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A STUDY ON RECENT CHANGES IN MONTHLY, SEASONAL AND ANNUAL EVAPORATION AT SELECTED LOCATIONS IN INDIA

1. The change of state of water from solid or liquid to vapour and its diffusion into the atmosphere is referred to as evaporation. It 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. India has great economic dependence on agriculture. Any major changes in evaporation 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

TABLE 1

Basic statistical parameters of annual evaporation (mm) and Trend line equations (significant at p > 0.95) at different locations in India

Station	Basic statistical parameters of annual evaporation (mm)							Trend line equations (significant at p > 0.95)
	Minimum	Maximum	Range	Mean	S.D.	C.V.(%)	Trend	
Bhubaneshwar	1480	2036	556	1711	127	7	decreasing	$Y = - 6.972\,x + 15556$
Bikramganj	1455	2133	678	1672	158	9	decreasing	$Y = - 11.563\,x + 24650$
Canning	1333	1780	447	1548	111	7	decreasing	$Y = - 6.008\,x + 13470$
Hebbal	1643	2234	591	1907	136	7	decreasing	$Y = - 12.592\,x + 26925$
Hissar	1884	2795	911	2256	236	10	decreasing	$Y = - 22.083\,x + 46070$
Jodhpur	2366	3518	1152	2993	320	11	decreasing	$Y = - 29.284\,x + 61115$
Karimganj	1033	1401	368	1174	111	9	decreasing	$Y = - 6.386\,x + 13850$
Pattambi	1536	2050	514	1797	148	8	decreasing	$Y = - 15.607\,x + 32777$
Pune	1711	2586	875	2110	203	10	decreasing	$Y = - 19.923\,x + 41670$
Rajamundry	1778	2789	1011	2176	238	11	decreasing	$Y = - 24.403\,x + 50570$

Note : S.D – Standard deviation; C.V – Coefficient of variation; *Y* – Annual evaporation (mm); *x* – Time (year).

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 *et al.* (1986) have studied evaporation rates from different pans under humid tropical conditions. Amirul Hussain (1986) has studied evaporation over Bangladesh. Biswas and Khambete (1988) have studied water consumption by dry land crops as related to pan evaporation. Chowdhury *et al*. (1999) have studied the relative contribution of different meteorological elements on evaporation. Chattopadhyay and Hulme (1997) have 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 have been studied in different parts of the world (Peterson *et al*. 1995, Roderick and Farquhar, 2004).

In this paper, an attempt is being made to study the variations in average monthly evaporation in different months and at different locations. Changes in evaporation have been studied using the linear trend analysis technique.

2. In the present study, thirty years evaporation time series data (1971-2000) recorded from US class-A evaporation pans for ten 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 Bhubaneshwar (20° 15′ N, 85° 50′ E) (Orissa), Bikramganj (25° 10′ N, 84° 15′ E) (Bihar), 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), Jodhpur (26° 18′ N, 73° 01′ E) (Rajasthan), Karimganj (24° 50′ N, 92° 20′ E) (Assam), Pattambi (10° 48′ N, 76° 12′ E) (Kerala), Pune (18° 32′ N, 73° 51′ E) (Maharastra) and Rajamundry (17° 00′ N,

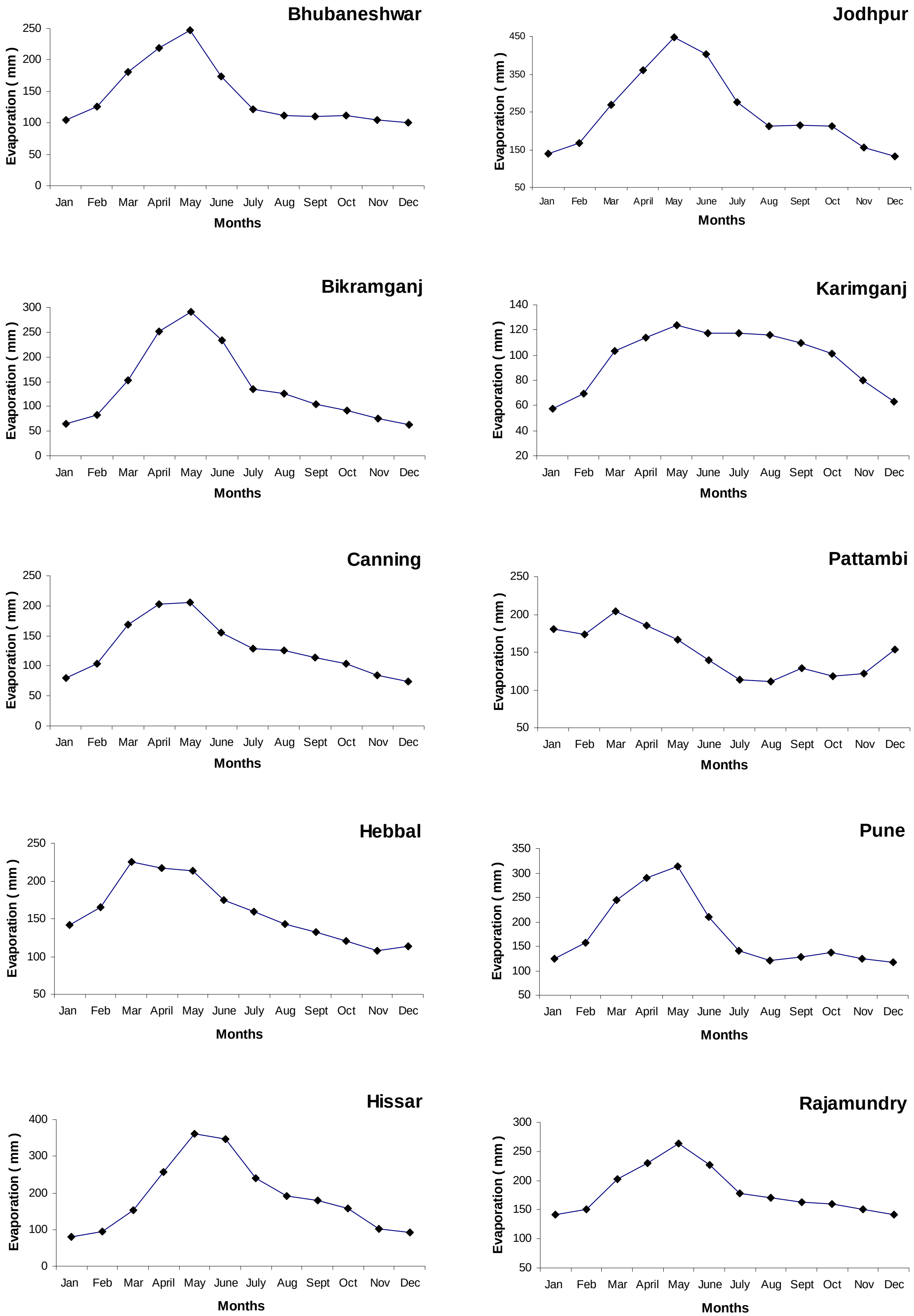

Fig. 1. Variations in average monthly evaporation at different locations in India

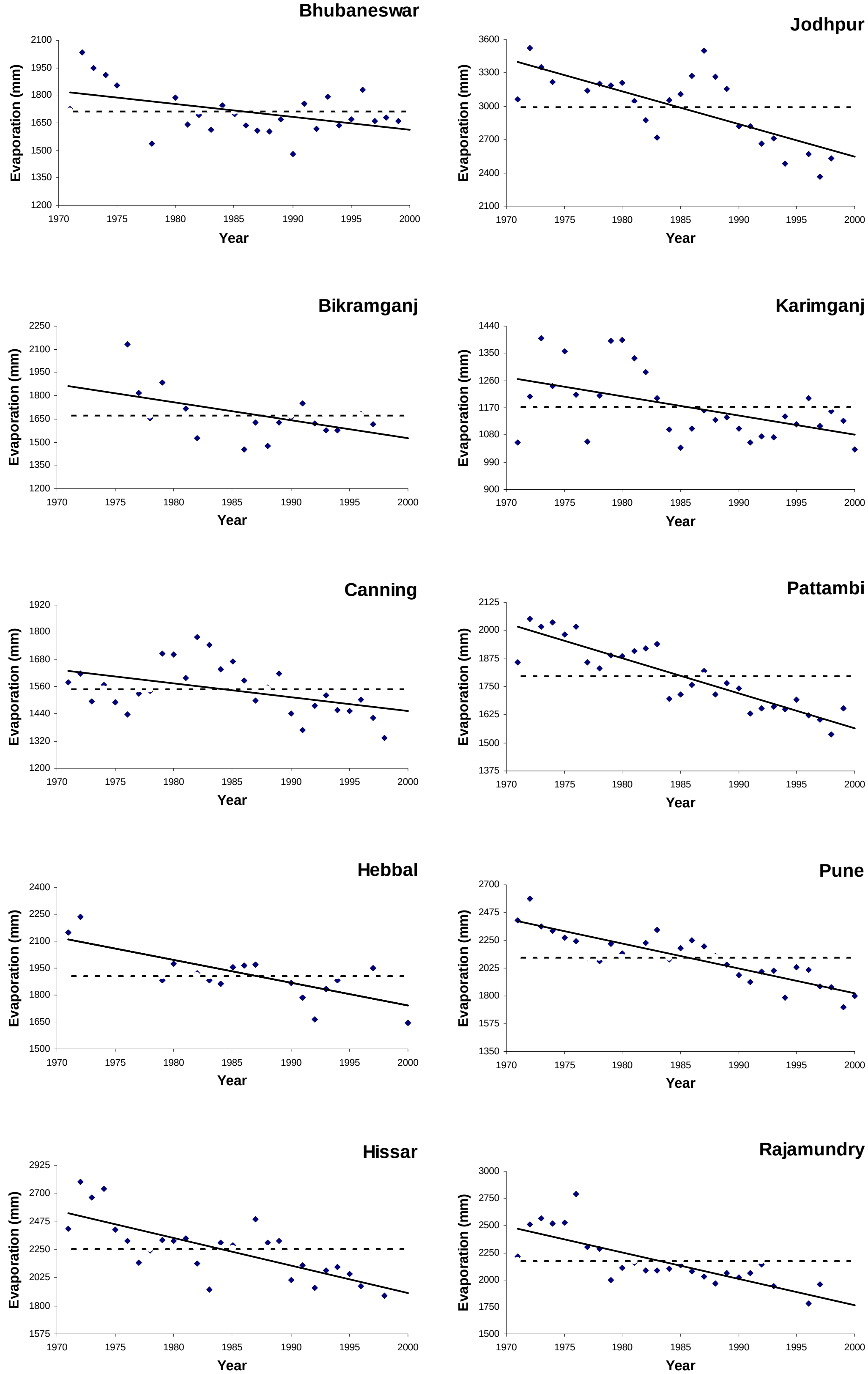

Fig. 2. Trends in annual evaporation with time and average annual evaporation (1971 - 2000) at different locations in India

TABLE 2

Correlation coefficient (r) of evaporation (mm) in different months, monsoon season (June-September) and annual at different locations in India

Period	Correlation coefficient (r)									
	Bhubaneshwar	Bikramganj	Canning	Hebbal	Hissar	Jodhpur	Karimganj	Pattambi	Pune	Rajamundry
January	-0.24	-0.49	-0.60	-0.52	-0.77	-0.75	-0.40	-0.69	-0.74	-0.73
February	-0.41	-0.56	-0.60	-0.48	-0.77	-0.65	0.00	-0.54	-0.79	-0.65
March	-0.38	-0.47	-0.41	-0.65	-0.66	-0.68	0.00	-0.73	-0.88	-0.70
April	-0.50	-0.30	-0.39	-0.71	-0.67	-0.66	0.00	-0.61	-0.77	-0.55
May	-0.41	0.00	-0.38	-0.47	-0.40	-0.47	-0.14	-0.74	-0.61	-0.63
June	-0.33	0.00	-0.14	-0.43	-0.55	-0.69	-0.10	-0.58	-0.49	-0.57
July	0.00	-0.30	-0.26	-0.26	-0.32	-0.22	-0.46	-0.65	-0.48	-0.57
August	-0.14	-0.32	-0.14	-0.39	-0.14	-0.28	-0.40	-0.50	-0.48	-0.44
September	0.00	-0.36	0.00	0.00	-0.41	-0.47	-0.32	-0.77	-0.49	-0.24
October	-0.33	-0.70	0.00	-0.42	-0.71	-0.59	-0.70	-0.82	-0.62	-0.30
November	-0.10	-0.75	-0.48	-0.49	-0.67	-0.50	-0.66	-0.71	-0.65	-0.50
December	0.00	-0.61	-0.51	-0.24	-0.47	-0.76	-0.58	-0.43	-0.56	-0.72
June - September	-0.28	-0.28	0.00	-0.44	-0.47	-0.65	-0.40	-0.80	-0.57	-0.58
Annual	-0.47	-0.51	-0.45	-0.74	-0.75	-0.73	-0.50	-0.89	-0.87	-0.78

81° 46′ E) (Andhra Pradesh). In this paper, for all ten stations, basic statistical parameters of annual evaporation (minimum, maximum, range, mean, standard deviation and coefficient of variation) have been computed. Variations in average monthly evaporation in different months and at different locations have been plotted. Graphs have been plotted for the linear trend analysis of annual evaporation. Trend analysis has also been carried out for evaporation in all the months (January – December) as well as during the monsoon season (June – September).

3.1. *Variations in annual evaporation* - Basic statistical parameters (minimum, maximum, range, mean, standard deviation (S.D) and coefficient of variation (C.V.) of annual evaporation have been computed for all 10 locations and given in Table 1. The minimum annual evaporation of 1033 mm has been observed at Karimganj. The maximum annual evaporation of 3518 mm has been observed at Jodhpur. The lowest range of 368 mm in annual evaporation has been observed at Karimganj. The highest range of 1152 mm in annual evaporation has been observed at Jodhpur. Large variations in mean annual evaporation may be observed among these 10 locations. The mean annual evaporation has been found to be lowest (1174 mm) at Karimganj. The mean annual evaporation has been found to be highest (2993 mm) at Jodhpur. The coefficient of variation (C.V) at these locations varied between 7 and 11 percent. The highest C.V. of 11 % has been observed at Jodhpur, whereas the lowest C.V. of 7 % has been observed at Bhubaneshwar, Canning and Hebbal.

3.2. *Variations in monthly* evaporation - Variations in average monthly evaporation from January through

TABLE 3

Results of trend analysis (at p > 0.95) of evaporation (mm) in different months, monsoon season (June – September) and annual at different locations in India

Period	Results of trend analysis (at p > 0.95) of evaporation (mm)									
	Bhubaneshwar	Bikramganj	Canning	Hebbal	Hissar	Jodhpur	Karimganj	Pattambi	Pune	Rajamundry
January	N S	significant	significant	significant	significant	significant	significant	significant	significant	significant
February	significant	significant	significant	significant	significant	significant	N S	significant	significant	significant
March	significant	significant	significant	significant	significant	significant	N S	significant	significant	significant
April	significant	N S	significant	significant	significant	significant	N S	significant	significant	significant
May	significant	N S	significant	significant	significant	significant	N S	significant	significant	significant
June	N S	N S	N S	significant	significant	significant	N S	significant	significant	significant
July	N S	N S	N S	N S	N S	N S	significant	significant	significant	significant
August	N S	N S	N S	N S	N S	N S	significant	significant	significant	significant
September	N S	N S	N S	N S	significant	significant	N S	significant	significant	N S
October	N S	significant	N S	significant	significant	significant	significant	significant	significant	N S
November	N S	significant	significant	significant	significant	significant	significant	significant	significant	significant
December	N S	significant	significant	N S	significant	significant	significant	significant	significant	significant
June-September	N S	N S	N S	significant	significant	significant	significant	significant	significant	significant
Annual	significant	significant	significant	significant	significant	significant	significant	significant	significant	significant

Note : N S = Not Significant

December and at different locations are given in Fig. 1. It may be seen that average monthly evaporation values, in general, show a rising tendency between January and May, *i.e*., when the season changes from winter to summer. The peak in average monthly evaporation is achieved in the month of May. The highest average monthly evaporation of 447 mm has been observed at Jodhpur in the month of May. The average monthly evaporation values, in general, show a falling tendency between June and September, *i.e*., when climatic conditions change under the influence of monsoon season. A further decrease in average monthly evaporation values is observed between October and January, *i.e*., when climatic conditions change under the influence of winter season. The lowest average monthly evaporation of 58 mm has been observed at Karimganj in the month of January. The pattern of variations in average monthly evaporation at Pattambi, however, has been found to be different from other locations. Here, the peak of average monthly evaporation is reached in the month of March; perhaps the climate of this location is greatly influenced due to the closeness of the seas.

3.3. *Linear trend analysis of evaporation time series data (1971 – 2000)* - To study the changes in annual evaporation at different locations, the evaporation time series data (1971-2000) was subjected to linear trend analysis by the method of least squares. The trends observed at these locations are given in Fig. 2. The dotted horizontal line in the figure represents average annual evaporation, whereas the thick line sloping downward represents the observed linear trend at the location. It may be clearly seen that, at all the locations, annual evaporation shows a decreasing trend. The trend line equations obtained are also given in Table 1. The observed trends were found significant at more than 95% probability level. Similar results of decreasing annual evaporation have been observed earlier in India as well as different parts of the world (Peterson *et al*. 1995). Although, one would expect increase in evaporation, due to rise in mean temperature. However decreasing evaporation trends are the result of increasing relative humidity, which plays a significant role in counterbalancing the effect of rising temperatures (Chattopadhyay and Hulme, 1997).

As, all the locations exhibit decreasing trend, the linear trend analysis was further extended to study the changes occurring in monthly evaporation (January through December) and also during the monsoon season (June-September). The correlation coefficients (r) obtained for the trend line, at various locations, in different months (January through December), monsoon season (June-September) and annual evaporation are given in Table 2. The results of test of significance, at more than 95% probability level, are given in Table 3. It may be seen in this table that, at Pattambi and Pune, the results of decreasing trend in evaporation have been found significant in all the 12 months (January through December) and also during the monsoon season (June-September). However, at Bhubaneshwar, the results of decreasing trend in evaporation have been found significant only during 4 months (February, March, April and May). During the monsoon season (June-September), decreasing trend in evaporation has been found significant in 7 out of 10 locations. These results also clearly show that January, February, March and November are 4 different months when decreasing trend in evaporation have been found significant in maximum number of stations (9 out of 10). It may also be seen that, July, August and September are 3 different months when decreasing trend in evaporation have been found significant in minimum number of stations (4 out of 10).

4. (*i*) The mean annual evaporation has been found to be lowest (1174 mm) at Karimganj and highest (2993 mm) at Jodhpur. The highest C.V. of 11 % has also been observed at Jodhpur.

(*ii*) The peak in average monthly evaporation is achieved in the month of May. The highest average monthly evaporation of 447 mm in this month has been observed at Jodhpur.

(*iii*) At all the locations, annual evaporation shows a decreasing trend, significant at more than 95% probability level.

(*iv*) For the monsoon season (June-September), decreasing trend in evaporation has been found significant in 7 out of 10 locations.

(*v*) January, February, March and November are 4 different months, when decreasing trend in evaporation have been found significant in maximum number (9 out of 10) of locations.

(*vi*) July, August and September are 3 different months, when decreasing trend in evaporation have been found significant in minimum number of locations (4 out of 10).

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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.

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

Rupa Kumar, 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**, 1, 7-20.

Sambasiva 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.

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