

Spatial and temporal characteristics of evaporation trends over India during 1971-2000

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सार – इस शोध-पत्र में 1971–2000 की अवधि के वाष्पोत्सर्जन और वर्षा के आँकड़ों का अध्ययन करने के लिए भारत के 58 सुवितरित केंद्रों को चुना गया है। समूचे देश तथा प्रत्येक केंद्र के वार्षिक (जनवरी–दिसम्बर) शीतकाल (दिसम्बर, जनवरी और फरवरी), और ग्रीष्मकाल (मार्च–मई), मानसून (जून–सितम्बर) और मानसूनोत्तर काल (अक्टूबर–नवम्बर) की अवधि के इन दो प्राचलों की प्रवृत्तियों का विश्लेषण किया गया और 95 प्रतिशत के विश्वस्यता स्तर तक परीक्षण किया गया है। इस विश्लेषण से पता चला है कि समूचे देश के लिए सभी ऋतुओं में वाष्पोत्सर्जन में कमी आई है जबकि वर्षा की प्रवृत्ति में कोई विशेष बात नहीं पाई गई है। 58 केंद्रों में से 45 (वार्षिक), 30 (शीतकाल), 42 (ग्रीष्मकाल) और 35 (मानसून और मानसूनोत्तर ऋतु) केंद्रों में वाष्पोत्सर्जन में विशेष रूप से कमी पाई गई है। इन प्रवृत्तियों के दशकीय विश्लेषण से पता चलता है कि वाष्पोत्सर्जन में परिवर्तनशीलता की प्रवृत्तियों में हो रही कमी पूरी अवधि के दौरान लगातार एक समान है किंतु यह 1991–2000 के दशक में अधिक पाई गई है। वाष्पोत्सर्जन की मौसमी प्रवृत्तियों के स्थानिक विश्लेषण से उत्तरी पूर्वी भाग को छोड़कर जहाँ कि प्रवृत्तियों में बढ़ोतरी देखी गई है, भारत के सभी भागों में प्रवृत्तियों में कमी का पता चलता है। देश में प्रवृत्तियों के स्थानिक विश्लेषण से वाष्पोत्सर्जन में विशेष रूप से कमी वाले क्षेत्र उत्तर, दक्षिण–पश्चिम और दक्षिण–पूर्व तथा उत्तर–पूर्व वाले भागों में वाष्पोत्सर्जन में बढ़ोतरी का पता चलता है। मौसमी वर्षा की प्रवृत्तियों के स्थानिक विश्लेषण से भारत के दक्षिण भाग में प्रवृत्तियों में बढ़ोतरी तथा मध्य और उत्तर पूर्वी भागों की प्रवृत्तियों में कमी का पता चलता है। लगभग 50 प्रतिशत केंद्रों में वाष्पोत्सर्जन की प्रवृत्तियाँ (अधिकांशतः भारत के दक्षिणी भाग) उसी अवधि में वर्षा के साथ अनुकूल संबंध दर्शाती हैं। वाष्पोत्सर्जन में शेष दीर्घ अवधि प्रवृत्तियाँ पवन गति, मेघ अवस्था, धूप की अवधि आदि जैसे अन्य प्राचलों में परिवर्तनशीलता के कारण हैं, जिसमें कि और जाँच की आवश्यकता है।

ABSTRACT. Evaporation and rainfall data for the period 1971-2000 for 58 well distributed stations over India were selected for this study. Trends of these two parameters for the country as a whole and for individual stations for annual (January – December), winter (December, January and February), summer (March – May), monsoon (June – September) and post-monsoon (October, November) period were analysed and tested for significance at 95% level of confidence. The analysis shows that for the country as a whole, the evaporation has significantly decreased in all seasons while there is no significant trend in rainfall. Out of 58 stations, numbers of stations having significant decrease in evaporation are 45 (annual), 30 (winter), 42 (summer) and 35 (monsoon and post monsoon seasons). Decadal analysis of trends shows that the variability of evaporation towards the decreasing trend is steadily maintained throughout the period but more in the decade 1991-2000. Spatial analysis of the seasonal trends of evaporation indicates the decreasing trends over all parts of India except northeast where it is increasing. Regions of significant decrease in evaporation *viz.*, North, Southwest and Southeast and increase in evaporation *viz.*, Northeast emerge from the spatial analysis of trends over the country. Spatial analysis of seasonal rainfall trends indicates the increasing trends in southern parts and decreasing trends in central and northeastern parts of the country. Evaporation trends of nearly 50% stations (mostly in southern parts of India) show complimentary relation with rainfall of the same period. Rest of the long term trends in evaporation may be due to the variation in other parameters like wind speed, cloud cover, sunshine duration etc. which needs further examination.

Keywords – Pan Evaporation, Rainfall, Radiation, Sunshine, Temperature, Vapour pressure deficit, Trends.

1. Introduction

Evaporation is the component of the hydrological cycle which is directly influenced by land use and climate.

Heat flux and evaporation consumes more water and energy available on the surface of the earth hence is a major determinant factor influencing the weather and climate. The rate of evaporation depends upon a number

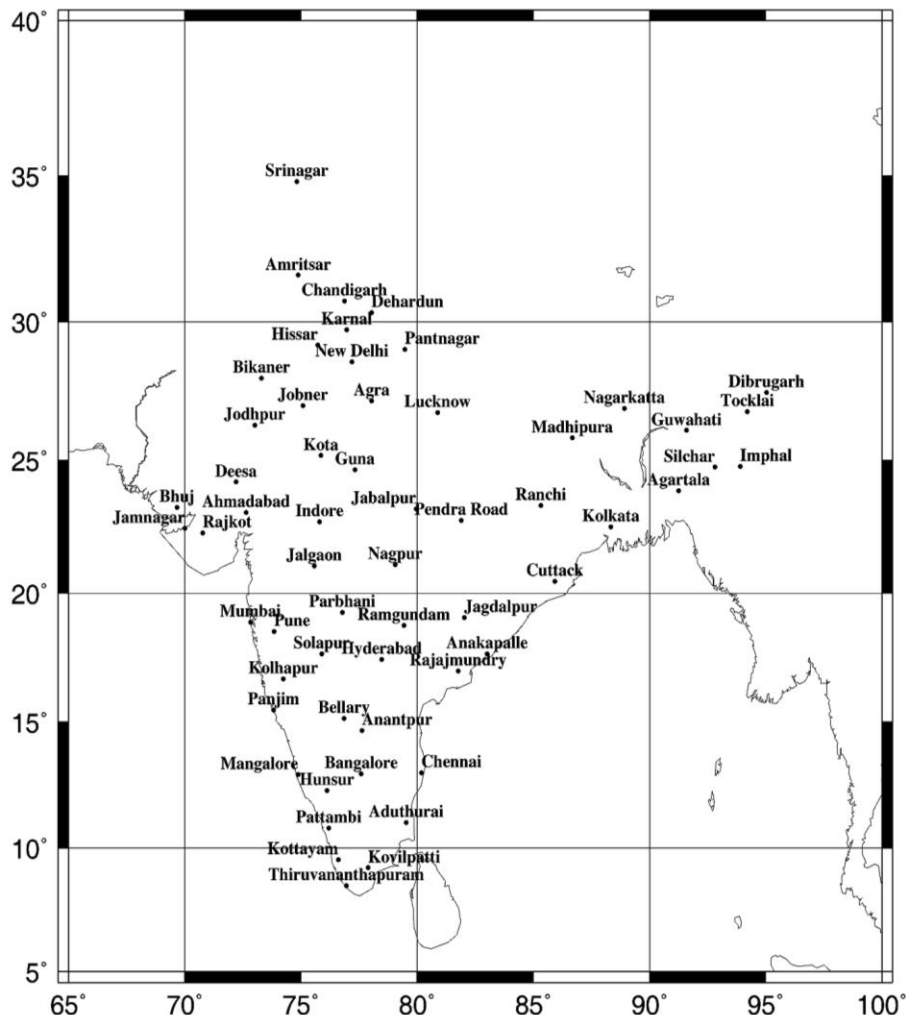


Fig. 1. Geographical distribution of 58 stations selected for study

of factors such as temperature, humidity and wind speed. Evaporation is greater when temperature and wind speed are high and the prevailing air is dry. Free surface evaporation is the quantity of water evaporated from an idealised, extensive open water surface per unit area under existing atmospheric conditions (Penman, 1948).

With the development of urbanization, the uninterrupted expansion of cities, the continued increase of population and thus interference of human activities acting on atmosphere together, the characteristics of atmospheric boundary layer seems to be undergoing change, which may be responsible to moderate the temperature, precipitation and radiation particularly in urban region. Studies show the increase in mean annual temperature at the Earth's surface during the last 150 years (Parker *et al.*, 1995; Jones *et al.*, 2001). Studies in

India in respect of temperature have been done by number of authors (Hingane *et al.*, 1985; Thapliyal and Kulshreshtra, 1991; Srivastava *et al.*, 1992; Rupakumar and Hingane, 1988; Govinda Rao *et al.*, 1996) who have found an increasing trend in mean temperature in most parts of the Indian subcontinent during post-monsoon and winter seasons. Concerns have been raised by investigators regarding the impact of global warming on evaporation. Higher evaporation rates result in more arid environments, while lower rates create more humid conditions. As a consequence of the general warming tendency over the globe (IPCC 2007), it is expected that the air may become drier leading to increase in terrestrial evaporation. But there are reports of decreasing evaporation trends which is contrary to the expectation that global warming may be accompanied by an increase in terrestrial evaporation and is known as the 'evaporation paradox'.

TABLE 1

Evaporation (Evp) and rainfall (Rf) trends in mm/year for annual, winter, summer, monsoon and post-monsoon for 1971 to 2000.
(Trends significant at 95% level are shown in bold)

Station Name	Annual		Winter		Summer		Monsoon		Post monsoon	
	Evp	Rf	Evp	Rf	Evp	Rf	Evp	Rf	Evp	Rf
Srinagar	1.04	-1.75	-0.09	-1.45	0.26	1.72	0.62	-1.44	0.36	-0.08
Amritsar	-1.42	0.81	-0.10	0.87	-0.17	-0.33	-0.92	0.49	-0.08	-0.04
Chandigarh	-8.91	1.47	-0.40	0.36	-2.35	-1.06	-4.00	2.83	-1.78	-0.34
Dehardun	-9.94	-0.72	-0.93	0.98	-3.99	1.31	-3.94	-2.43	-0.79	-0.26
Hissar	-16.46	1.73	-1.77	-0.36	-6.36	-0.77	-5.47	1.80	-2.44	1.27
Karnal	-22.32	4.55	-3.03	1.95	-10.06	-0.20	-6.95	2.71	-1.92	0.35
Pantnagar	-1.84	-0.52	-0.34	1.54	-1.59	1.25	1.36	-3.63	-0.86	0.58
Bikaner	8.16	-4.51	1.71	0.28	1.74	-2.56	5.56	-3.19	0.13	0.97
New Delhi	-42.54	-4.41	-5.78	1.68	-17.03	-0.39	-12.60	-5.02	-6.64	-0.56
Agra	-3.73	4.35	-0.97	-0.60	-1.95	0.24	0.39	4.59	-0.82	0.20
Dibrugarh	13.05	5.02	7.30	-0.83	0.16	3.48	1.28	3.99	4.44	-1.36
Jodhpur	-21.66	-2.64	-3.54	0.50	-6.74	-0.45	-7.47	-2.60	-3.07	-0.08
Jobner	-9.47	-8.80	-1.34	-0.16	-3.84	-0.57	-2.00	-8.26	-1.81	0.24
Lucknow	-7.33	-10.10	-1.36	0.84	-2.52	-0.49	-2.00	-9.44	-1.09	-0.72
Nagarkatta	-13.68	22.37	-1.97	0.96	-5.15	4.46	-4.74	22.55	-1.43	-5.47
Guwahati	10.68	2.69	3.85	0.24	0.72	1.74	3.15	0.72	3.34	0.10
Tockalai	-2.02	-22.72	0.35	-0.05	-1.33	-6.71	-0.84	-13.85	0.0	-1.95
Kota	-11.80	-5.82	-0.70	0.73	-5.06	0.74	-4.23	-5.08	-1.32	-2.11
Madhipura	-11.49	-11.26	-1.93	-0.03	-4.30	-4.25	-3.73	-1.77	-1.06	-5.10
Deesa	-23.83	-1.67	-1.39	-0.05	-9.82	-0.11	-8.51	-1.95	-3.29	0.47
Guna	-13.59	-2.86	-2.88	-0.12	-5.55	0.12	-1.94	-2.29	-2.72	-0.49
Silchar	-3.89	-4.92	-0.87	0.79	-1.70	-3.25	-1.09	-2.05	0.15	-0.20
Imphal	-8.79	0.30	-0.23	1.59	-2.57	1.45	-4.43	0.60	-1.12	-3.24
Bhuj	-1.95	1.51	-0.66	0.07	-2.43	1.29	0.74	-1.10	0.59	1.26
Ahmadabad	-33.61	0.33	-3.77	-0.11	-14.35	-0.09	-9.54	1.03	-4.88	-0.46
Jabalpur	-15.47	-3.17	1.38	0.08	-11.16	0.46	-5.89	-2.44	0.92	-1.06
Ranchi	-19.60	2.22	-2.62	-0.13	-7.57	-0.93	-6.32	3.88	-2.22	-0.44
Agartala	-9.49	-4.77	-1.22	-0.40	-5.45	-1.06	-2.30	-3.27	0.08	0.16
Jamnagar	-34.94	-4.58	-3.32	-0.02	-14.97	0.11	-9.93	-2.82	-5.32	-1.85
Rajkot	-10.99	-6.62	-2.47	0.16	-2.16	-0.17	-2.02	-1.91	-3.12	-4.68
Indore	-10.33	0.10	-1.29	0.32	-3.76	0.38	-2.63	0.43	-2.15	-0.97
Pendra	-1.07	-1.31	0.43	0.92	-0.33	-0.72	-0.25	-2.31	-0.51	0.96
Kolkata	-10.67	7.07	-1.05	-0.95	-3.38	-0.30	-4.04	4.20	-1.86	4.30
Jalgaon	-17.51	2.18	-2.99	0.0	-4.61	1.57	-6.93	0.42	-1.95	0.22
Nagpur	-24.27	-1.46	-2.85	-0.14	-12.22	1.11	-6.12	-1.86	-2.55	-0.35
Cuttack	-7.51	-8.64	-0.98	-1.62	-1.06	3.59	-3.45	-11.01	-1.45	0.48
Parbhani	-20.42	7.54	-0.97	0.97	-8.37	0.72	-10.23	4.75	0.09	1.20
Jagdarpur	-5.51	-5.63	-0.55	0.66	-3.90	1.97	-0.70	-7.68	-0.05	-0.52
Mumbai	-20.07	5.84	-4.13	0.51	-6.60	1.26	-5.22	3.13	-3.53	0.90
Pune	-20.09	4.35	-2.86	0.55	-7.75	-1.00	-5.62	2.80	-3.08	2.04
Ramgundam	-22.30	5.98	-2.77	0.99	-9.54	-0.53	-7.10	8.34	-2.34	-2.74
Anakapalle	-4.29	10.33	0.32	0.49	-2.37	0.66	-1.36	8.27	-0.15	0.95
Solapur	-4.23	2.91	0.20	0.30	-3.23	0.79	0.64	2.32	-0.77	-0.44
Hyderabad	-37.00	3.77	-6.78	0.13	-11.87	-0.44	-12.09	3.27	-5.43	0.86
Rajahmundry	-19.65	2.52	-4.03	0.70	-6.81	0.89	-5.62	5.06	-1.86	-4.29
Kolhapur	-17.95	-2.79	-2.39	0.54	-4.98	-1.86	-7.01	-0.11	-3.09	-1.29
Panjim	-8.14	11.90	-1.59	0.43	-3.42	2.58	-1.22	8.45	-1.08	0.49
Bellary	-23.01	2.31	-3.52	0.78	-6.93	-0.87	-8.15	2.28	-3.30	0.25
Anantpur	-17.81	3.36	-3.18	0.76	-7.05	-0.23	-4.19	5.82	-2.58	-2.91
Chennai	-8.27	-2.51	-0.15	3.78	-3.49	2.32	-3.55	-4.46	-0.37	-2.15
Mangalore	-6.51	1.62	-2.49	0.36	-3.80	0.89	-0.06	-3.26	0.77	3.70
Hunsur	-3.33	-3.27	0.22	-0.04	-0.76	-2.42	-1.40	-0.28	-0.09	-0.55
Bangalore	6.22	8.05	1.89	0.29	-1.94	1.16	3.60	4.43	3.06	-2.31
Aduthurai	-13.71	8.37	-0.94	8.44	-3.86	-0.95	-7.43	-0.17	-0.85	2.88
Pattambi	-19.19	-1.98	-3.04	0.11	-5.60	-2.75	-6.05	2.87	-3.51	-1.90
Kottayam	-10.89	7.28	-1.01	-0.66	-1.78	-3.62	-5.46	8.28	-1.79	3.68
Kovilpatti	-36.22	-4.19	-8.02	-0.37	-8.71	-1.15	-14.13	-0.71	-4.61	-1.28
Thiruvananthapuram	-5.32	-1.09	-1.43	-0.18	-0.94	-3.81	-1.69	0.32	-0.53	2.94

Studies of evaporation trends from many regions have been conducted and the conclusions vary. Evaporation has decreased over the USA, former Soviet Union and Eurasia for the period 1950-1990 (Peterson *et al.*, 1995; Golubev *et al.* 2001). Decreases in evaporation have also been noticed in China (Liu *et al.*, 2004; Thomas, 2000), Thailand (Tebakari *et al.*, 2005), Italy (Moonen *et al.* 2002), Australia (Roderick and Farquhar, 2004) and New Zealand (Roderick and Farquhar, 2005). Some mixed trends have also been reported such as in East Asia (Xu, 2001), Israel (Cohen *et al.* 2002) and northeast Brazil (da Silva, 2004). Relative contributions of meteorological parameters on evaporation at some Indian stations were examined by Rao *et al.* (1972) and Chowdhury *et al.* (1999). Based upon ten stations data for 1961-1992 and nine stations data for the period 1976-1990, Chattopadhyay and Hulme (1997) have concluded that there is significant decrease in pan evaporation in all parts of India during the pre-monsoon and monsoon seasons. All these reports confirm that there is a general declining trend in evaporation throughout the globe. It is important from hydrological point of view to know the effect of changes in evaporation on the water cycle. In the present study evaporation trends over India are studied along with the rainfall trends for the same period. The tendency of trends due to recent warming may indicate the conditions of the environment in future.

2. Data and methodology

In India Meteorological Department, evaporation measurements are made by Class-A Open Pan Evaporimeter at selected stations. Evaporation data from these stations are archived at National Data Centre (NDC), Pune of the India Meteorological Department along with rainfall data for these stations. Fifty eight (58) stations were identified having long-term and nearly full pan-evaporation data for the period 1971-2000. The distribution of these stations is shown in Fig. 1. Trends of total evaporation and rainfall were studied for annual (January to December), winter (December, January and February), summer (March to May), monsoon (June to September) and post-monsoon (October and November) seasons for individual stations as well as for country as a whole. Evaporation and rainfall trends for individual stations for annual, winter, summer, monsoon and post monsoon seasons were calculated and tested for significance at 95% level. These trend values (mm/year) are presented in Table 1 in which bold values indicate significant trends. Based upon 58 stations data for the period 1971-2000, all India trends of evaporation and rainfall for annual and four seasons were calculated and tested for significance at 95% level of confidence. The all India time-series of evaporation and rainfall for annual, winter, summer, monsoon and post-monsoon seasons are

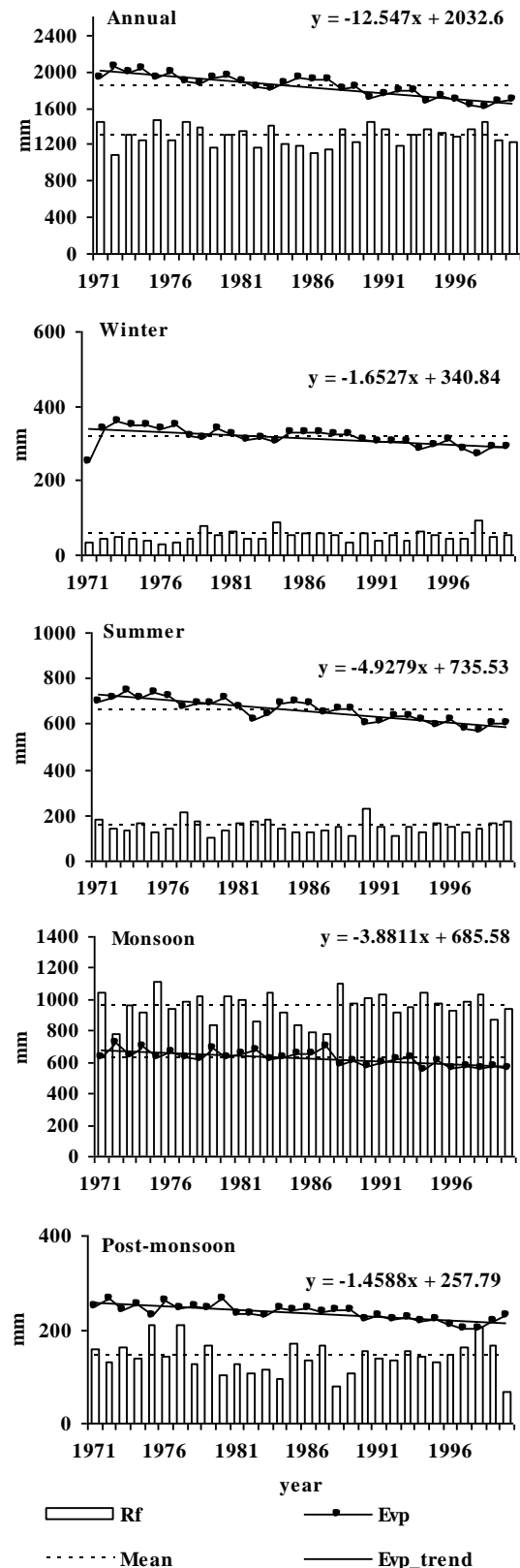


Fig. 2. Evaporation and rainfall trends for India based upon 58 stations for the period 1971 to 2000

TABLE 2

All India evaporation and rainfall trends (mm/year) based upon 58 stations for decades 1971-1980, 1981-1990, 1991-2000 and for the period 1971-2000. [Significantly increasing (+) or decreasing (-) trends are shown in bold]

	Evaporation trends				Rainfall trends			
	Decades			1971-2000	Decades			1971-2000
	1971-1980	1981-1990	1991-2000		1971-1980	1981-1990	1991-2000	
Annual	-8.66	-9.06	-14.58	-12.55	+0.43	+5.13	-1.84	+0.10
Winter	+2.64	+0.27	-2.71	-1.65	+2.03	-0.70	+1.58	+0.48
Summer	-2.45	-1.74	-4.89	-4.93	-2.48	-0.18	+3.52	-0.17
Monsoon	-3.45	-6.96	-6.34	-3.88	+3.75	+4.54	-5.35	+0.41
Post-monsoon	+0.34	-0.24	-1.11	-1.46	-1.96	+1.61	-0.46	-0.42

TABLE 3

Number of stations showing increasing or decreasing trends in evaporation and rainfall (Stations with significant trends are enclosed in parenthesis)

	Evaporation trends			Rainfall trends		
	Decreasing	Increasing	No trend	Decreasing	Increasing	No trend
Annual	53 (45)	5 (3)	0	28 (2)	30 (2)	0
Winter	48 (30)	10 (4)	0	21 (0)	37 (6)	1
Summer	54 (42)	4 (0)	0	31 (3)	27 (2)	0
Monsoon	49 (35)	9 (2)	0	29 (4)	29 (3)	0
Post-monsoon	46 (35)	11 (3)	1	32 (2)	26 (1)	0

shown in Fig. 2. Trends in evaporation and rainfall for the country as a whole were also found out decade-wise (1971-1980, 1981-1990 and 1991-2000) and are shown in Table 2 along with trends for entire period *viz.*, 1971-2000. Table 3 depicts number of stations with increasing or decreasing trends where numbers in bold shown in the parenthesis indicate the stations having significant trend. Fig. 3 shows some individual stations with significant decreasing/increasing trends of annual evaporation.

Spatial analysis of trends has been done using Generic Mapping Tools (GMT) which is freely available from internet site <http://gmt.soest.hawaii.edu/>. GMT is a geographic information system (GIS) which is used extensively in meteorology and oceanography for georeferencing of data, advanced mapping, drawing scientific diagrams and integration with other types of environmental data. GMT has also free world basemap with very accurate sea shorelines and fairly accurate lake shorelines, rivers and political boundaries. Spatial patterns in the trends were examined by plotting trends (mm/decade) using GMT. This facilitates the identification of geographic regions that have an unusually large or small value of trends. Spatial patterns of evaporation and rainfall trends for individual stations were analysed for annual, winter, summer, monsoon and post-

monsoon seasons and shown in Figs. 4 to 8. The shaded regions indicate increasing trends in evaporation/rainfall.

3. Results and discussion

3.1. All India series

Even though the trends in evaporation vary from station to station as summarized in Table 1, the average evaporation trends of 58 stations for the period 1971-2000 for the country as a whole shows (Fig. 2) significant decrease for annual and also for four seasons. The amount of decrease during this period is 19% (annual), 15% (winter), 20% (summer) and 17% (monsoon and post monsoon seasons). As seen from Table 2, the decrease in evaporation is 12.55 mm/year (annual), 1.65 mm/year (winter), 4.89 mm/year (summer), 3.88 mm/year (monsoon) and 1.46 mm/year (post monsoon). Decreasing trends in evaporation were also noticed for the three decades 1971-1980, 1981-1990 and 1991-2000 with a large significant decrease in the third decade (1991-2000). Similarly trends of average rainfall of the same period are not significant and show slight increase for annual, winter, and monsoon seasons and slight decrease for summer and post monsoon seasons. The rainfall trends are varying between -0.42 mm/year in post-monsoon to

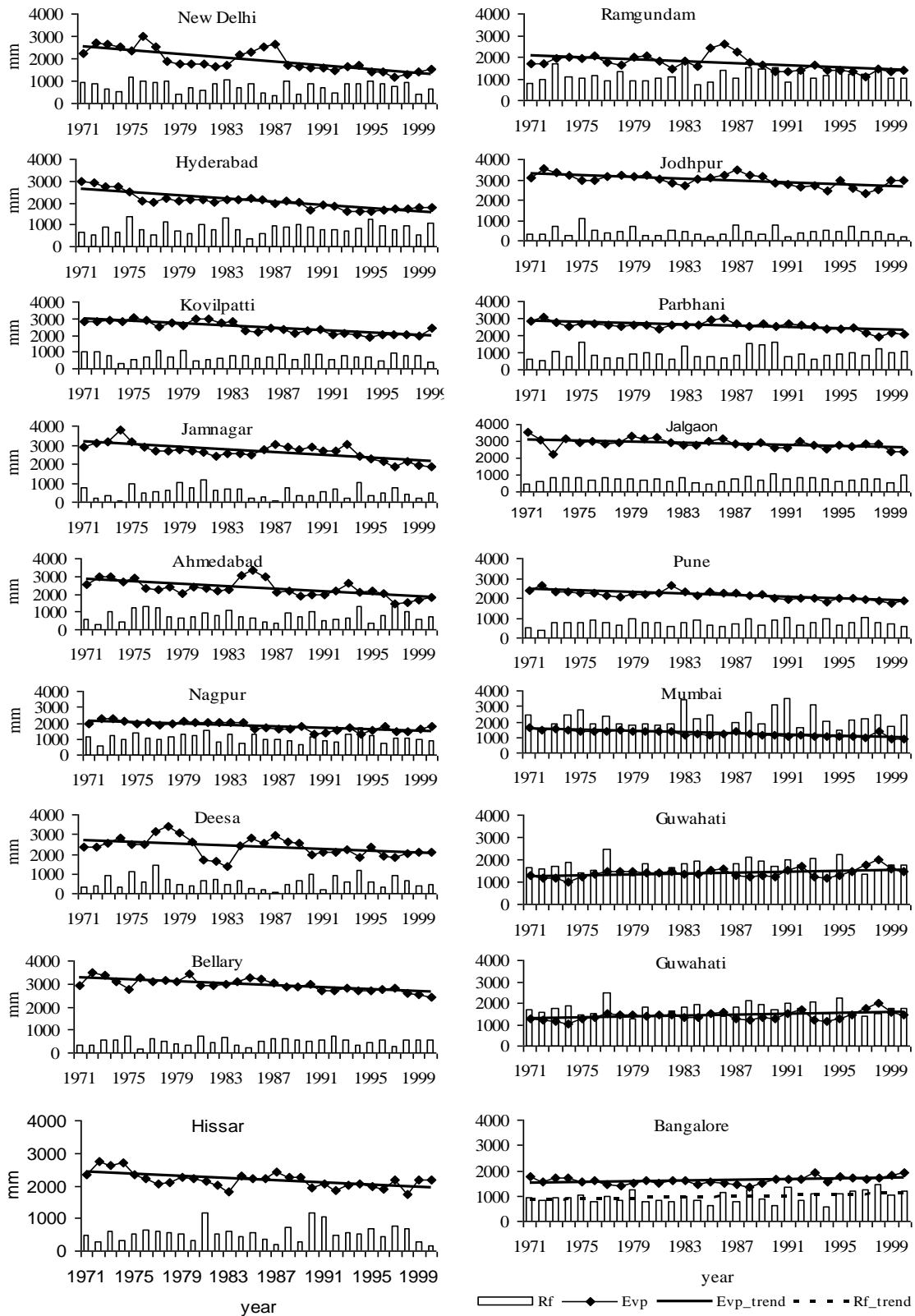
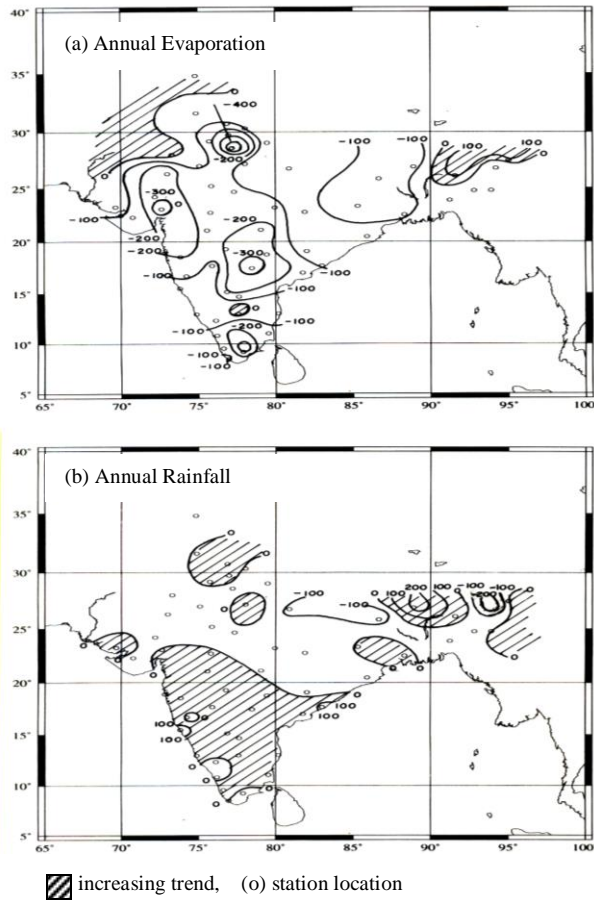
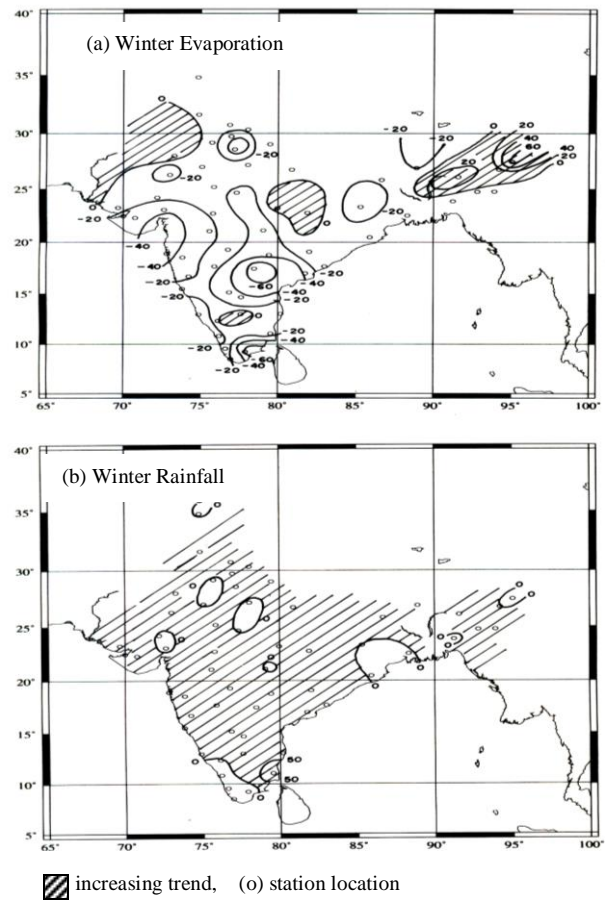


Fig. 3. Annual evaporation trends for some selected stations



Figs. 4(a&b). Spatial distribution of annual evaporation and rainfall trends (mm/decade) for 1971 to 2000



Figs. 5(a&b). Spatial distribution of winter season evaporation and rainfall trends (mm/decade) for 1971 to 2000

+0.48 mm/year in winter season. This may be due to the large interannual variability of rainfall over the country.

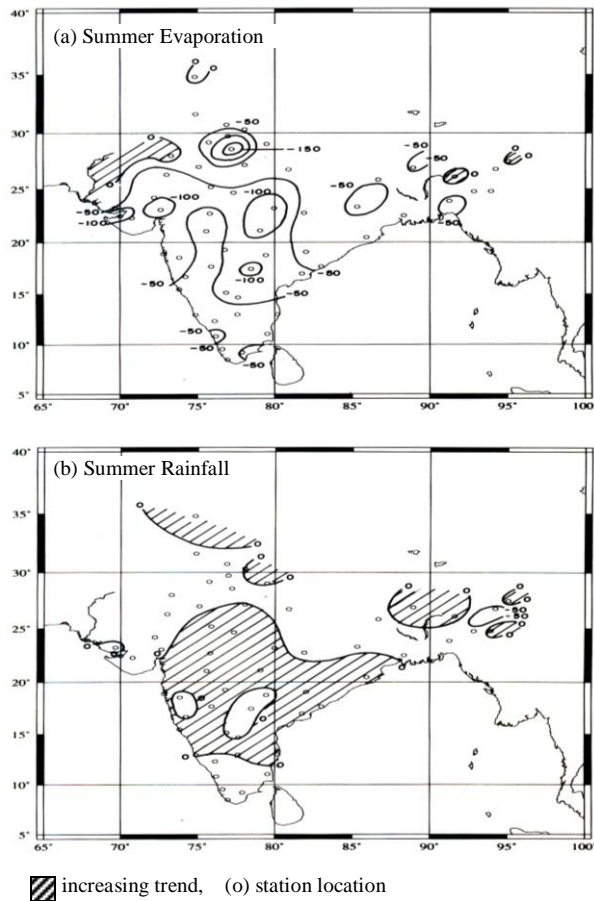
3.2. Annual

The numbers of stations having increasing/decreasing trends in evaporation and rainfall for annual and for each season are shown in Table 3. The figures in parenthesis indicate the number of stations with significant trend. The comparison of trends of rainfall and evaporation shows that the significant trends have been noticed for evaporation for more number of stations. Stations having significantly decreasing trends in evaporation are spread all over the country except Dibrugarh, Guwahati and Bangalore which show significant increasing trends. Some of the stations with significant decreasing/increasing trend in evaporation along with corresponding variations in rainfall are shown in Fig. 3. The annual evaporation trends vary between -42.54 mm/year at New Delhi to +13.05 mm/year at Dibrugarh (Table 1).

Spatial distribution of evaporation trends [Fig. 4(a)] show decreasing trends over the country except over a few parts of northeast India and west northwest India. Rainfall trends as shown in Fig. 4(b) are positive (though not significant) over peninsular India, parts of northeast India and extreme north India while they are negative for remaining parts of India.

3.3. Winter

During winter season evaporation trends are significantly decreasing for 30 stations and increasing for 4 stations (Table 3). Spatial analysis of winter season trends [Fig. 5(a)] indicate that evaporation is decreasing over the whole country except for a few pockets in northeast India and extreme parts of western India. The rainfall trends [Fig. 5(b)] are increasing (though not significant) over the whole country except for a few isolated pockets where they are decreasing. It agrees well with the increase in winter rainfall, low temperature values, less number of sunshine hours and less evaporation rates. The decrease in atmospheric



Figs. 6(a&b). Spatial distribution of summer season total evaporation and rainfall trends (mm/decade) for 1971 to 2000

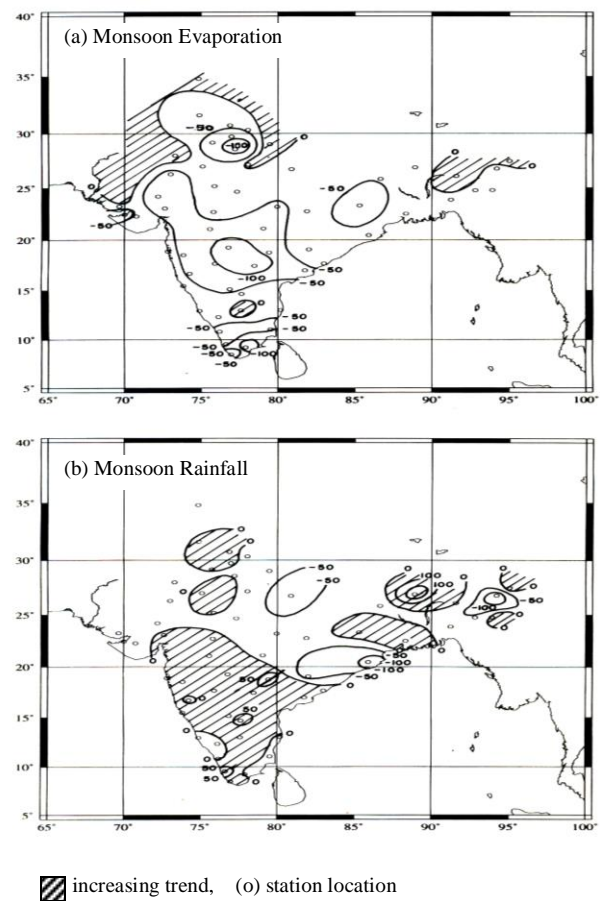
transparency leading to decrease in insolation (De *et al.* 2001) is also a contributing factor for the decreasing trend in evaporation in winter over large areas.

3.4. Summer

As shown in Table 3, evaporation trends in this season are significantly decreasing for 42 stations. Spatial analysis of evaporation trends of this period [Fig. 6(a)] indicates decreasing trends (mostly significant) over the country except for a smaller area of west Rajasthan. The rainfall trends are positive but not significant over the country [Fig. 6(b)] except over extreme parts of south peninsula, parts of Rajasthan, Madhya Pradesh, Uttar Pradesh and West Bengal. This season is characterized by high temperature, large convective activities with the formation of cumulonimbus clouds and rainfall with decrease in evaporation rates.

3.5. Monsoon

Out of 58 stations, evaporation trends in the monsoon season are seen to be significantly decreasing for

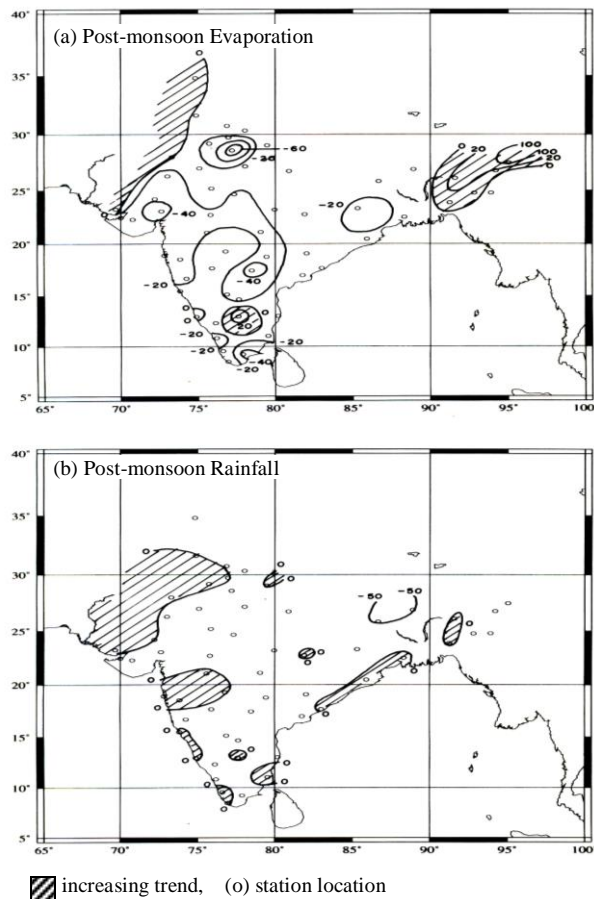


Figs. 7(a&b). Spatial distribution of monsoon season total evaporation and rainfall trends (mm/decade) for 1971 to 2000

35 stations and increasing for 2 stations only (Table 3). Spatial analysis indicates that evaporation trends are significantly decreasing over the country [Fig. 7(a)] except over parts of northeast India and northwest India. The rainfall trend is just opposite *i.e.*, increasing over the country (though not significant) except for a few isolated pockets [Fig. 7(b)]. The results confirm that during monsoon season there is increase in cloudiness, moisture, rainfall and hence the evaporation rates are decreasing.

3.6. Post-monsoon

Linear trends of evaporation in the post-monsoon season are seen to be significantly decreasing for 35 stations and increasing for 3 stations (Table 3). They are decreasing (mostly significant) all over the country except over parts of northeast and northwest India [Fig. 8(a)]. Rainfall trends during the season are also decreasing (not significant) over the country except over a few parts of northwest India, coastal parts of north Andhra Pradesh, Orissa, West Bengal, Tamilnadu, Maharashtra and Kerala where trends are increasing [Fig. 8(b)].



Figs. 8(a&b). Spatial distribution of post-monsoon season total evaporation and rainfall trends (mm/decade) for 1971 to 2000

Though the control mechanisms causing these trends are not yet clearly understood by the scientific community, there are several hypothesis existing which can explain the future scenario. Although the increases in temperatures are generally agreed upon, there are many factors that could enhance or suppress the total evaporation. The widespread decline of evaporation all over the world has lead investigators to propose two main hypothesis about the causes of this decline. First one is that there is decrease in solar radiance (Abakumova *et al.*, 1996; Stanhill and Cohen, 2001) resulting from increasing cloud coverage and aerosol concentration. Roderick and Farquhar, (2002) have concluded that the decrease in solar irradiance and associated changes in diurnal temperature range and vapour pressure deficit are responsible for the decrease in evaporation. The second concept is that increased terrestrial evaporation may increase moist air over the evaporation pan (Brutsaert and Parlange, 1998) and leading to an increase in cloudiness (Dai *et al.*, 1999), thus reducing evaporation from the pan. The role of urbanization taking place around the evaporation pans has also come into focus by the findings of Lawrimore and

Peterson (2000) and Golubev *et al.* (2001) who have established a complimentary relationship between pan and the terrestrial evaporation. Study by De *et al.* (2001) has shown a decrease in atmospheric transparency over the Indian region which is partly an urban effect accentuated by meteorological factors in winter season. Rao *et al.* (2004) studied effects of urbanization on meteorological parameters over 15 Indian cities having million plus population and concluded that there is general decrease in wind speed, sunshine duration and solar radiation and increase in relative humidity and minimum temperature across the country. Thus various studies on pan evaporation as referred earlier in the text imply that regionally and seasonally differing sets of meteorological variables are mainly responsible for changes in evaporation.

4. Conclusions

From the above discussions the following conclusions are drawn.

(i) There is significant decreasing trend in evaporation all over the country during annual and four seasons except parts of northwest and northeast India where trends are increasing. For the country as a whole the amount of decrease over the 30 years period is 19% (annual), 15% (winter), 20% (summer) and 17% (monsoon and post monsoon seasons).

(ii) Seasonal comparisons show that the decrease of evaporation is significant in all seasons. There is no significant trend in the average rainfall over the country as a whole for any season. Stations having statistically significant increase in evaporation are Dibrugarh, Guwahati, Tockalai and Bangalore.

(iii) The decadal trends for evaporation are decreasing in all the three decades (1971-1980, 1981-1990 and 1991-2000) but the rate of decrease is more in the decade 1991-2000 and significant for all seasons except post-monsoon. In case of rainfall the decadal trends are not similar. However for the 30 year period (1971-2000) the rainfall trends are increasing (though not significant) except for summer (March – May) and post – monsoon (Oct - Nov) seasons.

(iv) A large number of stations reported increasing trend in rainfall but the trend is statistically significant for a very few stations.

As evaporation relates to the meteorological elements *viz.*, temperature, humidity, sunshine duration, cloud cover, wind speed, vapour pressure deficit and to the enhanced presence of aerosols in the atmosphere, it needs to be examined thoroughly for detailed trend analysis.

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