MAUSAM, **59**, 3 (July 2008), 347-356

551.573 (540)

Recent variations and trends in pan evaporation over India

I. J. VERMA and V. N. JADHAV

India Meteorological Department, Pune – 411 005, India

(*Received 12 September 2006, Modified 4 June 2008*)

e mail : ijverma2@yahoo.co.in

सार – इस शोध पत्र में भारत में फैले हुए प्रमुख बीस स्थानों पर संस्थापित यू.एस. श्रेणी–ए के वाष्पीकरण–पात्रों (पैन्स) से निर्धारित समय पर प्राप्त किए गए तीस वर्षों (1971–2000) के वाष्पीकरण आँकड़ों का उपयोग किया गया है। इस स्थानों के लिए वार्षिक वाष्पीकरण के आधारभूत सांख्यिकीय प्राचलों न्यूनतम, अधिकतम, अवधि, औसत, मानक विचलन (एस.डी.) और विक्षेप (सी. वी.) का आकलन किया गया है। रैखिक प्रवृति विश्लेषण तकनीक का उपयोग करते हुए इसकी वार्षिक, ऋतुवार और मासिक प्रवृतियों का अध्ययन किया गया है। जब कभी भी महत्वपुर्ण परिवर्तन हुए उन विशिष्ट अवधियों का पता लगाने के लिए पैन वाष्पीकरण प्रवृतियों में पाई गई भिन्नताओं तथा परिवतनों के उपयुक्त आरेख तैयार किए गए है।

पैन वाष्पीकरण का वार्षिक औसत का न्यूनतम मान (1107 मि. मी.) बुरालीक्सन में तथा उच्चतम मान (3004 मि. मी.) राजकोट में पाया गया है। लगभग 11 प्रतिशत का उच्चतम विक्षेप गुणांक राजामुंद्री, जोधपुर, बुराललीक्सन और नेल्लोर में प्रेक्षित किया गया है। लगभग 2 प्रतिशत का न्यूनतम विक्षेप गुणांक अम्बिकापुर में प्रेक्षित किया गया है। कुल बीस स्थानों में से पन्द्रह स्थानों के पैन वाष्पीकरण के वार्षिक वाष्पीकरण मानों में गिरावट की प्रवति देखी गई है और पाँच स्थानों में किसी प्रकार की कोई महत्वपूर्ण प्रवृति नहीं देखी गई है। इनके वार्षिक डी. ई./डी.टी. मान –6.27 (कैनिग) से –29.30 (जोधपुर) मि. मी./वर्ष तक बदलते रहे हैं। भारत में वार्षिक औसत डी. ई./डी.टी. मान –14.90 मि.मी./वर्ष पाया गया है। पैन वाष्पीकरण अवधि का उपयोग करते हुए किसी स्थान विशेष का परिणात्मक वार्षिक डी. ई./डी.टी. मान का आकलन करके रैखिक समानता पाई गई है। भारत में ओसतन वार्षिक डी. ई./डी.टी. (मि.मी./वर्ष) तुलना में ऋतुगत डी. ई./डी.टी. का योगदान उच्चतम –5.63 (37.8 प्रतिशत) ऋतु–2 (मार्च–अप्रेल–मई) में तथा न्यूनतम –2.07 (13.9 प्रतिशत) ऋतु–1 (जनवरी–फरवरी) में पाया गया है। भारत में ओसतन वार्षिक डी. ई./डी.टी. (मि.मी./वर्ष) की तुलना में मासिक डी. ई./डी.टी. का योगदान उच्चतम –2.08 (14.0 प्रतिशत) मई में तथा न्यूनतम –0.77 (5.2 प्रतिशत) अगस्त में पाया गया है इनकी अरैखिक समानता (क) भारत में किसी विशेष माह के मासिक डी. ई./डी.टी. के मानों का औसत परिणात्मक आकलन करके (ख) भारत में किसी भी माह के सचयी डी. ई./डी.टी. के औसत मानों का परिणात्मक आकलन करके और (ग) भारत में किसी माह के औसत वार्षिक डी. ई./डी.टी. की तुलना में परिणात्मक योगदान (प्रतिशत) का आकलन करके पाई गई है।

ABSTRACT. Thirty years pan evaporation time series data (1971-2000) recorded from US class-A evaporation pans for twenty well distributed locations in India, have been utilized in the present study. For all the locations, basic statistical parameters of annual evaporation [minimum, maximum, range, mean, standard deviation (S.D.) and coefficient of variation (C.V.)] have been computed. Annual, seasonal and monthly trends have been studied using linear trend analysis technique. Suitable graphs have been plotted to study the variations and changes in pan evaporation trends and to identify the specific periods as and when significant changes occur.

The mean annual pan evaporation was found to be lowest (1107 mm) at Buralikson and highest (3004 mm) at Rajkot. The highest C.V. of nearly 11% was observed at Rajamundry, Jodhpur, Buralikson and Nellore. The lowest C.V. of nearly 2% was observed at Ambikapur. Out of twenty locations, significant decreasing trend in annual pan evaporation was observed at fifteen locations and no significant trend at five locations. The annual dE/d*t* values varied from -6.27 (Canning) to -29.30 (Jodhpur) mm/year. The average annual dE/d*t* over India was found to be -14.90 mm/year. Linear relationship was obtained to quantitatively estimate annual dE/d*t*, at a given location, using pan evaporation range. On an average, over India, the contribution of seasonal dE/d*t* towards annual dE/d*t* (mm/year) is highest -5.63 (37.8 %) in Season-2 (March-April-May) and lowest -2.07 (13.9 %) in Season-1(January- February). On an average, over India, the contribution of monthly dE/d*t* towards annual dE/d*t* (mm/year) is highest - 2.08 (14.0 %) in May and lowest -0.77 (5.2 %)

in August. Non linear relationships were obtained (a) to quantitatively estimate the average monthly dE/d*t* values over India, in any particular month (b) to quantitatively estimate the average cumulative dE/d*t* values over India (mm/year) upto any particular month and (c) to quantitatively estimate the contribution (per cent) towards average annual dE/d*t* over India, upto any particular month.

Key words – Annual evaporation, Seasonal evaporation, Monthly evaporation, Evaporation trends, Evaporation over India.

1. Introduction

Evaporation 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. Any major changes in evaporation will have profound implications for hydrological processes, water budget, agricultural crop performance and in turn, the economy of the country. In this context, studies related to long term changes in evaporation 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). However, studies related to long term changes in evaporation over India are scanty. Sambasiva Rao and Vamadevan (1986) studied evaporation rates from different pans under humid tropical conditions. Amirul Hussain (1986) studied evaporation over Bangladesh. Biswas and Khambete (1988) studied water consumption by dry land crops as related to pan evaporation. Rathore and Biswas (1991) prepared climatological maps of daily evaporation and weekly evaporation. These maps give a fairly good idea about the spatial variation in evaporation over India. Chowdhury *et al*. (1999) studied the relative contribution of different meteorological elements on evaporation. Chattopadhyay and Hulme (1997) studied the influence of different meteorological variables on changes in evaporation and found that compared to other variables relative humidity is strongly associated with changes in evaporation. Long term changes in evaporation were studied in different parts of the world (Peterson *et al*. 1995, Roderick and Farquhar, 2004).

In order to understand the implications of long period changes in evaporation on agriculture, 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 pan evaporation 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 pan evaporation time series data (1971-2000) recorded from US class-A evaporation pans for twenty 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 collected from National Data Center, India Meteorological Department, Pune. These stations are Adhartal (23° 09′ N, 79° 58′ E) (Madhya Pradesh), Akola (20° 42′ N, 77° 00′ E) (Maharashtra), Ambikapur (20° 08′ N, 83° 50′ E) (Madhya Pradesh), Anamalainagar (11° 24′ N, 79° 44′ E) (Tamilnadu), Bhubaneshwar (20° 15′ N, 85° 50′ E) (Orissa), Bikramganj (25° 10′ N, 84° 15′ E) (Bihar), Buralikson (26° 35′ N, 93° 50′ E) (Assam), Canning (22° 15′ N, 88° 40′ E) (West Bengal), Hebbal (13° 00′ N, 77° 38′ E) (Karnataka), Hissar (29° 10′ N, 75° 46′ E) (Haryana), Hyderabad (17° 32′ N, 78° 16′ E) (Andhra Pradesh), Jodhpur (26° 18′ N, 73° 01′ E) (Rajasthan), Karimganj (24° 50′ N, 92° 20′ E) (Assam), Nellore (14° 27′ N, 79° 59′ E) (Andhra Pradesh), Pantnagar (29° 00′ N, 79° 30′ E) (Uttaranchal), Pattambi (10° 48′ N, 76° 12′ E) (Kerala), Pune (18° 32′ N, 73° 51′ E) (Maharashtra), Rajamundry (17° 00′ N, 81° 46′ E) (Andhra Pradesh), Rajkot (22° 17′ N, 70° 48′ E) (Gujarat), Varanasi (28° 18′ N, 83° 03′ E) (Uttar Pradesh).

In this paper, for all twenty locations, the basic statistical parameters [minimum, maximum, range, mean, standard deviation (S.D.) and coefficient of variation (C.V.)] of annual evaporation have been computed. Annual, seasonal and monthly 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 pan evaporation trends and to identify the specific periods as and when significant changes occur. The annual rate of change (increase/decrease) in pan evaporation, at any location, in a given time period (annual, seasonal, monthly etc.) may be expressed quantitatively as dE/d*t*. The positive values of dE/d*t* indicate increase and negative values indicate decrease in pan evaporation in a given time period. Using trend analysis technique and slope of the trend line, dE/d*t* values have been computed. Attempt has been made to quantitatively estimate (*i*) annual dE/d*t*,

TABLE 1

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

Station	Basic statistical parameters of annual pan evaporation (mm)							
	Minimum	Maximum	Range	Mean	S.D.	C.V. (%)	Trend	dE/d*t* (mm/year)
Canning	1333	1780	447	1548	111	7.2	Decreasing	-6.27
Karimganj	1033	1401	368	1174	111	9.5	Decreasing	-6.39
Bhubaneshwar	1480	2036	556	1711	127	7.4	Decreasing	-7.00
Adhartal	1825	2253	428	2063	112	5.4	Decreasing	-8.10
Hyderabad	2497	2858	361	2656	116	4.4	Decreasing	-10.63
Bikramganj	1455	2133	678	1672	158	9.5	Decreasing	-11.55
Hebbal	1643	2234	591	1907	136	7.1	Decreasing	-12.35
Nellore	1741	2703	963	2105	222	10.5	Decreasing	-14.58
Buralikson	883	1281	398	1107	118	10.7	Decreasing	-15.0
Pattambi	1536	2050	514	1797	148	8.2	Decreasing	-16.00
Akola	2512	3322	810	2831	199	7.0	Decreasing	-19.60
Pune	1711	2586	875	2110	203	9.6	Decreasing	-20.20
Hissar	1884	2795	911	2256	236	10.5	Decreasing	-22.10
Rajamundry	1778	2789	1011	2176	238	10.9	Decreasing	-24.35
Jodhpur	2366	3518	1152	2993	320	10.7	Decreasing	-29.30
Ambikapur	1889	2024	136	1945	46	2.3	No Trend	-
Anamalainagar	2035	2519	483	2229	130	5.8	No Trend	-
Pantnagar	1721	2163	442	1894	107	5.6	No Trend	-
Rajkot	2693	3255	562	3004	159	5.3	No Trend	-
Varanasi	1604	2000	396	1737	156	9.0	No Trend	-

* S.D. – Standard deviation; C.V. – Coefficient of variation

at a given location, using pan evaporation range (*ii*) the average monthly dE/d*t* values over India, in any particular month (*iii*) the average cumulative dE/d*t* values over India (mm/year) up to any particular month and (*iv*) the contribution (percent) towards average annual dE/d*t* over India, up to any particular month.

3. Results and discussion

3.1. *Variations and trends in annual pan evaporation*

Basic statistical parameters [minimum, maximum, range, mean, standard deviation (S.D.) and coefficient of variation (C.V.)] and observed trends (1971-2000) of annual pan evaporation (significant at p > 0.95) for all twenty locations are given in Table 1. The minimum annual evaporation, at various locations, varied between 883 and 2693 mm. The lowest minimum annual evaporation of 883 mm was observed at Buralikson. The maximum annual evaporation, at various locations, varied between 1281 and 3518 mm. The highest maximum annual evaporation of 3518 mm was observed at Jodhpur. The annual evaporation range, defined as the difference of maximum and minimum, at various locations varied between 136 and 1152 mm. The lowest annual evaporation range of 136 mm has been observed at Ambikapur. The highest annual evaporation range of 1152 mm has been observed at Jodhpur. Large variations are observed in mean annual evaporation at various locations in India. Mean annual evaporation varied between 1107 and 3004 mm. The lowest mean annual evaporation of 1107 mm has been observed at Buralikson. The highest mean annual evaporation of 3004 mm has been observed

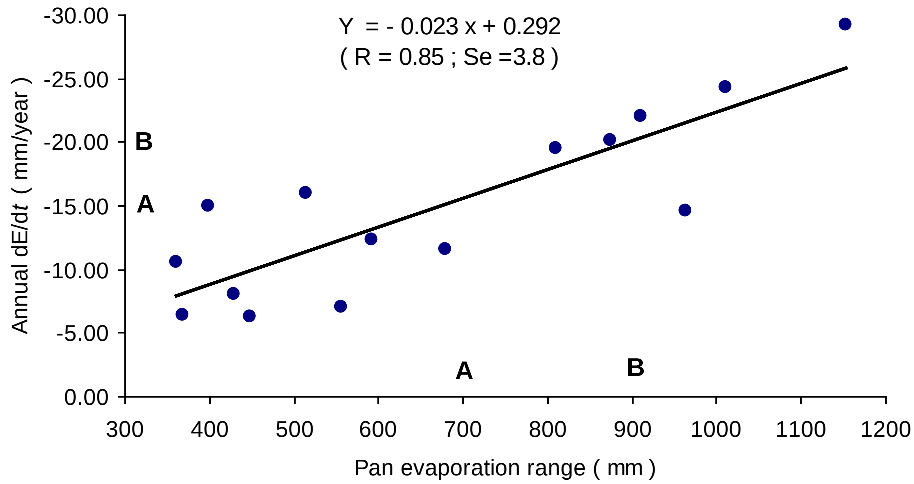


Fig. 1. Variation in annual dE/d*t* (mm/year) in relation to pan evaporation range (mm) over India (1971-2000)

at Rajkot. The coefficient of variation (C.V.), defined as the ratio of standard deviation to mean and expressed as per cent, at various locations varied between 2.3 and 10.9 per cent. The highest C.V. of nearly 11% has been observed at Rajamundry, Jodhpur, Buralikson and Nellore. The lowest C.V. of nearly 2% has been observed at Ambikapur.

Out of twenty locations, significant decreasing trends in annual evaporation have been observed at fifteen locations. No significant trend in annual evaporation has been observed at five locations (Ambikapur, Anamalainagar, Pantnagar, Rajkot and Varanasi). These five locations have been ignored in further study. The annual rate of change (increase/decrease) in pan evaporation, at any location, in a given time period (annual, seasonal, monthly etc.) may be expressed quantitatively as dE/d*t*. The positive values of dE/d*t* indicate increase while the negative values indicate decrease in pan evaporation in a given time period. Using trend analysis technique and slope of the trend line, dE/d*t* values have been computed for those fifteen locations in which significant decreasing trend in annual evaporation have been observed. These annual dE/d*t* values are given in Table 1. The annual dE/d*t* values, at various locations varied from -6.27 mm/year at Canning to -29.30 mm/year at Jodhpur. The average annual dE/d*t*, over India, has been found to be -14.90 mm/year. Variation in annual dE/d*t* (mm/year) in relation to pan evaporation range is shown in Fig. 1. Significant correlation has been observed between these parameters and the linear regression obtained is given by :

$$Y = -0.023 X + 0.292 \quad (r = 0.85 ; Se = 3.8)$$

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

X = pan evaporation range (mm)

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

Category	*Pan evaporation range (mm)*	*Annual dE/dt (mm/year)*
Category-1 (upto mark “A”)	300 and 700	-5.0 and -15.0
Category-2 (upto mark “B”)	701 and 900	-15.1 and -20.0
Category-3	above 900	-20.1 and -30.0

3.2. *Seasonal variations in* dE/d*t*

Seasonal dE/d*t*, *i.e.*, the rate at which pan evaporation decreases at a given location and in a particular season, has been computed for all the four seasons, *viz*., season-1 (Jan-Feb), season-2 (Mar-Apr-May), season-3 (Jun-Jul-Aug-Sep), and season-4 (Oct-Nov-Dec). Seasonal dE/d*t* values and their contribution towards annual dE/d*t* (significant at $p > 0.95$) at various locations in India are given in Table 2. One would normally expect a uniform distribution of dE/d*t* values in different seasons, however it is not so. It may be seen that there are large variations in dE/d*t* values from season-1

TABLE 2

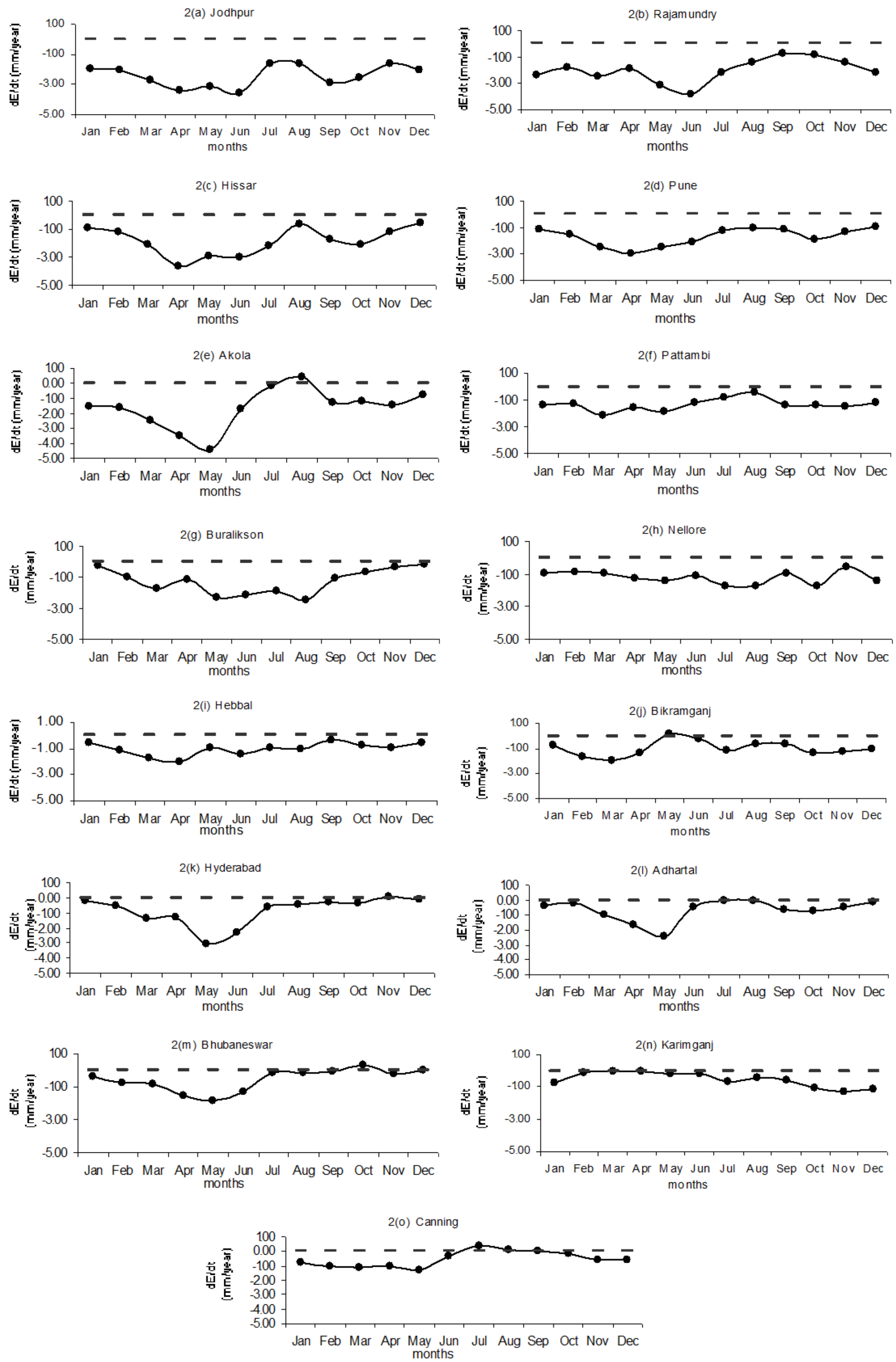
Contribution of different seasons towards annual dE/d*t* (mm/year) of pan evaporation (significant at p > 0.95)* at various locations in India (1971-2000)

S. No.	Station	dE/d*t* (mm / year)			
		Season 1	Season 2	Season 3	Season 4
1	Jodhpur	**-4.05 (13.82)**	**-9.32 (31.81)**	**-9.74 (33.24)**	**-6.19 (21.13)**
2	Rajamundry	**-4.20 (17.25)**	**-7.58 (31.13)**	**-8.17 (33.55)**	**-4.40 (18.07)**
3	Hissar	**-2.10 (9.50)**	**-8.65 (39.14)**	**-7.48 (33.85)**	**-3.87 (17.51)**
4	Pune	**-2.70 (13.37)**	**-7.90 (39.13)**	**-5.45 (26.99)**	**-4.14 (20.51)**
5	Akola	**-3.12 (15.92)**	**-10.39 (53.01)**	-2.69 (13.72)	**-3.40 (17.35)**
6	Pattambi	**-2.63 (16.44)**	**-5.53 (34.56)**	**-3.82 (23.88)**	**-4.02 (25.13)**
7	Buralikson	**-1.20 (8.00)**	**-5.13 (34.20)**	**-7.53 (50.20)**	-1.14 (7.60)
8	Nellore	**-1.86 (12.76)**	**-3.55 (24.35)**	**-5.45 (37.38)**	**-3.72 (25.51)**
9	Hebbal	**-1.67 (13.52)**	**-4.65 (37.65)**	**-3.73 (30.20)**	**-2.30 (18.62)**
10	Bikramganj	**-2.30 (19.91)**	-3.00 (25.97)	-2.63 (22.77)	**-3.62 (31.34)**
11	Hyderabad	**-0.75 (7.06)**	**-5.75 (54.09)**	**-3.65 (34.34)**	-0.48 (4.52)
12	Adhartal	-0.62 (7.65)	**-5.11 (63.09)**	-1.15 (14.20)	-1.22 (15.06)
13	Bhubaneshwar	**-1.20 (17.14)**	**-4.22 (60.29)**	-1.62 (23.14)	0.04 (-0.57)
14	Karimganj	-0.85 (13.30)	-0.24 (3.76)	**-1.81 (28.33)**	**-3.49 (54.62)**
15	Canning	**-1.75 (27.91)**	**-3.44 (54.86)**	0.27 (-4.31)	**-1.35 (21.53)**
	Average	**- 2.07 (13.9)**	**- 5.63 (37.8)**	**- 4.31 (28.9)**	**- 2.89 (19.4)**

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

through season 4. At all locations, seasonal dE/d*t* values varied between -10.39 and +0.27 mm/year. The highest range of variation from -10.39 to -2.69 mm/year has been observed at Akola. The lowest range of variation from -3.62 to -2.30 mm/year has been observed at Bikramganj. It may also be seen that the highest magnitude of seasonal dE/d*t* values, in maximum number of locations (9 out of 15) are occurring in season 2. The highest magnitude of seasonal dE/d*t* (mm/year) has been observed in season-1 at Rajamundry (-4.20), in season 2 at Akola (-10.39), in season 3 and season 4 at Jodhpur (-9.74 and -6.19).

In Table 2, significant values for the stations have been shown in bold and non significant in normal font. Values in bracket show per cent contribution. Although, the annual dE/d*t* values have been found significant for these stations, but the seasonal dE/d*t* values have not been found significant in all four seasons and even the trends



Figs. 2 (a-o). Variations in average monthly rate of decrease in pan evaporation (dE/d*t*) at different locations in India (1971-2000)

TABLE 3

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

S. No.	Station	dE/d*t* (mm/year)											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	Jodhpur	**-1.98**	**-2.07**	**-2.75**	**-3.39**	**-3.18**	**-3.58**	-1.58	-1.66	**-2.92**	**-2.53**	**-1.64**	**-2.02**
		(6.76)	**(7.06)**	**(9.39)**	**(11.57)**	**(10.85)**	**(12.22)**	(5.39)	(5.67)	**(9.97)**	**(8.63)**	**(5.60)**	**(6.89)**
2	Rajamundry	**-2.39**	**-1.81**	**-2.47**	**-1.92**	**-3.19**	**-3.85**	**-2.17**	**-1.42**	-0.73	-0.85	**-1.40**	**-2.15**
		(9.82)	**(7.43)**	**(10.14)**	**(7.89)**	**(13.10)**	**(15.81)**	**(8.91)**	**(5.83)**	(3.00)	(3.49)	**(5.75)**	**(8.83)**
3	Hissar	**-0.90**	**-1.20**	**-2.05**	**-3.66**	**-2.94**	**-3.00**	-2.16	-0.62	**-1.70**	**-2.08**	**-1.22**	**-0.57**
		(4.07)	**(5.43)**	**(9.28)**	**(16.56)**	**(13.30)**	**(13.57)**	(9.77)	(2.81)	**(7.69)**	**(9.41)**	**(5.52)**	**(2.58)**
4	Pune	**-1.17**	**-1.53**	**-2.44**	**-3.00**	**-2.46**	**-2.11**	**-1.22**	**-1.03**	**-1.09**	**-1.90**	**-1.32**	**-0.92**
		(5.79)	**(7.58)**	**(12.09)**	**(14.86)**	**(12.18)**	**(10.45)**	**(6.04)**	**(5.10)**	**(5.40)**	**(9.41)**	**(6.54)**	**(4.56)**
5	Akola	**-1.53**	**-1.59**	**-2.48**	**-3.48**	**-4.43**	-1.69	-0.17	0.41	**-1.24**	**-1.18**	**-1.42**	**-0.80**
		(7.81)	**(8.11)**	**(12.65)**	**(17.76)**	**(22.60)**	(8.62)	(0.87)	(-2.09)	**(6.33)**	**(6.02)**	**(7.24)**	**(4.08)**
6	Pattambi	**-1.38**	**-1.25**	**-2.12**	**-1.56**	**-1.85**	**-1.17**	**-0.84**	**-0.44**	**-1.37**	**-1.39**	**-1.48**	**-1.15**
		(8.63)	**(7.81)**	**(13.25)**	**(9.75)**	**(11.56)**	**(7.31)**	**(5.25)**	**(2.75)**	**(8.56)**	**(8.69)**	**(9.25)**	**(7.19)**
7	Buralikson	-0.26	**-0.94**	**-1.75**	**-1.12**	**-2.26**	**-2.11**	**-1.90**	**-2.46**	**-1.06**	-0.66	-0.35	-0.13
		(1.73)	**(6.27)**	**(11.67)**	**(7.47)**	**(15.07)**	**(14.07)**	**(12.67)**	**(16.40)**	**(7.07)**	(4.40)	(2.33)	(0.87)
8	Nellore	**-0.98**	-0.88	-0.92	-1.23	-1.40	-1.11	**-1.70**	**-1.72**	-0.92	**-1.76**	-0.58	**-1.38**
		(6.72)	(6.04)	(6.31)	(8.44)	(9.60)	(7.61)	**(11.66)**	**(11.80)**	(6.31)	**(12.07)**	(3.98)	**(9.47)**
9	Hebbal	**-0.50**	**-1.17**	**-1.70**	**-2.00**	**-0.95**	**-1.44**	-0.92	**-1.00**	-0.37	**-0.77**	**-0.98**	-0.55
		(4.05)	**(9.47)**	**(13.77)**	**(16.19)**	**(7.69)**	**(11.66)**	(7.45)	**(8.10)**	(3.00)	**(6.23)**	**(7.94)**	(4.45)
10	Bikramganj	**-0.68**	**-1.62**	**-1.90**	-1.30	0.20	-0.25	-1.17	-0.63	**-0.58**	**-1.32**	**-1.25**	**-1.05**
		(5.89)	**(14.03)**	**(16.45)**	(11.26)	(-1.73)	(2.16)	(10.13)	(5.45)	**(5.02)**	**(11.43)**	**(10.82)**	**(9.09)**
11	Hyderabad	**-0.20**	-0.55	**-1.40**	**-1.30**	**-3.05**	**-2.32**	-0.60	-0.45	-0.28	**-0.38**	0.03	-0.13
		(1.88)	(5.17)	**(13.17)**	**(12.23)**	**(28.69)**	**(21.83)**	(5.64)	(4.23)	(2.63)	**(3.57)**	(-0.28)	(1.22)
12	Adhartal	**-0.40**	-0.22	**-1.00**	**-1.66**	-2.45	-0.44	0.00	**-0.05**	**-0.66**	-0.70	-0.42	-0.10
		(4.94)	(2.72)	**(12.35)**	**(20.49)**	(30.25)	(5.43)	(0.00)	**(0.62)**	**(8.15)**	(8.64)	(5.19)	(1.23)
13	Bhubaneswar	-0.40	**-0.80**	-0.86	**-1.50**	**-1.86**	-1.30	-0.12	-0.15	-0.05	0.28	-0.24	0.00
		(5.71)	**(11.43)**	(12.29)	**(21.43)**	**(26.57)**	(18.57)	(1.71)	(2.14)	(0.71)	(-4.00)	(3.43)	(0.00)
14	Karimganj	**-0.72**	-0.13	-0.03	-0.05	-0.16	-0.18	**-0.63**	-0.46	-0.54	**-1.06**	**-1.27**	**-1.16**
		(11.27)	(2.03)	(0.47)	(0.78)	(2.50)	(2.82)	**(9.86)**	(7.20)	(8.45)	**(16.59)**	**(19.87)**	**(18.15)**
15	Canning	**-0.75**	**-1.00**	**-1.12**	**-1.02**	-1.30	-0.28	0.34	0.16	0.05	-0.12	**-0.63**	**-0.60**
		(11.96)	**(15.95)**	**(17.86)**	**(16.27)**	(20.73)	(4.47)	(-5.42)	(-2.55)	(-0.80)	(1.91)	**(10.05)**	**(9.57)**
	Average	**-0.95**	**-1.12**	**-1.67**	**-1.88**	**-2..08**	**-1.65**	**-0.99**	**-0.77**	**-0.90**	**-1.10**	**-0.94**	**-0.85**
		(6.4)	**(7.5)**	**(11.2)**	**(12.6)**	**(14.0)**	**(11.1)**	**(6.6)**	**(5.2)**	**(6.0)**	**(7.4)**	**(6.3)**	**(5.7)**

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

have reversed at a couple of occasions (dE/d*t* > 0). The number of seasons (out of four) in which dE/d*t* values have been found significant varied from 4 to 1. At seven (out of 15) locations (*i.e.*, Jodhpur, Rajamundry, Hissar, Pune, Pattambi, Nellore and Hebbal. The dE/d*t* values have been found significant in all four seasons. However, only at one location (*i.e.*, Adhartal) it has been found significant in only one season. In a particular season, the number of locations (out of 15) when dE/d*t* values have been found significant varied from 13 to 10. Maximum (13) numbers of locations have shown significant dE/d*t* values in season 1 and season 2, followed by 11 locations in season 4 and minimum (10) numbers of locations in season 3. On an average, over India, the contribution of seasonal dE/d*t* towards annual dE/d*t* (mm/year), in the order of rank, is highest -5.63 (37.8 %) in season 2, followed by -4.31 (28.9 %) in season 3, -2.89 (19.4 %) in season 4 and lowest -2.07 (13.9 %) in season-1.

3.3. *Monthly variations in dE/dt*

Monthly dE/d*t* values, (the rate at which pan evaporation decreases) at a given location and in a particular month, were computed for all (12) months

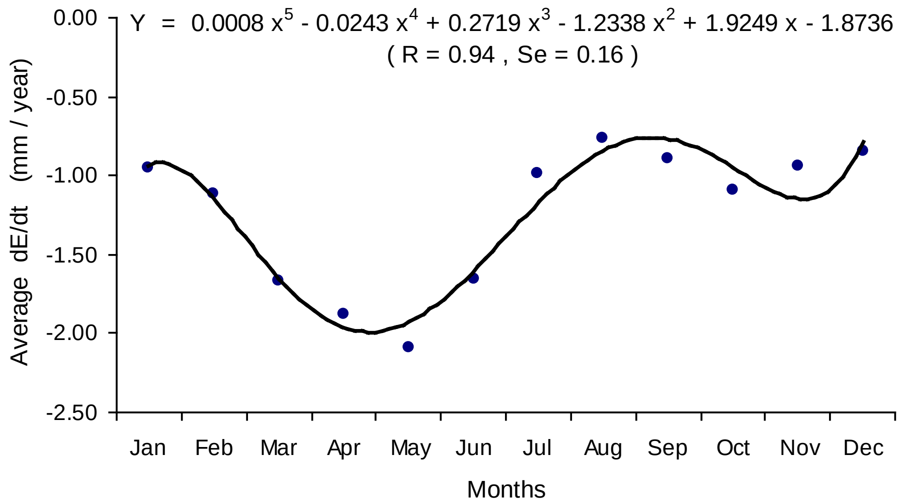


Fig. 3. Average monthly rate of decrease in pan evaporation (dE/d*t*) in different months over India (1971-2000)

(January through December), for various locations in India [Figs. 2(a-o)]. One would normally expect uniform distribution of dE/d*t* values in different months, however it is not so. It may be seen that there are large variations in dE/d*t* values from January through December and even the trends have reversed (dE/d*t* > 0) at few occasions. At all locations, monthly dE/d*t* values varied between -4.43 and +0.41 mm/year. The highest range of variation from -4.43 to +0.41 mm/year has been observed at Akola. The lowest range of variation from -1.76 to -0.58 mm/year has been observed at Nellore. It may also be seen that the highest magnitude of monthly dE/d*t* values, in maximum number of locations (12 out of 15) are occurring during the four month period (March, April, May and June). The highest magnitude of monthly dE/d*t* (mm/year), in a particular month, *i.e.*, in Jan (-2.39), Jun (-3.85), Jul (-2.17) and Dec (-2.15) has been observed at Rajamundry; in Feb (-2.07), Mar (-2.75) , Sep (-2.92), Oct (-2.53) and Nov (-1.64) at Jodhpur ; in April (-3.66) at Hissar ; in May (-4.43) at Akola and in August (-2.46) at Buralikson.

Monthly dE/d*t* values (significant at p > 0.95) and their contribution towards annual dE/d*t* at various locations in India are given in Table 3. Significant values for the stations have been shown in bold and non significant in normal font. Values in bracket show per cent contribution. Although, the annual dE/d*t* values have been found significant for these stations, the monthly dE/d*t* values have not been found significant in all months. The number of months (out of 12) in which dE/d*t* values have been found significant varied from 12 to 3. At two locations (*i.e.*, Pune and Pattambi), the dE/d*t* values have been found significant in all twelve months. At one location (*i.e.*, Bhubaneshwar) it has been found significant in three months. In a particular month, the number of locations (out of 15) when dE/d*t* values have been found significant varied from 13 to 6. Maximum (13) numbers of locations have shown significant dE/d*t* values in January and minimum (6) number of locations in July. On an average, over India, the contribution of monthly dE/d*t* towards annual dE/d*t* (mm/year), in the order of rank, is highest -2.08 (14.0 %) in May followed by Apr, Mar, Jun, Feb, Oct, Jul, Jan, Nov, Sep, Dec and lowest -0.77 (5.2 %) in Aug.

The average monthly dE/d*t* values over India, in different months may be seen in Fig. 3. Using best fit curve technique the following non linear relationship has been obtained. This equation may be used to quantitatively estimate the average monthly dE/d*t* values over India, in any particular month;

$$y = 0.0008\, x^5 - 0.0243\, x^4 + 0.2719\, x^3 - 1.2338\, x^2 + 1.9249\, x - 1.8736$$

(r = 0.94 , Se = 0.16)

y = average monthly dE/d*t* (mm/year) over India.

x = month number (1 to 12)

The average cumulative dE/d*t* values over India, in relation to different months and its contribution (per cent) towards average annual dE/dt over India may be seen in

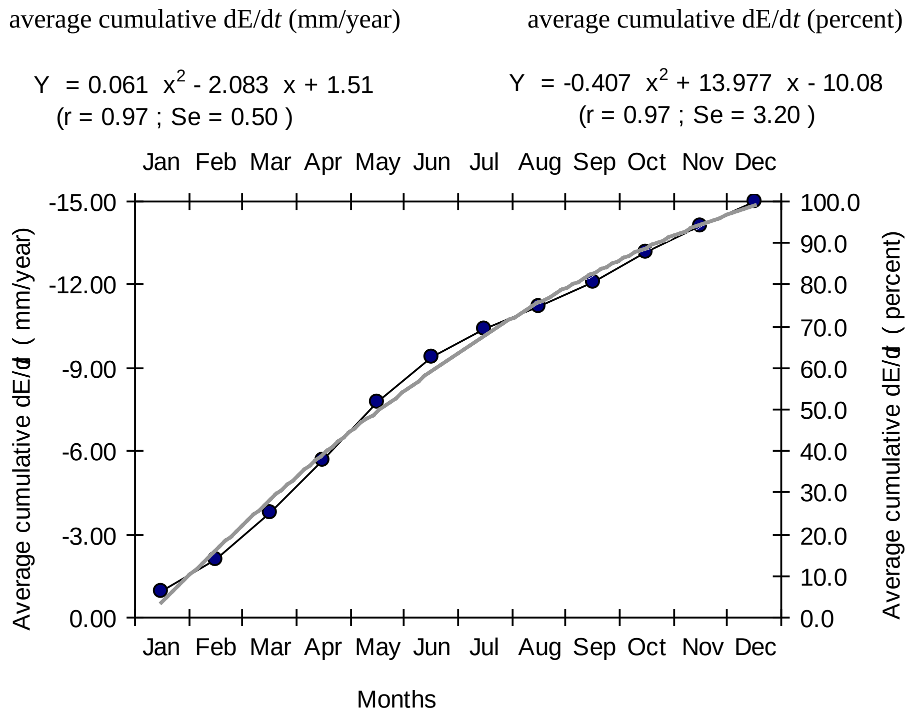


Fig. 4. Monthwise progress of average cumulative dE/d*t* (mm/year) and its contribution towards average annual dE/d*t* (per cent) over India (1971-2000)

Fig. 4. Using best fit curve technique the non linear relationship has been obtained. The following equation may be used to quantitatively estimate the average cumulative dE/d*t* values over India (mm/year) upto any particular month;

$$y = 0.061\ x^2 - 2.083\ x + 1.51 \quad (r = 0.97\ ;\ Se = 0.50)$$

y = average cumulative dE/d*t* (mm/year) over India,

x = month number (1 to 12)

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

$$y = -0.407\ x^2 + 13.977\ x - 10.08 \quad (r = 0.97\ ;\ Se = 3.20)$$

y = contribution (per cent) towards average annual dE/d*t* over India,

x = month number (1 to 12).

4. Conclusions

(*i*) The mean annual pan evaporation was found to be the lowest (1107 mm) at Buralikson and the highest (3004 mm) at Rajkot.

(*ii*) The highest C.V. (11%) was observed at Rajamundry, Jodhpur, Buralikson and Nellore while the lowest C.V. (2%) was observed at Ambikapur.

(*iii*) Out of twenty locations, significant decreasing trend in annual pan evaporation was observed at fifteen locations and no significant trend at five locations.

(*iv*) The annual dE/d*t* values varied from -6.27 (Canning) to -29.30 (Jodhpur) mm/year. The average annual dE/d*t* over India was found to be -14.90 mm/year. Linear relationship was obtained to quantitatively estimate annual dE/d*t*, at a given location, using pan evaporation range.

(*v*) On an average, over India, the contribution of seasonal dE/d*t* towards annual dE/d*t* (mm/year), in the order of rank, is the highest -5.63 (37.8 %) in season 2 (March-April-May), followed by -4.31 (28.9 %) in season 3, -2.89 (19.4 %) in season 4 and lowest -2.07 (13.9 %) in season 1(January-February).

(*vi*) On an average, over India, the contribution of monthly dE/d*t* towards annual dE/d*t* (mm/year), in the order of rank, is the highest -2.08 (14.0 %) in May, followed by Apr, Mar, Jun, Feb, Oct, Jul, Jan, Nov, Sep, Dec and the lowest -0.77 (5.2 %) in August.

(*vii*) Non linear relationships were obtained (a) to quantitatively estimate the average monthly dE/d*t* values over India, in any particular month (b) to quantitatively estimate the average cumulative dE/d*t* values over India (mm/year) up to any particular month and (c) to quantitatively estimate the contribution (per cent) towards average annual dE/d*t* over India, up to any particular month.

Acknowledgements

The authors express their sincere thanks to staff of DFR section for their assistance in data collection, analysis and typing of the manuscript.

References

Amirul Hussain, M., 1986, "Evaporation over Bangladesh", *Mausam*, **37**, 3, 373-376.

Biswas, B. C. and Khambete, N. N., 1988, "Water consumption by dryland crops as related to pan evaporation", *Mausam*, **39**, 1, 91-96.

Chattopadhyay, N. and Hulme, M., 1997, "Evaporation and potential evapotranspiration in India under conditions of recent and future climate change", *Agricultural and Forest Meteorology*, **87**, 55-73.

Chowdhury, A., Das, H. P. and Gaikwad, S. D., 1999, "Determination of relative contribution of different meteorological elements on evaporation", *Mausam*, **50**, 4, 365-374.

Govinda Rao, P., Kelly, P. M. and Hulme, M., 1996, "Climate change, green house gas emissions, future climate and response strategies: the implications for India", *Theor. Appl. Climatol.*, **55**, 41-64.

Hingane, L. S., Rupakumar, K. and Ramamurthy, B. V., 1985, "Long term trends of surface air temperature in India", *J. Climatol*., **5**, 521-528.

Peterson, T. C., Golubev, V. S. and Groisman, P. Y., 1995, "Evaporation losing its strength", *Nature*, **377**, 687-688.

Rathore, L. S. and Biswas, B. C., 1991, "Evaporation maps of India" Agrimet. Monograph No. 13, India Meteorological Department, Pune.

Roderick, M. L. and Farquhar, G. D., 2004, "Changes in Australian pan evaporation from 1970 to 2002", *Int. J. Climatol.*, **24**, 1077-1090.

Rupakumar, K., Krishnakumar, K. and Pant, G. D., 1994, "Diurnal asymmetry of surface air temperature trends over India", *Geophys. Res. Lett*., **15**, 677-680.

Srivastava, H. N., Dewan, B. N., Dikshit, S. K., Prakash Rao, G. S., Singh, S. S. and Rao, K. R., 1992, "Decadal trends in climate over India", *Mausam*, **43**, 7-20.

Sumbasiva Rao, A. and Vamadevan, V. K., 1986, "Evaporation rates from different pans under humid tropical conditions", *Mausam*, **37,** 3, 325-328.

Thapliyal, V. and Kulshrestha, S. M., 1991, "Climate change and trends over India", *Mausam*, **42**, 333-338.