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Recent variations and trends in potential evapotranspiration (PET) over India

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सार – इस षोध पत्र में एफ. ए. ओ. द्वारा सिफारिष किए गए पेनमेन–मोनटीयथ समीकरण का उपयोग करते हुए संभाव्य वाष्पोत्सर्जन का आकलन करने के लिए भारत में बाईस सुवितरित स्थानों के लिए तीस वर्षो के मौसम विज्ञान संबंधी समयवार श्रृंखलाओं के आँकड़ों (1971–2000) का उपयोग किया गया है। इसके लिए रैखिक प्रवृत्ति विष्लेषण तकनीक का उपयोग करते हुए वार्षिक, मौसमी और मासिक पी. ई. टी. प्रवृत्तियों का अध्ययन किया गया है। पी. ई. टी. की प्रवृत्तियों की भिन्नताओं और परिवर्तनों का अध्ययन करने के लिए और जब कभी उल्लेखनीय परिवर्तन होते हैं उन विषिष्ट अवधियों का पता लगाने के लिए उचित प्रकार के आलेख तैयार किए गए हैं।

माध्य वार्षिक पी. ई. टी. बुरालीक्सन में सबसे कम (1100 मि. मी.) और बेलारी में सबसे अधिक (2109 मि. मी.) पाया गया है। बाईस स्थानों में से सत्रह स्थानों में वार्षिक पी. ई. टी. में उल्लेखनीय रूप से ह्रास की प्रवृति पाई गई है और पाँच स्थानों में कोई भी उल्लेखनीय प्रवृत्ति नहीं पाई गई है। भारत में माध्य वार्षिक d*E*o/d*t* –9.36 मि.मी. प्रति वर्ष पाया गया है। एक निष्चित स्थान पर, वार्षिक पी. ई. टी. दूरी का उपयोग करते हुए वार्षिक dEo/d*t* का मात्रात्मक रूप से आकलन करने के लिए रैखिक संबंध प्राप्त किया गया है। (क) भारत में माध्य वार्षिक dEo/d*t* मानों का मात्रात्मक रूप से आकलन करने के लिए (ख) किसी भी निष्चित माह तक भारत (मि. मी. ⁄ वर्ष) में औसत संचयी dEo/d*t* मानों का मात्रात्मक रूप से आकलन करने के लिए (ग) किसी भी निष्चित माह तक भारत में औसत वार्षिक dEo/d*t* के लिए योगदान (प्रतिषत) का मात्रात्मक रूप से आकलन करने के लिए अरैखिक संबंध प्राप्त किए गए हैं।

ABSTRACT. Thirty years meteorological time series data (1971-2000), for twenty two well distributed locations in India, have been utilized to compute potential evapotranspiration using FAO recommended Penman-Monteith equation. Annual, seasonal and monthly PET trends have been studied using linear trend analysis technique. Suitable graphs have been plotted to study the variations and changes in PET trends and to identify the specific periods as and when significant changes occur.

The mean annual PET has been found to be lowest (1100 mm) at Buralikson and highest (2109 mm) at Bellary. Out of twenty two locations, significant decreasing trend in annual PET has been observed at seventeen locations and no significant trend at five locations. The mean annual dEo/d*t* over India has been found to be -9.36 mm/year. Linear relationship has been obtained to quantitatively estimate annual dEo/d*t*, at a given location, using annual PET range. Non linear relationships have been obtained (a) to quantitatively estimate the mean monthly dEo/d*t* values over India, (b) to quantitatively estimate the average cumulative dEo/d*t* values over India (mm/year) up to any particular month and (c) to quantitatively estimate the contribution (percent) towards average annual dEo/d*t* over India, up to any particular month.

Key words – Potential evapotranspiration, PET over India, Annual PET, Seasonal PET, Monthly PET, Trends in PET.

1. Introduction

The change of state of water from solid or liquid to vapour and its diffusion into the atmosphere is referred to as evaporation. In evapotranspiration, two processes occur simultaneously; evaporation from the soil and transpiration from crop canopy's surface. Potential evapotranspiration (PET or ETo) is the maximum possible amount of water vapour loss, under a given climate from an extensive surface of green, well-watered grass canopy of uniform height, which is actively growing and completely shading the ground. (FAO, 1998; Gangopadhyay *et al.* 1966). PET may be characterized as a process of mass transport wherein evaporation is treated as a diffusive process driven by vapor pressure gradient (Mckenny and Rosenberg, 1991). PET is calculated using empirical equations (FAO, 1998). PET plays a major role in the redistribution of thermal energy between the earth and the atmosphere, and is an essential part of the hydrological cycle. It also plays an important role in agro meteorological studies like water balance and irrigation assessment. India has great economic dependence on agriculture. Any major changes in PET will have profound implications for hydrological processes, water budget and agricultural crop performance, and in turn, the economy of the country. In this context, studies related to long term changes in evaporation/potential evapotranspiration are very important.

In India, studies related to long term changes in temperature and rainfall have been carried out by many researchers (Hingane *et al*. 1985, Thapliyal and Kulshrestha, 1991, Srivastava *et al.* 1992, Rupa kumar *et al.* 1994, Govinda Rao *et al.* 1996). Long term changes in evaporation have been studied in different parts of the world (Peterson *et al*. 1995, Roderick and Farquhar, 2004). However, studies related to long term changes in PET over India are scanty. Rao *et al*. (1971) computed annual and monthly PET values based on (1931- 60) data for several locations in India, using modified penman formula. Khambete and Biswas (1992) computed weekly PET values from meteorological normal data (1951-80) for 62 locations in India, using modified penman formula. Debnath and Samui (1988) have studied the oscillation of potential evapotranspiration in India and its significance on seasonal potential water requirement of crops. Researchers have studied the influence of different meteorological variables on changes in PET and found that compared to other variables relative humidity and radiation is strongly associated with changes in PET. (Mckenny and Rosenberg, 1993; Chattopadhyay and Hulme, 1997). Rathore and Biswas (1991) have prepared climatological maps of daily evaporation and weekly evaporation. These maps give fairly good idea about the spatial variation in evaporation over India. In order to understand the implications of long period changes in potential evapotranspiration, there is need to understand the distribution of these changes, to identify the specific periods when significant changes occur and quantitatively estimate these changes. Hence, in this paper, an attempt has been made to study the recent variations and trends in potential evapotranspiration using linear trend analysis technique, to identify the specific periods when significant changes occur and quantitatively estimate these changes.

2. Data and methodology

In the present study, thirty years meteorological time series data (1971-2000), for twenty two well distributed locations in India, have been utilized. The distribution of the stations is reasonably representative of different regions of the country. The data were obtained from National Data Center, India Meteorological Department, Pune. These stations are : Adhartal (Jabalpur) (23° 09′ N 79° 58′ E), Akola (20° 42′ N 77° 00′ E), Anand (22° 35′ N 72° 55′ E), Anamalainagar (11° 24′ N 79° 44′ E), Bellary (15° 09′ N 76° 51′ E), Bhubaneshwar (20° 15′ N, 85° 50′ E), Bikramganj (25° 10′ N, 84° 15′ E), Buralikson (26° 35′ N 93° 50′ E), Canning (22° 15′ N, 88° 40′ E), Coimbatore (11° 00′ N 77° 00′ E), Dharwad (15° 26′ N 75° 07′ E), Hebbal (13° 00′ N, 77° 38′ E), Hissar (29° 10′ N, 75° 46′ E), Hyderabad (17° 32′ N 78° 16′ E), Jodhpur (26° 18′ N, 73° 01′ E), Karimganj (24° 50′ N, 92° 20′ E), Kovilpatti (09° 12′ N 77° 53′ E), New Delhi (28° 40′ N 77° 10′ E), Pantnagar (29° 00′ N 79° 30′ E), Pattambi (10° 48′ N, 76° 12′ E), Pune (18° 32′ N, 73° 51′ E) and Rajamundry (17° 00′ N, 81° 46′ E).

In this paper, potential evapotranspiration (PET) has been calculated by using FAO recommended Penman-Monteith equation (FAO, 1998). This method provides a standard to which evapotranspiration in different periods of the year or in other regions can be compared and to which the evapotranspiration from other crops can be related. The FAO Penman-Monteith method requires radiation, air temperature, air humidity and wind speed data to compute the potential evapotranspiration as given in equation below ;

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

where,

ET_0 = potential/reference evapotranspiration [mm day^{-1}],

$\mathrm{R_n}$ = net radiation at the crop surface [MJ m^{-2} day^{-1}],

G = soil heat flux density [MJ m^{-2} day^{-1}],

T = 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],

Δ = slope vapour pressure curve [kPa °C^{-1}],

γ = psychrometric constant [kPa °C^{-1}].

TABLE 1

Basic statistical parameters of annual PET and trends (significant at p > 0.95)* at various locations in India (1971-2000)

Station	Climate	Basic statistical parameters of annual PET (mm)						
		Minimum	Maximum	Range	Mean	S.D.	C.V.(%)	Trend
Jodhpur	Arid	1604.8	2322.1	717.3	1975.7	196.8	10	Decreasing
Coimbatore	Arid	1622.8	1918.1	295.3	1796.8	73.2	4.1	No trend
Hissar	Arid	1429.3	1792.1	362.8	1626.2	98	6	Decreasing
Bellary	Semi Arid	1838.2	2373.9	535.7	2109	145.7	6.9	Decreasing
Akola	Semi Arid	1791.5	2202.5	411	2005.5	120.4	6	Decreasing
Anamalainagar	Semi Arid	1702.9	1919.6	216.7	1795.7	56.8	3.2	Decreasing
Hyderabad	Semi Arid	1506.5	1963.8	457.2	1736.3	119.3	6.9	Decreasing
Pune	Semi Arid	1551	1748.7	197.7	1653.4	49.7	3	No trend
Hebbal	Semi Arid	1352.1	1733.1	381	1626	82.1	5.1	Decreasing
Rajamundry	Semi Arid	1450.2	1732.8	282.6	1603.6	67.6	4.2	Decreasing
Anand	Semi Arid	1464.8	1743.2	278.4	1602.2	82.2	5.1	Decreasing
Dharwad	Semi Arid	1497.9	1731.7	233.8	1597.4	74.3	4.7	Decreasing
New Delhi	Semi Arid	1214.3	1756.7	542.4	1450	131.7	9.1	Decreasing
Bhubaneshwar	Sub Humid	1303.2	1806.7	503.5	1600.8	132.5	8.3	Decreasing
Canning	Sub Humid	1387.3	1697.4	310.1	1530.8	84.5	5.5	Decreasing
Bikramganj	Sub Humid	1287.9	1627.3	339.4	1494.5	81.6	5.5	No trend
Pantnagar	Sub Humid	1240	1644.3	404.2	1457.3	90.2	6.2	Decreasing
Adhartal	Sub Humid	1272.9	1618.8	345.9	1438.8	87.5	6.1	Decreasing
Kovilpatti	Humid	1759	2207.9	449	1964.1	128.9	6.6	Decreasing
Pattambi	Humid	1428.6	1617.7	189	1524.4	49.4	3.2	No trend
Buralikson	Per Humid	1044	1161.6	117.6	1100.8	35.4	3.2	No trend
Karimganj	Per Humid	1035.8	1203	167.2	1131.7	41.5	3.7	Decreasing

* S.D – Standard Deviation; C.V – Coefficient of Variation.

For all twenty two locations, basic statistical parameters of annual PET [minimum, maximum, range, mean, Standard Deviation (S.D) and Coefficient of Variation (C.V.)] have been computed. Annual, seasonal and monthly PET trends have been studied using linear trend analysis technique. Results obtained have been tested for its significance at more than 95% probability level ($p > 0.95$). Suitable graphs have been plotted to study the variations and changes in PET trends and to identify the specific periods as and when significant changes occur.

The annual rate of change (increase/decrease) in PET, at any location, in a given time period (annual, seasonal, monthly etc.) may be expressed quantitatively as dEo/dt. The positive values of dEo/dt indicate increase and negative values indicate decrease in PET in a given time period. Using trend analysis technique and slope of the trend line, dEo/dt values have been computed. Attempt has been made to quantitatively estimate (*i*) annual dEo/dt, at a given location, using PET range (*ii*) the average monthly dEo/dt values over India, in any particular month (*iii*) the average cumulative dEo/dt values over India (mm/year) up to any particular month and (*iv*) the contribution (percent) towards average annual dEo/d*t* over India, up to any particular month.

3. Results and discussion

3.1. *Variations and trends in annual PET*

Basic statistical parameters [minimum, maximum, range, mean, standard deviation (S.D) and coefficient of variation (C.V.)] and observed trends (1971-2000) of annual PET (significant at $p > 0.95$) for all twenty two locations are given in Table 1. The minimum annual PET, at various locations, varied between 1035.8 and 1838.2 mm. The lowest minimum annual PET of 1035.8 mm has been observed at Karimganj. The climate of Karimganj is Per-Humid. The low value of PET at Karimganj is mainly due to relatively lower temperatures, very high relative humidity, lower wind speeds and lesser duration of bright sunshine hours. The maximum annual PET, at various locations, varied between 1161.6 and 2373.9 mm. The highest maximum annual PET of 2373.9 mm has been observed at Bellary. The climate of Bellary is Semi Arid. The high value of PET at Bellary, compared to Jodhpur and Hissar (Arid climate) is mainly due to latitudinal position and much higher wind speeds. This difference is largely evident during the period October to March, when Bellary received greater amount of solar radiation. Wide difference in PET may also be observed between Jodhpur and Hissar. The high value of PET at Jodhpur, compared to Hissar is mainly due to latitudinal position, relatively higher temperatures, lower relative humidity, higher wind speeds and greater duration of bright sunshine hours. Under the influence of all these causal elements the difference in PET is evident in all months (January to December). The annual PET range, defined as the difference of maximum and minimum, at various locations varied between 117.6 and 717.3 mm. The annual PET range has been found to be highest in Arid climate (717.3 mm at Jodhpur), followed by Semi Arid climate (542.4 mm at New Delhi), followed by Sub Humid climate (503.5 mm at Bhubaneshwar), followed by Humid climate (449 mm at Kovilpatti) and lowest in Per Humid climate (117.6 mm at Buralikson). Large variations may be observed in mean annual PET at various locations in India. Mean annual PET varied between 1100.8 and 2109.0 mm. The lowest mean annual PET of 1100.8 mm has been observed at Buralikson. The climate of Buralikson is Per-Humid. The highest mean annual PET of 2109.0 mm has been observed at Bellary. The climate of Bellary is Semi Arid. The mean annual PET over India has been found to be 1628.2 mm. The Coefficient of Variation (C.V.), defined as the ratio of standard deviation to mean and expressed as percent, at various locations varied between 3.0 and 10.0 percent.

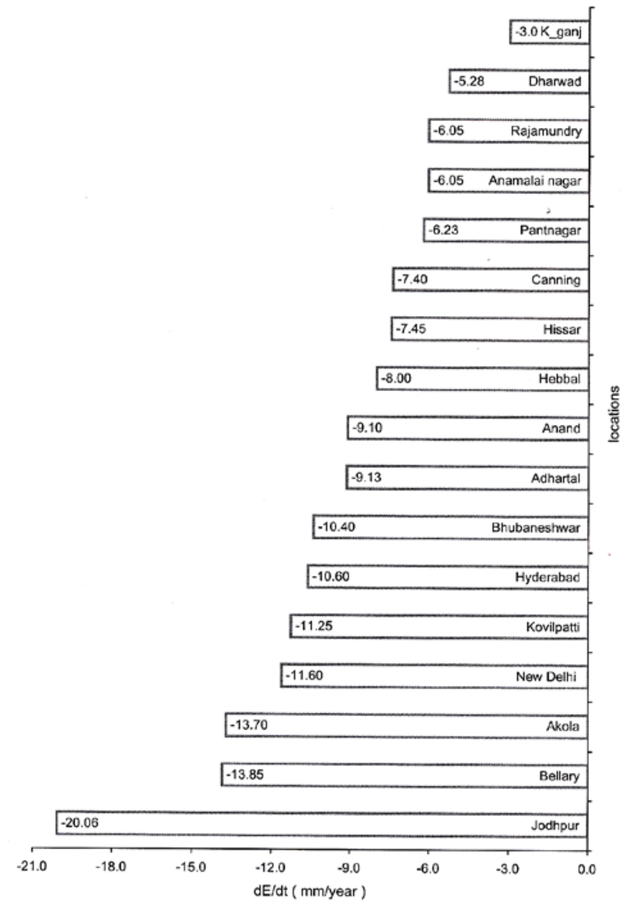


Fig. 1. Mean annual rate of decrease in PET (dEo/d*t*) at different locations in India (1971-2000)

The highest C.V. of 10% has been observed at Jodhpur (Arid climate) and lowest C.V. of 3% at Pune (Semi Arid climate).

Out of twenty two locations, significant decreasing trends in annual PET have been observed at seventeen locations. No significant trend in annual PET has been observed at five locations. These five locations are Pattambi, Pune, Buralikson, Bikramganj and Coimbatore. The annual rate of change (increase/decrease) in PET, at any location, in a given time period (annual, seasonal, monthly etc.) may be expressed quantitatively as dEo/d*t*. The positive values of dEo/d*t* indicate increase and negative values indicate decrease in PET in a given time period. Using trend analysis technique and slope of the trend line, dEo/d*t* values have been computed for those seventeen locations in which significant decreasing trend in annual PET have been observed. These annual dEo/d*t* values, arranged in the ascending order of the magnitude are given in Fig. 1. The annual dEo/d*t* values, at various locations varied from -3.00 mm/year at Karimganj to

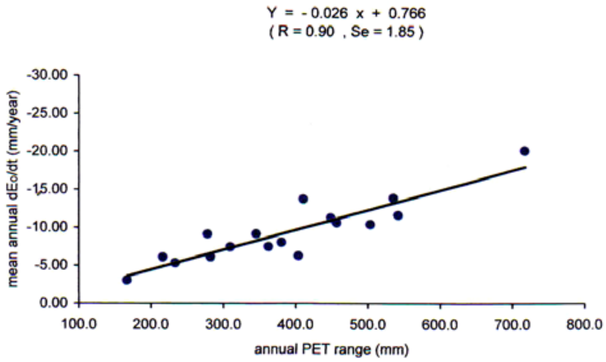


Fig. 2. Variation in mean annual dEo/d*t* in relation to annual PET range over India (1971-2000)

–20.06 mm/year at Jodhpur. The average annual dEo/d*t*, over India, has been found to be -9.36 mm/year. To attribute this negative trend, the trend of six causal elements [temperature (maximum, minimum)], relative humidity (maximum, minimum), wind speed and actual duration of bright sunshine hours were also studied. The trend analysis revealed that in large number of locations 'No significant trend' has been observed for temperatures, 'significant increasing trend' has been observed for relative humidity (maximum, minimum), 'significant decreasing trend' has been observed for wind speed and 'significant decreasing trend' has also been observed for actual duration of bright sunshine hours. The relationship between PET and the two most significantly influencing causal elements (actual duration of bright sunshine hours and wind speed) is given below;

$$Y = 103.5\ X_1 + 49.3\ X_2 + 493.5 \quad (R = 0.90,\ Se = 60)$$

Y = annual PET (mm)

X_1 = actual duration of bright sunshine hours

X_2 = wind speed (kmph)

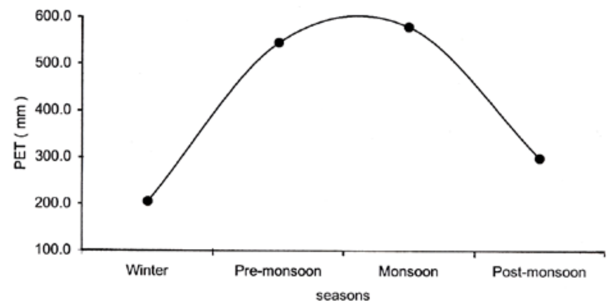
Variation in annual dEo/d*t* (mm/year) in relation to annual PET range is shown in Fig. 2. Significant correlation has been observed between these parameters and the linear regression obtained is given by;

$$Y = -0.026\ x + 0.766 \quad (R = 0.90,\ Se = 1.85)$$

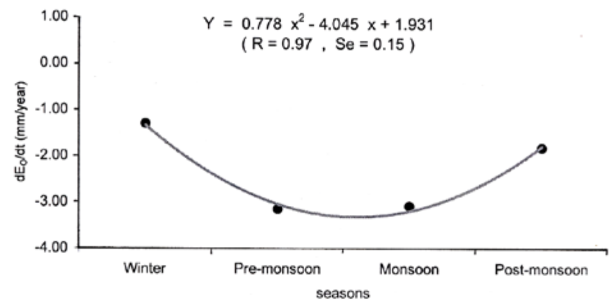
Y = annual dEo/d*t* (mm/year)

x = annual PET range (mm)

(a) Mean seasonal PET



(b) Mean seasonal dEo/d*t*



Figs. 3(a&b). Variation in mean seasonal PET and mean seasonal (dEo/d*t*) over India (1971-2000)

Using this equation, it is possible to estimate annual dEo/d*t*, at a given location, using annual PET range. On the basis of this relationship, the annual dEo/d*t* at various locations over India may be broadly divided into following three categories;

Category	*Annual PET range (mm)*	*Annual dEo/dt (mm/year)*
Category-1	150 and 400	-3.0 and -10.0
Category-2	401 and 600	-10.1 and -15.0
Category-3	above 600	-15.1 and -20.0

3.2. *Variations and trends in seasonal PET*

Seasons are defined as : Winter or season-1 (Jan-Feb), Pre monsoon or season-2 (Mar-April-May), Monsoon or season-3 (June-July-Aug-Sept), and Post monsoon or season-4 (Oct-Nov-Dec). Variations in mean seasonal PET over India are shown in Figs. 3(a&b). Mean seasonal PET values varied between 205.3 and 545.0 mm. The mean seasonal PET values, in the order of rank, is highest 579.1 mm (35.6 %) in Season-3, followed by 545.0 mm (33.5%) in Season-2, 298.8 mm (18.3%) in Season-4 and lowest 205.3 mm (12.6 %) in Season-1.

TABLE 2

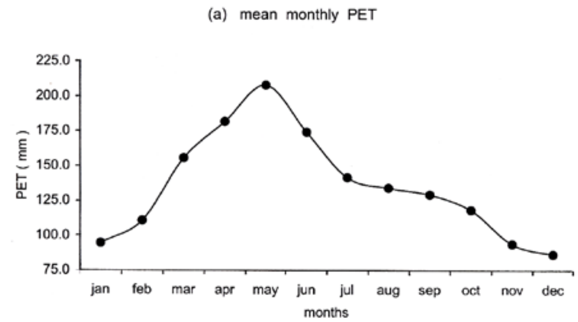
Contribution of different seasons towards annual dEo/d*t* (significant at p > 0.95)* at various locations in India (1971-2000)

S. No.	Station	dEo/d*t* (mm/year)			
		Winter	Pre-monsoon	Monsoon	Post-monsoon
1.	Jodhpur	**-3.25**	**-7.18**	**-4.63**	**-5.00**
2.	Bellary	**-1.82**	**-4.08**	**-5.89**	**-2.06**
3.	Akola	**-2.09**	**-5.27**	-2.76	**-3.58**
4.	New Delhi	**-1.13**	**-4.13**	**-3.55**	**-2.79**
5.	Kovilpatti	**-1.85**	**-2.05**	**-5.60**	**-1.75**
6.	Hyderabad	**-1.19**	**-3.93**	**-3.78**	**-1.70**
7.	Bhubaneshwar	**-1.50**	**-4.30**	**-2.85**	**-1.75**
8.	Adhartal	**-1.04**	**-3.82**	**-2.84**	**-1.43**
9.	Anand	**-0.86**	**-3.19**	**-4.08**	**-0.97**
10.	Hebbal	**-1.43**	**-2.24**	**-2.96**	**-1.37**
11.	Hissar	**-0.78**	**-2.83**	-2.87	**-0.97**
12.	Canning	**-1.00**	**-2.84**	**-1.60**	**-1.96**
13.	Pantnagar	**-0.92**	**-2.85**	-1.00	**-1.46**
14.	Anamalai nagar	-0.09	-1.36	**-3.78**	-0.82
15.	Rajamundry	**-0.70**	**-1.37**	**-3.29**	-0.69
16.	Dharwad	**-1.72**	**-1.42**	-0.26	**-1.88**
17.	Karimganj	**-0.72**	-0.70	-0.75	**-0.83**
	Average (percent)	-1.30 (13.88)	-3.15 (33.66)	-3.09 (32.98)	-1.82 (19.48)

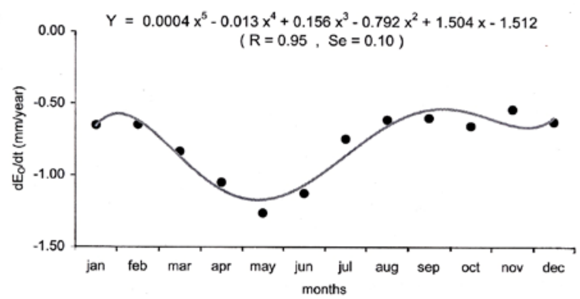
* Significant values for the stations have been shown in bold and non significant in normal font. Values in bracket ( ) show percent contribution.

Seasonal dEo/d*t*, *i.e*., the rate at which PET decreases at a given location and in a particular season, has been computed for all the four seasons. Seasonal dEo/d*t* values (significant at p > 0.95) at various locations in India are given in Table 2. One would normally expect a uniform distribution of dEo/d*t* values in different seasons, however it is not so. It may be seen that there are large variations in dEo/d*t* values from season-1 through season-4. The highest range (4.03) of variation from -1.82 to -5.89 mm/year has been observed at Bellary. The lowest range (0.13) of variation from -0.70 to -0.83 mm/year has been observed at Karimganj. In Table 2, significant values for the stations have been shown in bold and non significant in normal font. Values in bracket show percent contribution. Although, the annual dEo/d*t* values have been found significant for these 17 locations, but the

(a) Mean seasonal PET



(b) Mean seasonal dEo/d*t*



Figs. 4(a&b). Variation in mean monthly PET and mean monthly (dEo/d*t*) over India (1971-2000)

seasonal dEo/d*t* values have not been found significant for all the four seasons. The number of seasons (out of four) in which dEo/d*t* values have been found significant varied from 4 to 1. In ten (out of 17) locations (*i.e*., Jodhpur, Bellary, New Delhi, Kovilpatti, Hyderabad, Bhubaneshwar, Adhartal, Anand, Hebbal and Canning) the dEo/dt values have been found significant in all four seasons. However, only at one location (*i.e*., Anamalainagar) it has been found significant in only one season. On an average, over India, the contribution of mean seasonal dEo/d*t* towards annual dEo/d*t* (mm/year), in the order of rank, is highest - 3.10 (nearly 33 %) in Season-2 and Season-3, followed by -1.82 (20%) in Season-4 and lowest - 1.30 (14 %) in Season-1. Variations in mean seasonal dEo/d*t* over India are shown in Figs. 3(a&b). Using best fit curve technique the following non linear relationship has been obtained. This equation may be used to quantitatively estimate the mean seasonal dEo/d*t* values over India;

$$Y = 0.778\ x^2 - 4.045\ x + 1.931$$
(R = 0.97 , Se = 0.15)

Y = mean seasonal dEo/d*t* (mm/year) over India,

x = season number (1 to 4)

TABLE 3

Contribution of different months towards annual dEo/d*t* (significant at p > 0.95)* at various locations in India (1971-2000)

S. No.	Station	dEo/d*t* (mm/year)											
		Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
1.	Jodhpur	**-1.57**	**-1.69**	**-2.15**	**-2.46**	**-2.58**	**-2.07**	-0.76	-0.65	**-1.14**	**-1.54**	**-1.68**	**-1.77**
2	Bellary	**-0.75**	**-1.07**	**-1.42**	**-1.17**	**-1.49**	**-1.42**	**-1.70**	**-1.99**	-0.78	**-0.99**	**-0.57**	**-0.50**
3	Akola	**-1.09**	**-1.00**	**-1.09**	**-1.86**	**-2.33**	-1.05	-0.42	0.07	**-1.35**	**-1.29**	**-1.13**	**-1.16**
4	New Delhi	**-0.63**	**-0.50**	**-0.72**	**-1.67**	**-1.74**	**-1.69**	-0.65	-0.65	-0.56	**-1.00**	**-0.87**	**-0.92**
5	Kovilpatti	**-1.00**	**-0.85**	**-0.58**	-0.68	-0.79	**-1.46**	**-1.79**	**-1.60**	**-0.75**	-0.62	**-0.58**	**-0.55**
6	Hyderabad	**-0.55**	**-0.64**	**-0.86**	**-1.42**	**-1.65**	**-1.22**	-0.97	-1.01	-0.58	**-0.68**	**-0.48**	**-0.54**
7	Bhubaneshwar	**-0.73**	**-0.77**	**-1.15**	**-1.30**	**-1.85**	**-1.60**	-0.32	-0.32	**-0.61**	**-0.50**	**-0.64**	**-0.61**
8	Adhartal	**-0.59**	**-0.45**	**-0.88**	**-1.36**	**-1.58**	**-1.42**	-0.39	-0.31	**-0.72**	**-0.44**	**-0.44**	**-0.55**
9	Anand	**-0.47**	-0.39	**-0.68**	**-1.13**	**-1.38**	**-2.00**	**-1.44**	0.34	**-0.98**	**-0.50**	-0.16	**-0.31**
10	Hebbal	**-0.62**	**-0.81**	**-0.83**	**-0.94**	-0.47	**-1.03**	**-0.85**	**-0.75**	-0.33	-0.46	**-0.48**	**-0.43**
11	Hissar	**-0.33**	**-0.45**	**-0.72**	**-1.04**	-1.07	**-1.33**	-0.60	-0.35	-0.59	**-0.57**	-0.24	-0.16
12	Canning	**-0.51**	**-0.49**	**-1.12**	-0.59	**-1.13**	-0.58	**-0.52**	-0.20	-0.30	**-0.75**	**-0.67**	**-0.54**
13	Pantnagar	**-0.49**	**-0.43**	**-0.57**	-0.88	**-1.40**	-0.23	-0.06	-0.34	**-0.37**	**-0.44**	**-0.46**	**-0.56**
14	Anamalai nagar	-0.07	-0.02	0.00	-0.64	-0.72	**-1.19**	-0.61	**-1.73**	-0.25	**-0.72**	0.07	-0.17
15	Rajamundry	**-0.44**	-0.26	**-0.42**	-0.32	-0.63	-1.12	**-1.19**	-0.53	-0.45	-0.23	-0.05	**-0.41**
16	Dharwad	**-0.93**	**-0.79**	**-0.66**	-0.47	-0.29	0.02	-0.19	-0.01	-0.08	**-0.07**	**-0.60**	**-1.21**
17	Karimganj	**-0.31**	**-0.41**	**-0.36**	0.06	-0.40	0.23	-0.23	-0.38	-0.37	**-0.36**	**-0.20**	**-0.27**
	Average (percent)	-0.65 (6.96)	-0.65 (6.92)	-0.84 (8.93)	-1.05 (11.22)	-1.26 (13.51)	-1.13 (12.04)	-0.75 (7.98)	-0.61 (6.54)	-0.60 (6.41)	-0.66 (7.01)	-0.54 (5.77)	-0.63 (6.70)

* Significant values for the stations have been shown in bold and non significant in normal font. Values in bracket ( ) show percent contribution

3.3. *Variations and trends in monthly PET*

Variations in mean monthly PET over India are shown in Figs. 4(a&b). Mean monthly PET values varied from 86.5 mm in December to 207.8 mm in May. It may be seen that mean monthly PET values, show a steady rising tendency between January and May. The peak in mean monthly PET is achieved in the month of May. The values show a steady falling tendency between June and July. A further gradual decrease in values is observed between August and December. The mean monthly PET values have been found lowest in December.

Monthly dEo/d*t*, *i.e.*, the rate at which PET decreases at a given location and in a particular month, has been computed for all months (January through December). Monthly dEo/d*t* values (significant at p > 0.95) at various locations in India are given in Table 3. One would normally expect a uniform distribution of dEo/d*t* values in different months, however it is not so. It may be seen that there are wide variations in dEo/d*t* values from January through December and even the trends have reversed (dEo/d*t* > 0) at few occasions. The highest range (2.39) of variation from +0.07 to –2.33 mm/year has been observed at Akola. The lowest range (0.64) of variation from +0.23 to –0.41 mm/year has been observed at Karimganj. In Table 2, significant values for the stations have been shown in bold and non significant in normal font. Values in bracket show percent contribution. Although, the annual dEo/d*t* values have been found significant for these 17 locations, but the monthly dEo/d*t* values have not been found significant in all months. The number of months (out of 12) in which dEo/d*t* values have been found significant varied from 11 to 3. At Bellary, the dEo/d*t* values have been found significant in maximum (11) number of months. At Anamalainagar, it has been found significant in minimum (3) number of months. On an average, over India, it has been found that the highest

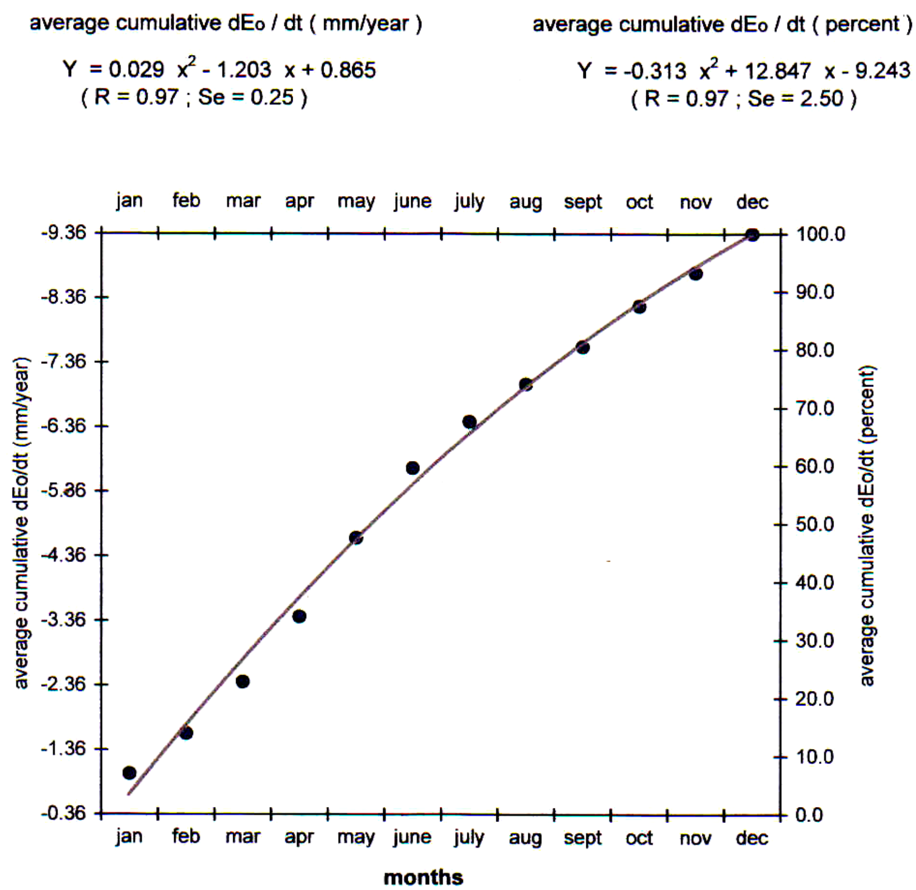


Fig. 5. Monthwise progress of average cumulative dEo/d*t* (mm/year) and its contribution towards average annual dEo/d*t* (percent) over India (1971-2000)

magnitude of monthly dEo/d*t* values, are occurring during the three month period (April, May and June). The contribution of monthly dEo/d*t* towards annual dEo/d*t* (mm/year), in the order of rank, is highest –1.26 (13.51 %) in May, followed by June, April, March, July, October, January, February, December, September and lowest –0.54 (5.77 %) in November. Variations in mean monthly dEo/d*t* over India are shown in Figs. 4(a&b). Using best fit curve technique the following non linear relationship has been obtained. This equation may be used to quantitatively estimate the average monthly dEo/d*t* values over India;

$$Y = 0.0004\ x^5 - 0.013\ x^4 + 0.156\ x^3 - 0.792\ x^2 + 1.504\ x - 1.512$$

(R = 0.95 , Se = 0.10)

Y = mean monthly dEo/d*t* (mm/year) over India.

x = month number (1 to 12)

The month wise progress of average cumulative dEo/d*t* (mm/year) and its contribution towards average annual dEo/d*t* (percent) over India (1971-2000) may be seen in Fig. 5. Using best fit curve technique the non linear relationship has been obtained. The following equation may be used to quantitatively estimate the average cumulative dEo/d*t* values over India (mm/year) up to any particular month;

$$Y = 0.029\ x^2 - 1.203\ x + 0.865$$

(R = 0.97 ; Se = 0.25)

Y = average cumulative dEo/d*t* (mm/year) over India,

x = month number (1 to 12)

The following equation may be used to quantitatively estimate the contribution (percent) towards average annual dEo/d*t* over India, up to any particular month;

$$Y = -0.313\ x^2 + 12.847\ x - 9.243$$
$$(R = 0.97\ ;\ Se = 2.50)$$

Y = contribution (percent) towards average annual dEo/d*t* over India,

x = month number (1 to 12)

4. Conclusions

(*i*) The mean annual PET has been found to be highest (2109 mm) at Bellary and lowest (1100 mm) at Buralikson. The highest C.V. of 10% has been observed at Jodhpur and lowest C.V. of 3% at Pune.

(*ii*) Out of twenty two locations, significant decreasing trend in annual PET has been observed at seventeen locations and no significant trend at five locations.

(*iii*) The annual dEo/d*t* values varied from – 3.00 (Karimganj) to – 20.06 (Jodhpur) mm/year. The mean annual dEo/d*t* over India, has been found to be – 9.36 mm/year.

(*iv*) The mean seasonal PET is highest 579.1 mm (35.6 %) in Season-3 and lowest 205.3 mm (12.6 %) in Season-1. On an average, over India, the contribution of mean seasonal dEo/d*t* towards annual dEo/d*t* (mm/year), in the order of rank, is highest – 3.10 (nearly 33 %) in Season-2 and Season-3, followed by – 1.82 (20%) in Season-4 and lowest – 1.30 (14 %) in Season-1.

(*v*) Mean monthly PET is highest 207.8 mm in May and lowest 86.5 mm in December. On an average, over India, it has been found that the highest magnitudes of monthly dEo/d*t* values are occurring during the three month period (April, May and June). The contribution of mean monthly dEo/d*t* towards annual dEo/d*t* (mm/year), in the order of rank, is highest – 1.26 (13.51 %) in May, followed by June, April, March, July, October, January, February, December, September and lowest – 0.54 (5.77 %) in November.

(*vi*) Linear relationship has been obtained to quantitatively estimate annual dEo/d*t*, at a given location, using annual PET range. Non linear relationships have been obtained (*a*) to quantitatively estimate the mean monthly dEo/d*t* values over India, (*b*) to quantitatively estimate the average cumulative dEo/d*t* values over India (mm/year) up to any particular month and (*c*) to quantitatively estimate the contribution (percent) towards average annual dEo/d*t* over India, up to any particular month.

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