MAUSAM, 49, 3 (July 1988), 387-394

551.573 : 631.671 : 633.1

Oscillation of potential evapotranspiration in India and its significance on seasonal potential water requirement of crops

G.C. DEBNATH and R.P. SAMUI

Meteorological Office, Pune-411005, India

(Received 31 July 1996, Modified 12 February 1997)

सार — देश के विभिन्न भागों में स्थित 47 स्टेशनों के सामान्य साप्ताहिक सम्भाव्य वाष्पीकरण मानों का हार्मोनिक विश्लेषण के अनुसार अध्ययन किया गया। स्टेशनों के आयाम में प्रायद्वीपीय भारत के पश्चिम तट पर 5 मि.मी. से लेकर देश के उत्तरी पश्चिमी भागों में 24 मि.मी. तक की बड़ी भिन्नता पाई गई है। साप्ताहिक दोलन की अधिकता देश के सुदूर दक्षिण पश्चिम तट पर फरवरी के अंत/मार्च के प्रारम्भ के आस-पास अपने अधिकतम मान पर थी जबकि उत्तर पश्चिम राजस्थान, उत्तर पूर्वी भारत और आंध्र प्रदेश के राजमुंदरी के कुछ निकटवर्ती क्षेत्रों में और बिहार के पूसा में यह स्थिति जून के तीसरे सप्ताह में थी। देशान्तर और विभिन्न समूहों के संबंधित केन्द्रों की मौसमी फसलों (खरीफ, रबी और जायद) के लिए जल की सम्भावित आवश्यकता के मध्य नकारात्मक सहसंबंध से पता चलता है कि प्रत्येक समूहों में विभिन्न मौसमों में फसलों की सम्भावित जल की मांग प्रतिकूलतः आनुपातिक है जो कि समूह चार के स्थानों के खरीफ के मौसम के अलावा अक्षांशीय मान में वृद्धि के अनुरूप है, जबकि खरीफ के मौसम में स्थिति प्रतिकूल थी।

ABSTRACT. In this study, the normal weekly potential evapotranspiration values of 47 stations situated over different parts of the country have been subjected to harmonic analysis. The amplitude of the stations varies greatly ranging from 5 mm in the west coast of peninsular India to 24 mm over northwest parts of the country. The peak of weekly oscillation attains its maximum value around end of February/early March over extreme southwest coast of the country, while it is third week of June over northwest Rajasthan, northeast India and over small pockets around Rajamundry of Andhra Pradesh and Pusa of Bihar. A negative correlation between latitude and the seasonal (kharif, rabi and summer) potential water need of the respective stations of different groups indicates that potential water demand of crops at different seasons in each of the groups is inversely proportional with increase in latitudinal value except for kharif season of group IV stations where it is reverse.

Key words — Potential evapotranspiration (PET), Harmonic analysis, Regression equation, Seasonal water demand.

1. Introduction

The agricultural potentialities of any region are dependent on the availability of water during different crop growing periods. Potential evapotranspiration (PET) is defined as the evapotranspiration from an actively growing short green vegetation completely shading the ground and never short of moisture availability. Actual water requirement (ET) of a crop grown in a particular place is directly related to the PET of the place. The seasonal course of ET is a characteristic of the location of the station that determines the water demand of the crop. Therefore, the study of seasonal course of ET is important for water management and crop planning purposes. The march of ET at a particular station that takes into account atmospheric evaporative demand is, to a large extent, a systematic oscillation repeating practically in a similar fashion year-after-year. So, the character of the variation of the components of the oscillation with respect to stations alongwith the relationship between seasonal potential water demand of crops with the latitude form the subject of study in this paper.

2. Data and methodology

Mean weekly (standard meteorological week) PET values calculated through modified Penman method for various stations over India by Khambete and Biswas (1992) have been considered for the present study. Harmonic analysis has been used to the time series consisting of these 52 PET values for each of the stations. These series, having finite number of equally spaced data points can be accounted for by a finite number of sine and cosine terms in a Fourier analysis. Symbolically the Fourier series can be expressed as follows:

$$PET = \overline{PET} + \sum_{r=1}^{N/2} \left(Ar \cos\frac{360}{p} rx + Br \sin\frac{360}{p} rx \right) \qquad (1)$$

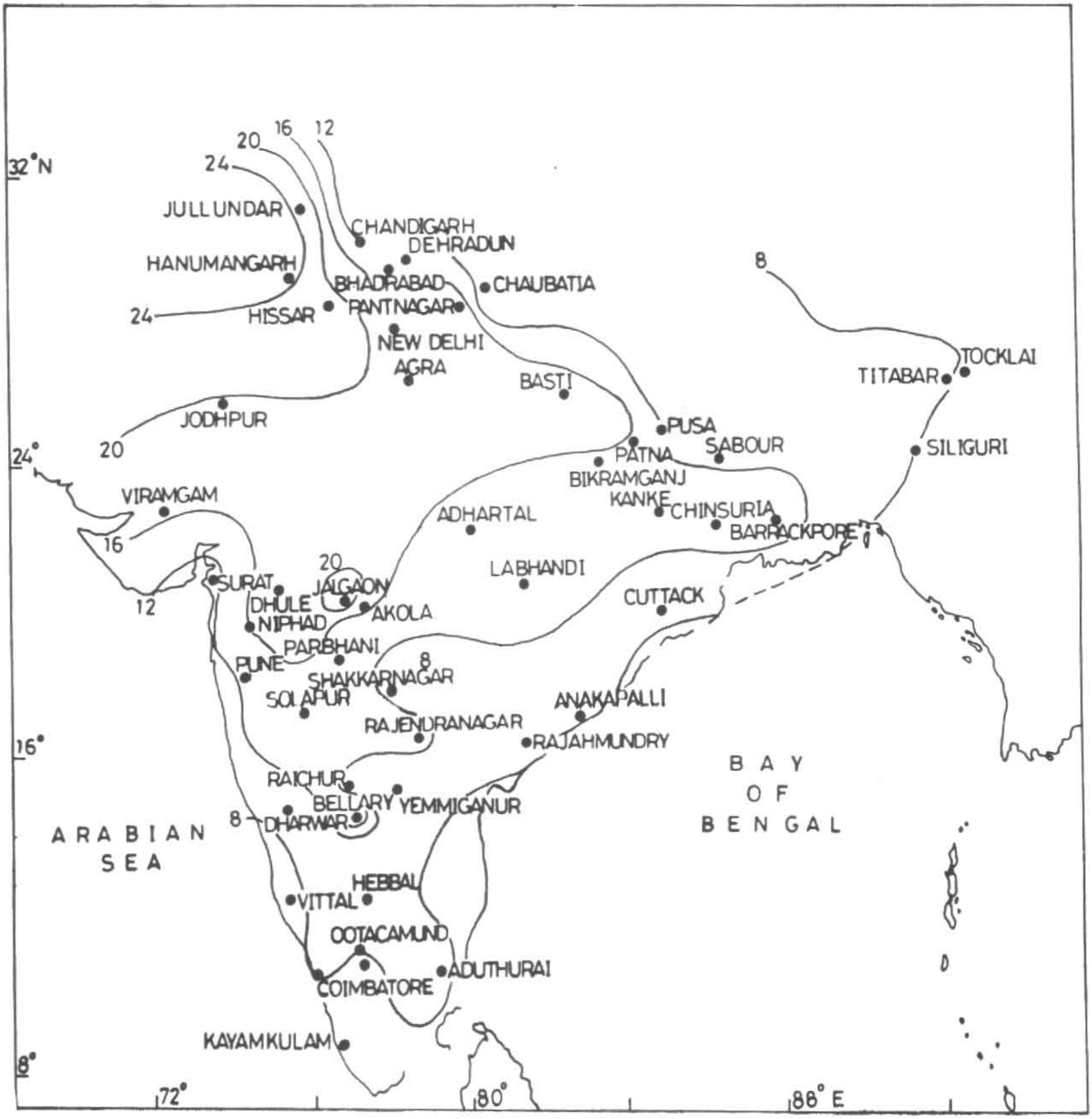


Fig.1. Amplitude of weekly oscillation of potential evapotranspiration in mm (First harmonic)

where, $\overline{\text{PET}}$ is the mean value over the entire period of length P (52 weeks), N is the number of equally spaced data points, Ar (52 weeks), N is the number of equally spaced data points, Ar and Br are the amplitudes of the various terms, p is the period of the fundamental cycle, r is the number of harmonics and x is the time factor varying from 0 to 51. A more convenient expression of Fourier analysis is obtained by combining both sine and cosine term as follows:

$$\text{PET} = \overline{\text{PET}} + \sum_{r=1}^{N/2} Cr \sin\left(\frac{360}{p} rx + \phi r\right) \qquad (2)$$

where, Cr is the amplitude of the rth harmonic and is given by $(Ar^2 + Br^2)^{1/2}$ and ϕr is the phase angle given by $\tan^{-1}$ (Ar/Br). For a fuller discussion of the method of analysis reference may be made to Conrad and Pollak (1950), Panofsky and Brier (1958). Different scientists (Pearce and Gold 1959, Carson 1963) have reported that the

TABLE 1

Harmonic components of potential evapotranspiration for selected stations in relation to first three harmonics

Station	Latitude (degree)	First harmonic Amp. (mm)	First harmonic Var. (%)	Date of maxima	Second harmonic Amp. (mm)	Second harmonic Var. (%)	Third harmonic Amp. (mm)	Third harmonic Var. (%)	Total variance (3 harmonics) (%)
Adhartal	23.09	15.0	71	24 May	7.9	20	3.9	5	96
Aduthurai	11.01	9.9	94	27 May	1.9	2	0.6	1	97
Agra	27.10	18.0	86	10 June	6.5	11	2.8	2	99
Akola	20.42	17.8	74	23 May	8.7	17	5.1	6	97
Barracpore	22.45	12.6	75	27 May	6.5	20	1.5	1	96
Bellary	15.09	15.8	95	3 June	2.2	2	1.0	1	98
Bikramganj	25.10	15.0	81	5 June	6.9	17	1.2	1	99
Chaubatia	29.45	8.9	79	2 June	4.3	19	1.4	2	100
Chandigarh	30.45	9.7	66	16 June	6.8	32	0.8	1	99
Chinsura	22.52	14.2	78	25 May	7.0	19	2.1	2	99
Coimbatore	11.00	6.4	70	16 May	3.2	17	0.6	1	88
Cuttack	20.28	11.2	70	16 May	6.8	26	1.9	2	98
Dehradun	30.20	12.6	86	13 June	4.5	11	2.0	2	99
Dharwad	15.26	10.0	72	16 April	5.9	25	1.4	1	98
Dhulia	21.20	17.4	68	18 May	10.7	26	4.3	4	98
Hanumangarh	29.15	24.3	95	23 June	4.3	3	2.2	1	99
Hebbal	13.00	9.2	90	12 May	2.6	7	0.3	1	98
Hissar	29.10	21.7	92	23 June	4.6	4	2.9	2	98
Jalgaon	21.03	23.0	69	13 May	13.1	22	6.2	5	96
Jallandhar	31.28	21.8	92	20 June	4.9	5	2.6	1	98
Jodhpur	27.08	20.2	87	9 June	6.3	8	3.2	2	97
Kasargod	12.30	5.3	54	11 Mar	4.5	38	1.6	5	97
Kayangulam	9.08	4.7	63	3 May	3.3	32	0.8	2	97
Labhandi	21.16	15.4	75	22 May	7.9	20	3.3	4	99
Nagpur	21.06	14.4	70	21 May	7.6	20	4.5	7	97
New Delhi	28.35	18.8	86	14 June	6.4	10	3.0	3	99
Niphad	20.06	16.2	72	21 May	9.3	24	3.5	3	99
Padegaon	18.12	12.1	70	19 May	7.2	25	2.6	3	98
Pantnagar	29.00	16.8	84	8 June	6.7	13	2.9	2	99
Parbhani	19.16	15.3	80	26 May	6.6	15	3.0	3	98
Patna	25.36	15.6	85	12 June	6.4	14	0.7	1	100
Pattambi	10.48	8.1	78	23 Feb	3.8	17	1.6	3	98
Pune	18.32	12.0	73	15 May	6.8	23	2.4	3	99
Pusa	25.29	11.6	85	24 June	4.6	14	0.5	1	100
Raichur	16.12	11.3	74	12 May	5.8	19	0.6	1	94
Rajahmundry	17.00	10.0	79	22 June	4.4	15	0.8	1	95
Rajendranagar	17.19	13.4	92	30 May	3.0	5	1.4	1	98
Ranchi	23.19	13.9	79	29 May	6.8	19	1.9	1	99
Rudrur	18.30	8.3	77	15 May	4.0	19	1.0	1	97
Sabour	25.14	10.2	79	26 May	4.9	18	0.9	1	98
Sabaranpur	29.58	15.4	87	18 June	5.4	11	2.0	2	100
Samalcot	17.03	9.9	79	20 May	4.4	16	1.3	1	96
Silicoori	24.50	7.6	77	15 June	3.8	19	0.6	1	97
Solapur	17.40	14.9	82	16 May	6.4	15	1.7	1	98
Surat	21.12	11.6	65	2 June	7.5	27	3.3	5	97
Titbar	26.35	8.4	90	27 June	2.6	8	0.3	1	99
Tocklai	26.47	8.2	88	27 June	2.5	8	0.6	1	97

Amp. — Amplitude Var. — Variance

annual cycle of meteorological and agro-meteorological parameters is fairly well described by the first harmonic alone. But others (Lettau 1954, Krishnan and Kushwaha 1972) have reported that first harmonic alone is not sufficient to describe the annual cycle and the effect of higher harmonics has to be considered. Lamba and Khambete (1991) and Samui (1994) also used higher harmonics to describe the annual cycle of soil temperature and soil mois-

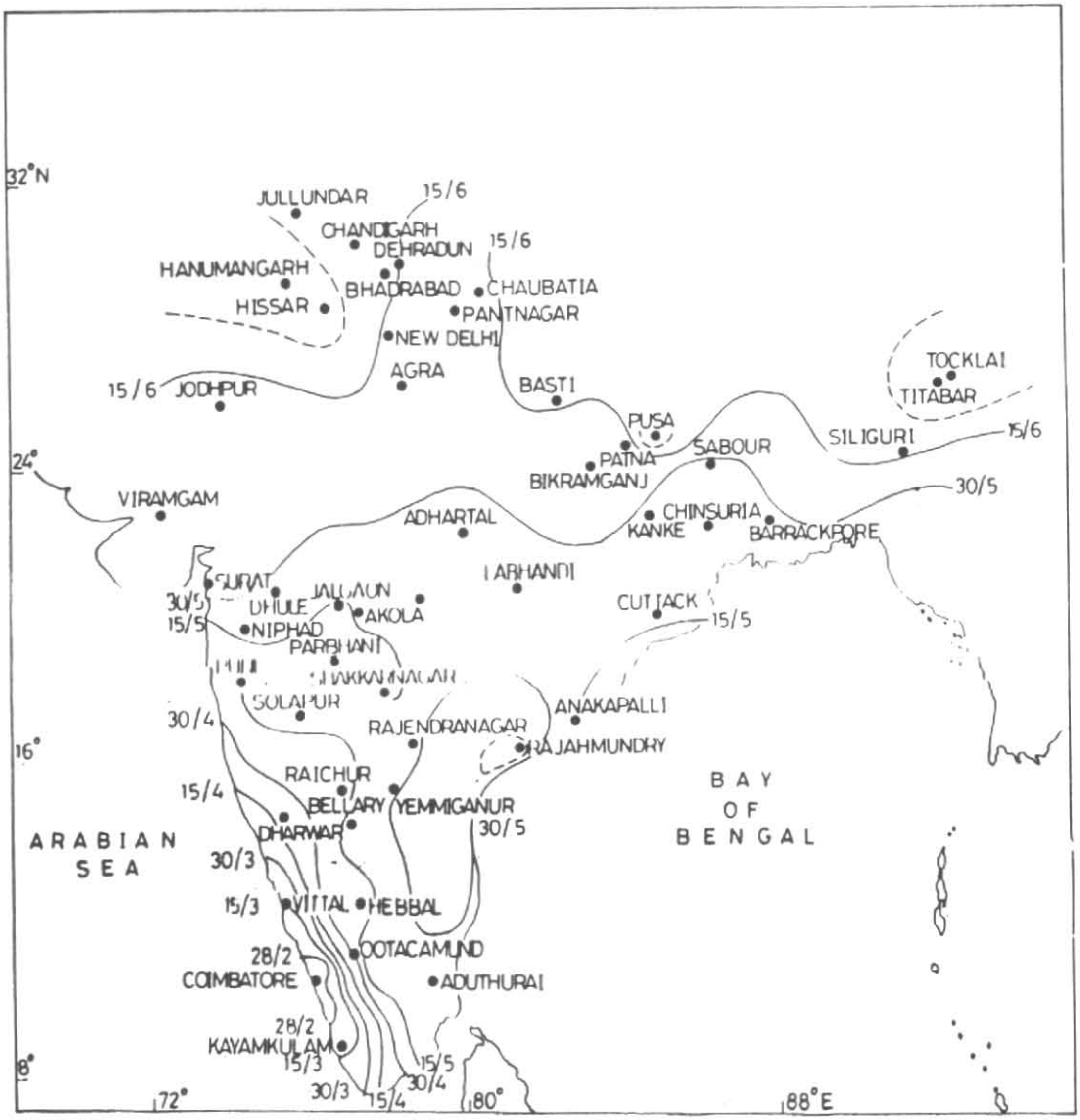


Fig.2. Date of maximum of weekly oscillation of potential evapotranspiration (First harmonic)

ture respectively in their studies. In this study, an attempt has been made to represent the variation of weekly PET in respect of their amplitude and phase angle for the first three harmonics. The maximum in the oscillation of the rth order will occur when

$$\sin\left[\left(\frac{360}{p} rx\right) + \phi r\right] = 1 \qquad (3)$$

i.e. when,

$$\left(\frac{360}{p} rx\right) + \phi\, r = \pi/2 \text{ or } 5\pi/2 \qquad (3a)$$

The date of occurrence of the maximum was obtained from the phase angle considering the fact that unit of time is considered as 52 weeks of the year and the origin of the time axis corresponds to 3 January assuming that mean weekly PET are representative of the middle of the week. So, the date of maxima (D_t) is calculated as follows:

$$D_t = 7.02 * rx + 3 \text{ days (from 1 January)} \qquad (4)$$

where, rx was calculated from Eqn. (3) for the first harmonic. The variance explained by each of the harmonics has also been calculated. The stations have been categorised into five groups on the basis of their amplitude for the first harmonic. Regression equations for potential water need of the stations of different groups were worked out following seasonal PET and latitude of respective stations of the groups. Seasons have been considered as kharif (23-44 week), rabi (45-12 weeks of the succeeding year) and summer (13-22 weeks).

3. Results and discussion

3.1. *Amplitude and date of maxima*

The values of harmonic components alongwith the latitude for different stations in relation to first three harmonics are presented in Table 1. It is seen that first harmonic is more important as both the amplitude and variance explained are more than the others. Therefore, date corresponding to the maxima has been presented with respect to the first harmonic only. The highest amplitude of about 24 mm represented by Hanumangarh is found to occur over the region of northwest Rajasthan followed by Jalgoan in Maharashtra. The amplitude variation with latitude for the first harmonic is presented at Fig.1. It reveals that lowest value in the order of 5 mm is found at Kasargod and Kayangulam in the west coast of peninsular India followed by 8 mm over peninsular India and northeast region of the country. Amplitude generally increases northwards and is highest over northwest Rajasthan.

The date of maximum weekly oscillation of PET occurs in late February / early March over southern parts of west coast, *viz*., Kasargod, Kayangulam and Pattambi (Fig.2). Most of the stations of Central India, parts of Bihar, Andhra Pradesh, Gangetic West Bengal, Orissa, southern parts of east coast and interior parts of Andhra Pradesh have its peak value in the second half of May. Most of the parts of northern India, southern Assam, Sub- Himalayan West Bengal and Sikkim, northern Bihar, Rajasthan and Gujarat have experienced the maximum PET by the middle of June. Extreme northwest India, foot-hills of northeast India and a small pocket near Rajahmundry of Andhra Pradesh and Pusa of Bihar have the highest value during 3rd week of June.

3.2. *Variance explained by different harmonics*

The variance explained by first harmonic is much higher as compared to other harmonics (Table 1). Hanumangarh and Bellary show the highest (95%) percentage variance for the first harmonic followed by Aduthurai (94%). First harmonic alone explains 54 to 95 percent of the total variance (Table 1) with respect to the stations under study. The second harmonic explains between 2 to 38 percent of the total variance. From Table 1 it is also seen that variance accounted by the third harmonic is not significant. The total variance explained by the first three harmonics at different stations amounts to 88 to 100 percent.

3.3. *Relationship with latitude*

With a view to determine the nature of the dependence of seasonal PET values with the position of the stations, they are categorised into five groups on the basis of amplitude. Values of seasonal PET of the stations of these groups are shown in Table 2. The correlation coefficient (CC) between the seasonal potential water demand, hereinafter, water demand and latitude of the place of these groups are given in Table 3. The high CC with respect to different seasons and the latitude of the stations of the group suggest a close relationship between the two. Therefore, seasonwise linear relationship of latitude and potential evapotranspiration would enable quicker estimation of water demand during the crop growing season. The linear relationship is of the following form,

$$\text{PET} = a_0 + a_1 L \quad (5)$$

where, a_0 and a_1 are the constants estimated through regression analysis L denotes latitude of the station. The details of the linear relationship for PET are given in Table3.

Fig. 3(a) depicts the variation of PET with latitude for different stations of group I during kharif, rabi and summer seasons. Most of the stations of this group are either from peninsular India or from northeast India. At Kayangulam, Pattambi and Kasargod water demand is highest during rabi season followed by kharif and summer seasons respectively. For other stations of the group kharif season water demand is highest followed by rabi and summer seasons except Chaubatia and Titbar where sequence is kharif followed by summer and rabi (Table 2). During kharif season the value of coefficient of determination (R^2) is very low (0.24) as compared to that of rabi and summer season of the group where they are 0.96 and 0.59 respectively (Table 3). The lower value of R^2 of kharif season may be due to the fact that PET values of the stations namely Kayangulam, Pattambi and Kasargod exhibit a scattering pattern than those of other stations of the group.

From Fig.3 (a) it is also evident that there is a linear decrease of PET of the stations with increase in latitude although the slope of the relationship varies with the season. The slope of the relationship plotted in Fig.3(a) decreases from - 6.7 for kharif to -21.9 for rabi and -6.2 for summer. Fig. 3 (a) also reveals that water demand decreases northward at the rate of 21.9, 6.7 and 6.2 mm per degree increase in latitude during rabi, kharif and summer season respectively. However, the variation of water demand of the crops between rabi and summer is more in the lower latitude (west coast of peninsular India) which decreases with increase in latitude and becomes equal around 27°22′N and beyond that summer season demand increases than that of rabi season. On the contrary, the water demand of rabi crops is more than that of kharif season at Kayangulam that decreases with increase in latitudinal value and becomes at par around 10°05′N and after that, the case is reverse, where kharif

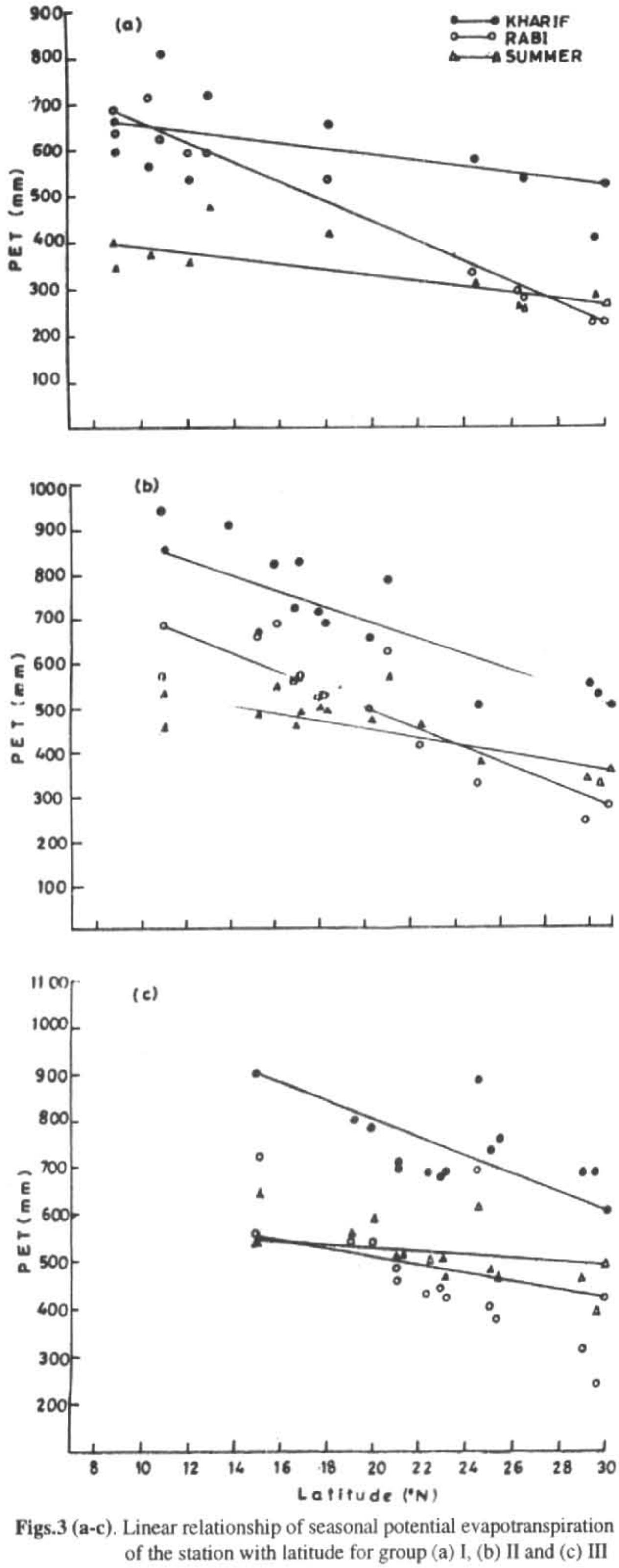
TABLE 2

Seasonal potential evapotranspiration (mm) of various stations under different groups

Group	Amplitude	Station	Season		
			Kharif	Rabi	Summer
I	< 10	Coimbatore	809.2	632.5	392.1
		Chaubatia	413.7	236.0	284.9
		Kasargod	543.9	603.4	363.3
		Kayangulam	600.6	644.0	351.4
		Pattambi	572.3	723.1	381.5
		Titbar	559.2	294.0	265.3
		Rudrur	662.9	541.8	422.1
		Hebbal	725.2	603.1	438.6
		Tocklai	546.7	289.1	257.6
		Silicoori	583.8	362.6	314.3
II	≥ 10-13	Pune	684.6	527.1	494.9
		Padegaon	709.8	524.3	500.5
		Cuttack	649.6	498.4	475.3
		Raichur	820.4	687.4	545.3
		Rajendranagar	824.6	560.7	487.2
		Surat	781.3	619.5	563.5
		Sabour	498.8	324.1	387.8
		Darwar	658.0	656.6	485.1
		Aduthurai	940.1	565.6	450.1
		Rajahmundry	718.2	556.9	453.6
		Pusa	656.6	319.2	354.9
		Dehradun	545.9	238.7	335.4
		Barrackpore	649.6	413.7	455.7
		Samalcot	691.6	529.9	446.6
		Chandigarh	523.6	333.2	332.6
III	≥14-17	Adhartal	681.9	444.1	501.2
		Labhandi	695.1	463.4	522.2
		Nagpur	708.5	487.6	513.8
		Niphad	783.3	539.7	589.4
		Parbhani	803.2	543.2	551.6
		Solapur	884.8	697.9	612.5
		Saharanpur	690.9	296.1	394.8
		Patna	762.3	382.9	466.2
		Ranchi	688.1	428.4	466.9
		Bellary	1078.7	724.5	642.6
		Chinsura	688.1	435.4	498.4
		Bikramganj	736.1	408.8	478.8
		Pantnagar	689.5	319.2	464.1
IV	≥18-21	Akola	790.3	534.1	591.5
		Dhulia	822.8	583.8	644.0
		New Delhi	816.9	354.2	480.9
		Agra	813.4	397.2	498.4
		Jodhpur	1004.2	557.9	599.2
V	≥ 22	Jalgaon	938.0	725.9	791.7
		Jallandhar	828.8	279.3	409.8
		Hanumangarh	990.5	347.2	512.4
		Hissar	887.6	301.0	466.2

season demand is more than rabi and the difference increases with increase in latitudinal value.

Most of the stations of group II lie in the dry farming tract of Maharashtra, Andhra Pradesh and Gujarat. All the stations of this group show higher water demand during kharif season followed by rabi and summer seasons except Sabour, Pusa, Dehradun and Barrackpore where sequence is kharif followed by summer and rabi (Table 2). The R^2 value of kharif, rabi and summer seasons are 0.67, 0.74 and 0.52 respectively. The water demand of the stations for summer season show greater scattering indicating lower association with latitude as compared to kharif and rabi season. The slope of the relationship for kharif, rabi and summer seasons varies from - 17.7, -20.9 and -9.2 respectively (Table 3) thereby indicating that the rate of water demand of the stations decreases largely in rabi season as compared to the other seasons with increase in latitudinal values. A significant feature of the Fig.3(b) is that the



Figs.3 (a-c). Linear relationship of seasonal potential evapotranspiration of the station with latitude for group (a) I, (b) II and (c) III

difference of PET values between kharif and summer season is largest around 11°N latitude which gradually becomes narrower with increase in latitude indicating that difference of water requirement of crops to the northern latitude is less as compared to that of southern latitude. On the other hand, water demand of crops during rabi season is more than that of summer season at the lower latitude which gradually decreases with increase in latitudinal value and becomes equal around 24°N latitude beyond that the case is reverse.

Most of the stations of group III comprise of central and northern parts of the country. Stations of this group need more water during kharif season followed by summer and rabi season except Solapur and Bellary where sequence is kharif followed by rabi and summer (Table 2). For this group, coefficient of determination is lowest during summer season followed by rabi and kharif season (Table 3). Moreover, a linear decrease of PET with increase in latitude for all the stations is also evident. The highest slope in kharif season (-19.6) followed by rabi (-8.8) and summer season (-4.2) indicates that decrease of water demand by the crops would be more during kharif season followed by rabi and summer for a degree increase in latitude. The difference of water demand between kharif and summer season is largest in the lower latitude which gradually becomes narrower with increase in latitude and becomes least at Pantnagar indicating that variation of water demand of crops is less in the northern latitude. On the contrary, the difference of water demand of crops between rabi and summer is less in the lower latitude than that of higher latitude [Fig.3 (c)].

The stations of group IV are from arid and semi-arid regions of central and northern India. All the stations of this group are having higher water demand during kharif season followed by summer and rabi season (Table 2). A significant feature of this group is that kharif season water demand is positively correlated with latitude but for both rabi and summer seasons CCs were negative. The coefficient of determination is very less (0.15) during kharif season followed by rabi (0.49) and summer season (0.55) (Table 3). The higher R^2 values during summer season indicate that variation of water demand among the stations is less as compared to that of rabi and kharif seasons. There is a decrease of water demand with increase in latitude for rabi and summer seasons while for kharif season the case is reverse when PET increases with increase in latitude. The slope of the relationship for kharif, rabi and summer seasons varies from 9.1, -19.6 and -14.1 respectively. Table 3 indicates that the rate of water demand of the stations decreases steeply in rabi season than during summer season.

Most of the stations of group V are from northern parts of arid and semi-arid regions of India. The correlation coefficient is very high for both rabi and summer season as compared to kharif season (Table 3). The higher R^2 values with lower standard error (SE) also indicate the adequacy of the regression equation for rabi and summer seasons. A steep linear decrease of PET values with increase in latitude, having slope of -37.0 during summer season as compared to -6.3 and -4.6 during kharif and rabi season respectively, indicates that as the slope of the relationship varies considerably among the seasons the

TABLE 3

Results of regression analysis on potential evapotranspiration

Group	Season	Constants		r	R^2	S.E.
		a_0	a_1			
I	Kharif	734.0	-6.7	-.49	0.24	0.310
	Rabi	893.2	-21.9	-.98	0.96	0.071
	Summer	460.3	-6.2	-.77	0.59	0.231
II	Kharif	1049.0	-17.7	-.82	0.67	0.160
	Rabi	916.7	-20.9	-.86	0.74	0.143
	Summer	637.9	-9.2	-.72	0.52	0.193
III	Kharif	1200.5	-19.6	-.73	0.53	0.207
	Rabi	689.4	-8.8	-.53	0.29	0.254
	Summer	617.1	-4.2	-.48	0.23	0.265
IV	Kharif	623.0	9.1	.39	0.15	0.532
	Rabi	971.5	-19.6	-.70	0.49	0.410
	Summer	913.0	-14.1	-.74	0.55	0.385
V	Kharif	1085.0	-6.2	-.41	0.17	0.643
	Rabi	1677.0	-4.6	-.98	0.96	0.111
	Summer	1570.3	-37.0	-.99	0.98	0.086

S.E.— Standard error

rate of water demand of the stations also decreases largely during summer as compared to other seasons with increase in latitudinal values.

4. Conclusions

The study leads to the following conclusions:

(*i*) Amplitudes of PET are lowest at west coast of peninsular India and generally increase northwards and attain highest value over northwest India.

(*ii*) The maximum of weekly values occur at the end of February/early March over southern parts of west coast where amplitude is also less. On the other hand, over northwestern parts of the country and foot-hills of northeast India, alongwith a small pockets near Rajahmundry of Andhra Pradesh and Pusa of Bihar, the maximum occurs in the third week of June.

(*iii*) The correlation coefficient between latitude and seasonal PET of the respective stations, under groups I and II, show a higher association during rabi season. For group I, rabi is followed by summer and kharif, whereas for group II rabi season is followed by kharif and summer. For group III, it is kharif followed by rabi and summer. For group IV and V the sequence of association between PET and latitude is summer followed by rabi and kharif.

(*iv*) The water demand of crops decreases linearly with increase in latitudinal values of the stations for all the seasons except kharif season for the stations under group IV.

(*v*) For a given degree increase in latitudinal value, the decrease in water demand is highest during rabi season followed by kharif and summer for the stations under group I and II. For the stations of group III it is kharif followed by rabi and summer. In case of the stations of group IV the sequence is rabi followed by summer and kharif while for group V it is summer followed by kharif and rabi.

Acknowledgements

The authors express their sincere thanks to Shri S.K. Shaha, Director for his encouragement to carry out the study. Thanks are also due to Miss. Anita Ballal for typing the manuscript.

References

Carson, J.K., 1963, "Analysis of soil and air temperatures by Fourier techniques", *J. Geophys. Res.*, **68**, 2217-2232.

Conrad, V. and Pollak, L.W., 1950, "Methods in climatology", 2nd Ed. Harvard University Press, Cambridge, Massachusetts, 119-154.

Khambete, N.N. and Biswas, B.C., 1992, "Weekly potential evapotranspiration over India", *Met. Monograph Agrimet .No.14.*

Krishnan, A. and Kushwaha, R.S., 1972, "Analysis of soil temperature in the arid zone of India by Fourier techniques", *Agric. Meteorol.*, **10**, 55-64.

Lamba, B.S. and Khambete, N.N., 1991, "Analysis of soil temperature at various depths by Fourier technique", *Mausam*, **42**, 3, 269-274.

Lettau, H., 1954, "Improved models of thermal diffusion in soils", *Trans. Amer. Geophys. Union*, **35**, 121-132.

Panofsky, H.A. and Brier, G.W., 1958, "Some applications of statistics to Meteorology", Pennysylvania state Univ. Press, 254p.

Pearce, D.C. and Gold, I.W., 1959, "Observations of ground temperature and heat flow at Ottawa, Canada", *J. Geophys. Res.*, **64**, 1293-1298.

Samui, R.P., 1994, "Fourier analysis of weekly soil moisture at Pune", *Mausam*, **45**, 1, 29-34.