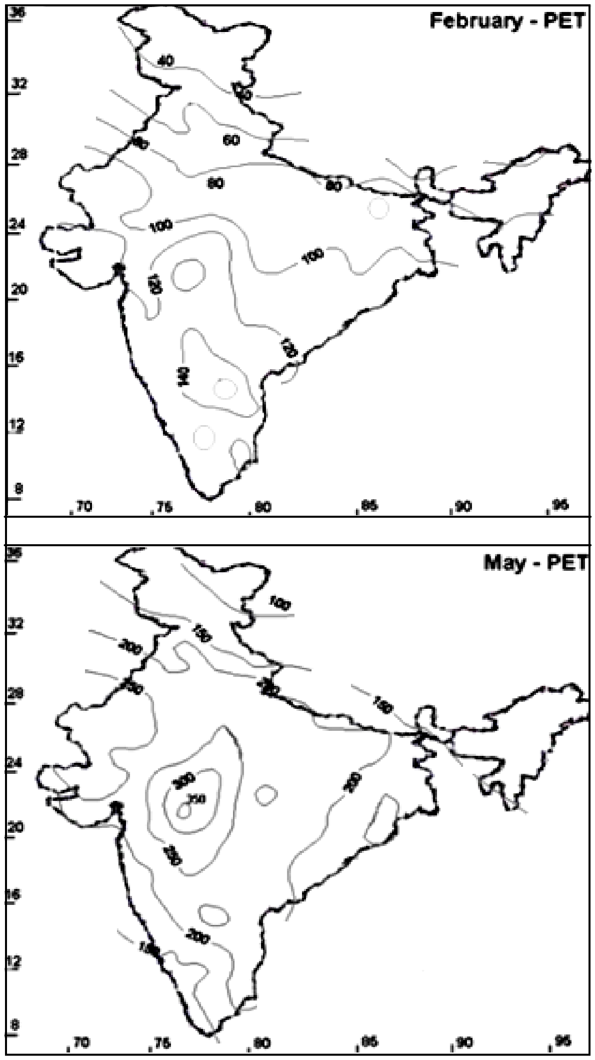

Fig. 3(a). Spatial variability of potential evapotranspiration (PET) in February and May over India

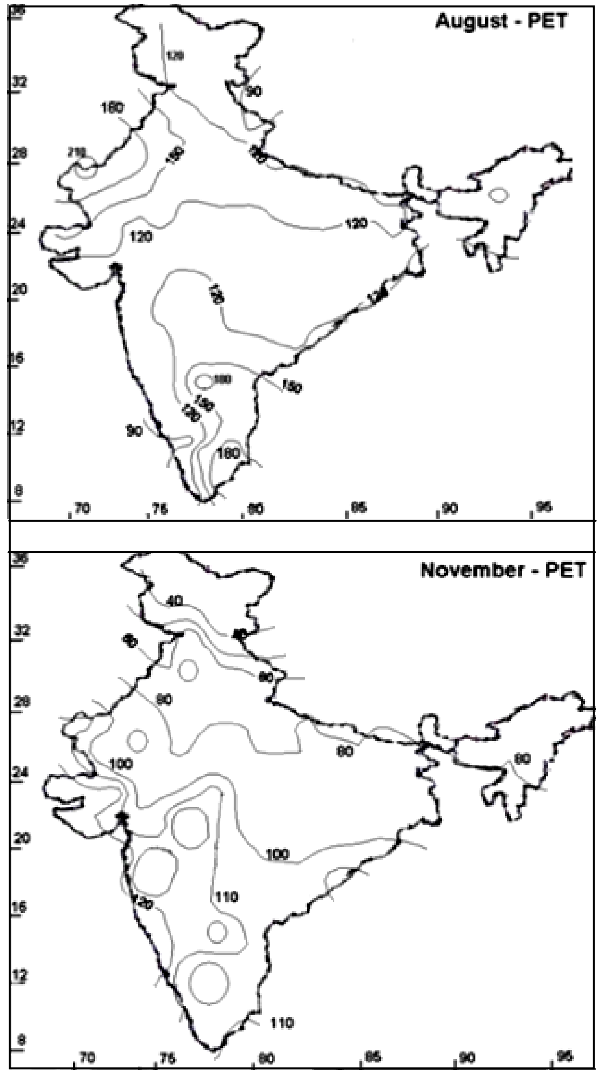

Fig. 3(b). Spatial variability of potential evapotranspiration (PET) in August and November over India

Δ - Slope of saturated vapour pressure in relation air temperature curve (kPa °C^{-1}),

γ - Psychrometric constant (0.0674 kPa °C^{-1})

The net radiation from bright sunshine hours is calculated as follows;

$$Rn = Rsw - Rlw$$

$$Rsw = 0.77 * Rs$$

$$Rlw = \{0.00\ 00\ 00\ 00\ 4903 * [(Tx + Tn)/2]\} * [0.34 - (0.14 * \sqrt{ea})] * [(1.35 * Rs / 0.75 * Ra) - 0.35]$$

$$Rs = (0.25 + 0.5 * BSSH\_a / BSSH\_N)$$

where,

*T*x	-	Maximum temperature
*T*n	-	Minimum temperature
Rsw	-	Short wave radiation
Rlw	-	Long wave radiation
Rs	-	Solar radiation
Ra	-	Extra terrestrial radiation
BSSH_a	-	Actual sunshine hours
BSSH_N	-	Maximum possible sunshine hours

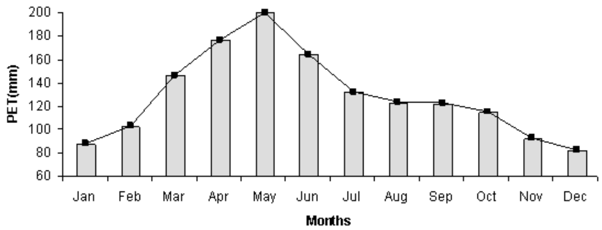

Fig. 4. Variation of mean monthly PET (mm) in different months over India

The spatial variability of annual and monthly PET have been worked out. Besides, mean annual and monthly PET over (2° × 2°) latitude/longitude grids have been developed and presented. Development of gridded data requires understanding of spatial correlation structure of data, interpolation techniques to fill the missing data and angular distance weighting techniques etc. The technique of developing the gridded data and suitable mathematical algorithms is described in (www.interscience.wiley.com), Srivastava *et al*. (2009).

3. Results and discussion

3.1. *Annual potential evapotranspiration (PET)*

The spatial distribution of long-term average annual potential evapotranspiration (PET) over India is given in Fig. 2. The highest average annual PET of 2342.0 mm is noticed at Jalgaon and the lowest of 921.0 mm at Ging. The range of average annual PET is 1421.0 mm. The mean annual PET averaged for all stations over India is 1546.9 mm with 12% in winter, 34% in pre-monsoon, 35% in monsoon, and 19% in post-monsoon seasons. The coefficient of variation (C.V.) is 19.4%.

The lowest centres with annual PET less than 1400 mm are mainly located north of 30 degree latitude. In northern parts of India it is due to latitudinal position and lower temperatures in winter, whereas in north-eastern parts of India, it is due to cloudiness and humid climate. The centres with high annual PET more than 1800 mm are located in desert area and central India attributed to high temperatures, strong wind and dry climate. In the arid and semi-arid regions of central and northwest India, average bright sunshine duration of more than 8 hours a day is observed during all-sky conditions. The lowest values are found in north-eastern parts of India due to clouding associated with and the decrease in the length of the day with increasing latitude. The mean annual PET in different regions of India are 1830.8 mm (north-west), 1762.3 mm (south), 1728.0 mm (central), 1493.9 mm (east), 1169.1 mm (north) and 1099.8 mm (north-east). The highest range of 777.8 mm is observed in south India and the lowest range of 345.2 mm in north-eastern region.

3.2. *Monthly potential evapotranspiration (PET)*

The spatial distribution of long-term average monthly potential evapotranspiration (PET) over India for four representative months (February, May, August and November) is given in Figs. 3(a&b). In Winter Season, lowest monthly PET values occur in January at Srinagar (22.9) and highest in February at Anantapur (169.7). In Pre-monsoon, lowest monthly PET values occur in March at Srinagar (58.5) and highest in May at Jalgaon (374.2). In Monsoon, lowest monthly PET areas are shifted in July to Ootacamund (71.7) and highest values are found in June at Jaisalmer (297.6).In Post-monsoon, lowest monthly PET values are located in December around Srinagar and highest values occur in October at Jalgaon (165.4). In general lowest values of PET are observed at hill stations during most of the months. The higher monthly PET values in excess of 200 mm are normally observed during Pre-monsoon and Monsoon over western and Central India. As the monsoon advances, the monthly PET values over western India decrease gradually. The lower PET values are observed during winter and post-monsoon season.

Averaged across all the stations, the variation in long-term mean monthly PET is given in Fig. 4. The statistics of monthly and annual variability of potential evapotranspiration (PET) over India is given in Table 1. The mean monthly PET values ranged between 82.1 and 199.6 mm in different months over India. The range of variation in mean monthly PET from December to May is rapid due to change of season from winter to summer. Mean monthly PET value again starts declining with the progress of monsoon. The range of variation in mean monthly PET is little 132.5 mm in July to 115.4 mm in Sept, under the influence of monsoon season. The mean monthly PET value gradually decrease thereafter when it reaches the lowest mean monthly PET of 82.1 mm in December due to change of season to winter. The coefficient of variation (C.V), has been the highest (34.0%) in January and the lowest (16.8%) in October.

3.3. *Annual PET over (2° × 2°) Lat./Long. grids*

The mean annual PET over (2° × 2°) latitude/longitude grids over India are given in Table 2. Maximum range of 1196.0 mm (highest = 2277.1 and lowest = 1081.1) of mean annual PET are observed along the latitude grids (28-26) degrees. Similarly, maximum range of 1373.7 mm (highest = 2183.0 and lowest = 809.3) of mean annual grids PET are observed along the longitude grids (76-78) degrees.

TABLE 1

Statistics of monthly and annual variability of potential evapotranspiration (PET) over India (values in mm)

Months	Highest	Lowest	Range	Mean	C.V.
Jan	149.7	22.9	126.8	88.0	34.0
Feb	169.7	32.6	137.1	103.0	28.3
Mar	237.4	58.5	178.9	146.6	22.4
Apr	306.0	92.2	213.8	176.4	21.7
May	374.2	102.4	271.8	199.6	26.2
June	297.6	78.4	219.2	164.3	27.3
July	242.3	71.7	170.6	132.5	23.8
Aug	220.1	74.7	145.4	123.8	21.8
Sep	204.0	73.6	130.4	122.5	18.1
Oct	165.4	65.2	100.2	115.4	16.8
Nov	143.2	36.7	106.5	92.8	22.9
Dec	138.5	22.3	116.2	82.1	32.3
Annual	2342.0	921.0	1421.0	1546.9	19.4

TABLE 2

Mean annual PET over (2° × 2°) latitude/longitude grids over India (values in mm)

Long./Lat.	68 70	70 72	72 74	74 76	76 78	78 80	80 82	82 84	84 86	86 88	88 90	90 92	92 94	94 96
36 34			1068.2	936.9	**809.3**	741.2								
34 32			1243.6	1093.7	1097.4	796.6								
32 30			1485.9	1355.3	1204.5	1177.5								
30 28			1510.3	1450.9	1408.0	1265.2	1230.0						996.3	1027.0
28 26		**2277.1**	1955.3	1577.6	1585.5	1624.8	1448.6	1471.8	1340.5	1206.4	**1081.1**	1164.5	1098.4	1100.6
26 24		1810.2	1687.8	1569.4	1667.0	1567.7	1527.7	1522.5	1521.5	1515.2		953.6	1178.3	
24 22	1861.7	1907.2	1815.7	1953.8	2010.3	1607.8	1381.1	1551.3	1413.4	1462.4		1298.8		
22 20		1800.2	1588.1	1981.3	2021.9	1587.6	1644.1	1536.3	1532.5	1566.9				
20 18			1604.3	1696.1	1872.2	1596.3	1589.6	1559.2	1592.8					
18 16				1702.6	1883.1	1762.2	1684.9							
16 14				1621.0	**2183.0**	1940.5								
14 12				1465.6	1566.5	2031.6								
12 10					1405.2	1900.5								
10 08					1596.3	1929.5								

4. Conclusions

The highest average annual PET of 2342.0 mm over India has been observed at Jalgaon and lowest of 921.0 mm at Ging. Range of average annual PET is 1421.0 mm. The mean annual PET averaged for all stations over India is 1546.9 mm. The lowest centers with annual PET less than 1400 mm are mainly located north of 30 degree latitude. The high centers with annual PET more than 1800 mm are located in desert area and central India. As the monsoon advances, the PET values over western India decrease gradually. The mean monthly PET values ranged between 82.1 (December) and 199.6 mm (May) in different months over India. The lowest mean monthly PET of 82.1 mm is observed in December and highest mean monthly PET of 199.6 mm is observed in May. Mean annual PET over (2° × 2°) latitude/longitude grids over India have been developed and presented.

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