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Factors affecting the trends in evaporation during different crop growing seasons over India

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सार – इस अध्ययन के लिए भारत के 58 सुवितरित स्टेशनों के लिए 1971 – 2004 तक की अवधि के वाषोत्सर्जन, वर्षा और मौसम वैज्ञानिक आँकड़ों का उपयोग किया गया है। खरीफ, रबी और ग्रीष्म की फसल वृद्धि की विभिन्न ऋतुओं के दौरान भारत के पाँच क्षेत्रों नामतः उत्तर पश्चिम, उत्तर, उत्तर पूर्व, मध्य और प्रायद्वीपीय क्षेत्रों में वाष्पोत्सर्जन और वर्षा की प्रवृत्ति में सहायक मौसम वैज्ञानिक कारकों का इस शोध पत्र में विश्लेषण किया गया है। देश के सभी क्षेत्रों में वार्षिक वाष्पोत्सर्जन में कमी की प्रवृत्ति का पता चला है। खरीफ, रबी और ग्रीष्म ऋतु में देश के उत्तर पश्चिमी, उत्तर, मध्य ओर प्रायद्वीपीय क्षेत्रों में मौसमी वाष्पोत्सर्जन की प्रवृत्ति में कमी देखी गई जबकि पूर्वोत्तर भारत के कुछ स्थानों नामतः गुवाहाटी, डिब्रूगढ़ और टॉकलई में खरीफ और रबी ऋतुओं के दौरान वाष्पोत्सर्जन की प्रवृत्ति में वृद्धि हुई है। प्रायद्वीपीय भारत के कुछ केन्द्रों को छोड़कर जहाँ वृद्धि की प्रवृत्ति देखी गई भारतीय क्षेत्र में वार्षिक और मौसमी वर्षा में कोई महत्वपूर्ण प्रवृत्ति नहीं देखी गई।

अधिकतम तापमान, सापेक्षिक आर्द्रता और वाष्पदाब की सामान्यीकृत विसंगतियों से फसल वृद्धि के तीनों मौसमों के दौरान उत्तर पश्चिम और उत्तरी क्षेत्रों में वृद्धि की प्रवृति का पता चला है जबकि देश के केवल मध्य भाग को छोड़कर, जहाँ ग्रीष्म ऋतु के दौरान वृद्धि की प्रवृत्ति देखी गई, देश के सभी भागों में पवन वेग में घटने की प्रवृत्ति अथवा किसी भी प्रवृत्ति के नहीं होने का पता चला है।

चूँकि वाष्पोत्सर्जन मौसम वैज्ञानिक तत्वों नामतः तापमान, धूप की अवधि, पवन वेग और सापेक्ष आर्द्रता से संबंधित है अतः ऐसे परिवर्तनों के संभावित कारणात्मक मौसम वैज्ञानिक कारकों का अध्ययन किया गया है। रबी और ग्रीष्म ऋतु के दौरान देश के मध्य और प्रायद्वीपीय, अंतरदेशीय क्षेत्रों में अधिकतम तापमान में वृद्धि की प्रवृत्ति देखी गई जबकि खरीफ ऋतु के दौरान पूर्वोत्तर क्षेत्र में मामूली सी कमी की प्रवृत्ति का पता चला है। अधिकतम तापमान और पवन वेग के बीच उच्च सकारात्मक सहसंबंध से पता चलता है कि वाष्पोत्सर्जन में प्रवृत्ति इन दो कारकों से अधिकतर प्रभावित होती है। आर्द्रता में वृद्धि और तेज धूप के घंटों में कमी दोनों महत्वपूर्ण हैं इनका वाष्पोत्सर्जन में कमी से सहसंबंध पाया गया है।

ABSTRACT. Evaporation, rainfall and meteorological data for the period 1971-2004 for 58 well distributed stations over India were selected for the study. Trends of evaporation and rainfall in five regions, *viz*., Northwest, North, Northeast, Central and Peninsular regions of India during different crop growing seasons, *viz*., kharif, rabi and summer and the meteorological factors contributing towards the trend were analyzed. Annual evaporation shows decreasing trend in all the regions of the country. Trends in seasonal evaporation during kharif, rabi and summer seasons also showed decreasing trends in Northwest, North, Central and Peninsular regions of the country while few locations in Northeast India, *viz*., Guwahati, Dibrugarh and Tocklai showed significant increasing trend in evaporation during kharif and rabi seasons. No significant trend in annual and seasonal rainfall was observed in Indian region except a few stations in peninsular India where increasing trend was observed.

Normalized anomalies of maximum temperature, relative humidity and vapour pressure showed increasing trend in Northwest and Northern regions during all the three crop growing seasons while decreasing trend or no trend in wind velocity was observed in all the regions except in central region where increasing trend was observed during summer season.

As evaporation relates to the meteorological elements, *viz*., temperature, sunshine duration, wind velocity and relative humidity, the likely causative meteorological factors for such changes are studied. Increasing trends in maximum temperature was observed in central and peninsular inland regions of the country during rabi and summer seasons while slight decreasing trends were observed in the Northeast region during kharif season. High positive correlation found between maximum temperature and wind velocity indicates that the trend in evaporation is mostly influenced by these

two factors. Increase in humidity and decrease in bright sunshine hours were both important and found correlated with the decrease in evaporation.

Key words – Evaporation, Trends, Maximum Temperature, Rainfall, Sunshine hours.

1. Introduction

Evaporation is the component of the hydrological cycle which is directly influenced by land use and climate. Evaporation dissipates 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 of factors such as temperature, humidity, vapour pressure deficit, bright sunshine duration and wind speed. Earlier studies over India have showed increasing trend in mean temperature in most parts of the Indian sub continent during post monsoon and winter seasons (Rupakumar and Hingane 1988; Govinda Rao *et al*., 1996). Concerns have been raised over the effect of increased mean temperature as well as variability of other meteorological parameters on evaporation. In the last 10 years significant changes in measured evaporation from open water surfaces have been reported from a widespread range of sites; most of the studies reported overall reductions in the rates of water loss to the atmosphere (Cohen *et al*., 2002; Roderick and Farquhar, 2004). There is also large area now under irrigation in India compared to that of previous 2-3 decades. Irrigated area becomes the source of free available surface water. It is, therefore, important from hydrological and agricultural point of view to know the factors that affect the trend in evaporation. Earlier studies on evaporation trends from different regions of the world showed a general decline in evaporation trends (Peterson *et al*. 1995; Liu *et al*., 2004). It was first reported by Peterson *et al*. (1995) for the United States and subsequently for India by Chattopadhyay and Hulme (1997).

In this study an attempt has been made to determine evaporation trends in different regions of India during different crop growing seasons and the meteorological factors contributing towards the trend over India during summer, kharif and rabi seasons.

2. Data and methodology

Evaporation and other meteorological data for the period 1971-2004 have been collected from National Data Centre, Pune to study the trend of evaporation in different regions of the country. Data are grouped corresponding to crop growing seasons, *i.e*., Kharif, rabi and summer season for the five regions, *viz*., Northwest, North, Northeast, Central and Peninsular India. Representative stations have been selected from each region and trends in evaporation and met parameters, *viz*., maximum temperature, humidity (RH), vapour pressure (VP), wind velocity and bright sunshine duration and rainfall have been studied for kharif, rabi and summer seasons. Trends in annual evaporation and rainfall in different regions of India are presented in Figs. 1 (a-f). Normalized Anomalies of evaporation and met parameters were computed for five regions during different crop growing seasons and presented in Figs. 2(a-f). Annual evaporation and rainfall trends and seasonal evaporation trends are depicted in Figs. 3 & 4 respectively.

3. Result and discussions

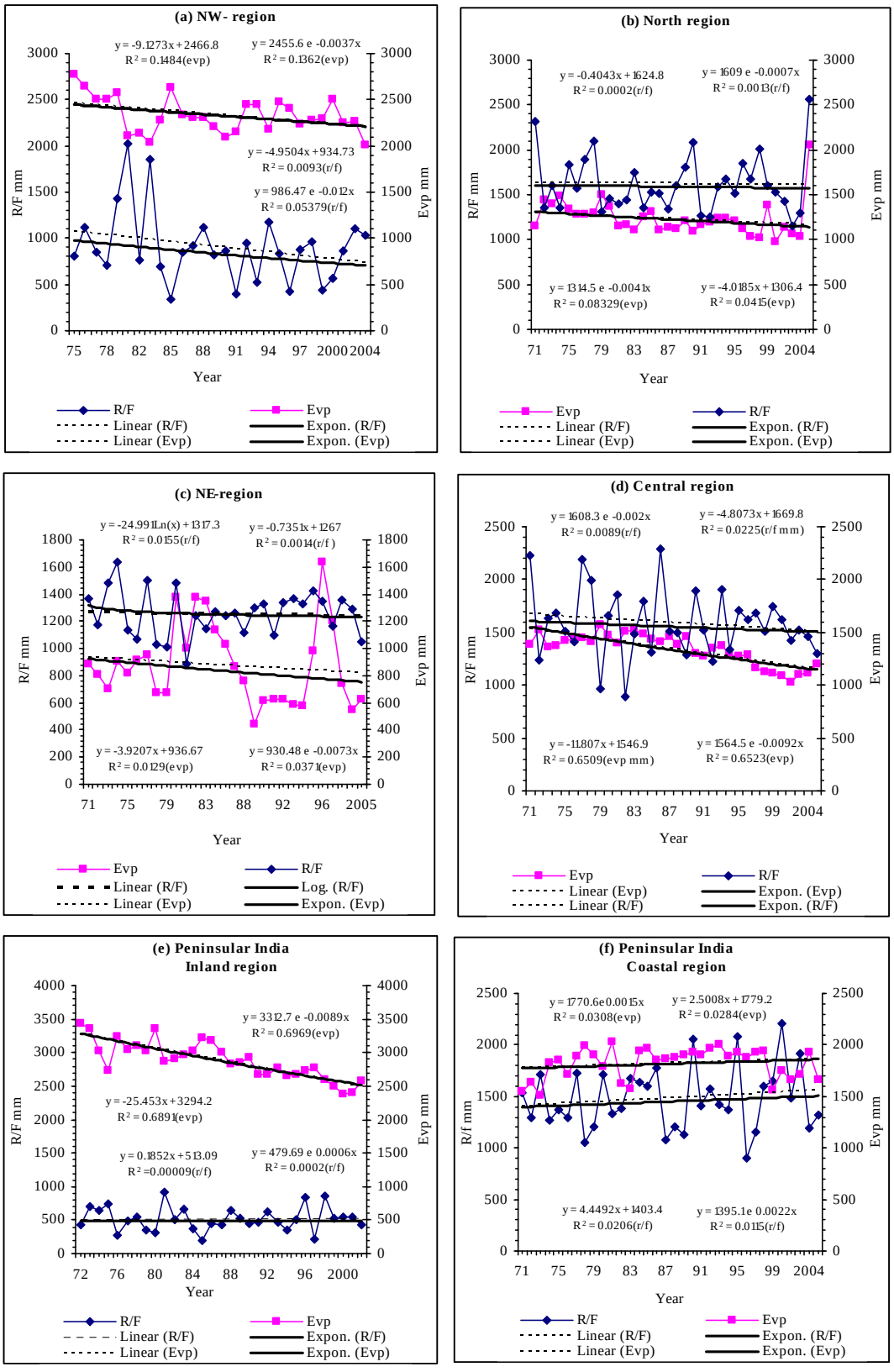
3.1. *Time trends*

Linear and non-linear time trends in annual evaporation for different regions of India showed decreasing trends in all regions except in the coastal regions where slight increasing trends were observed [Fig. 3(a)]. The decreasing trends were significant in northeast and central regions of the country (Table 1).

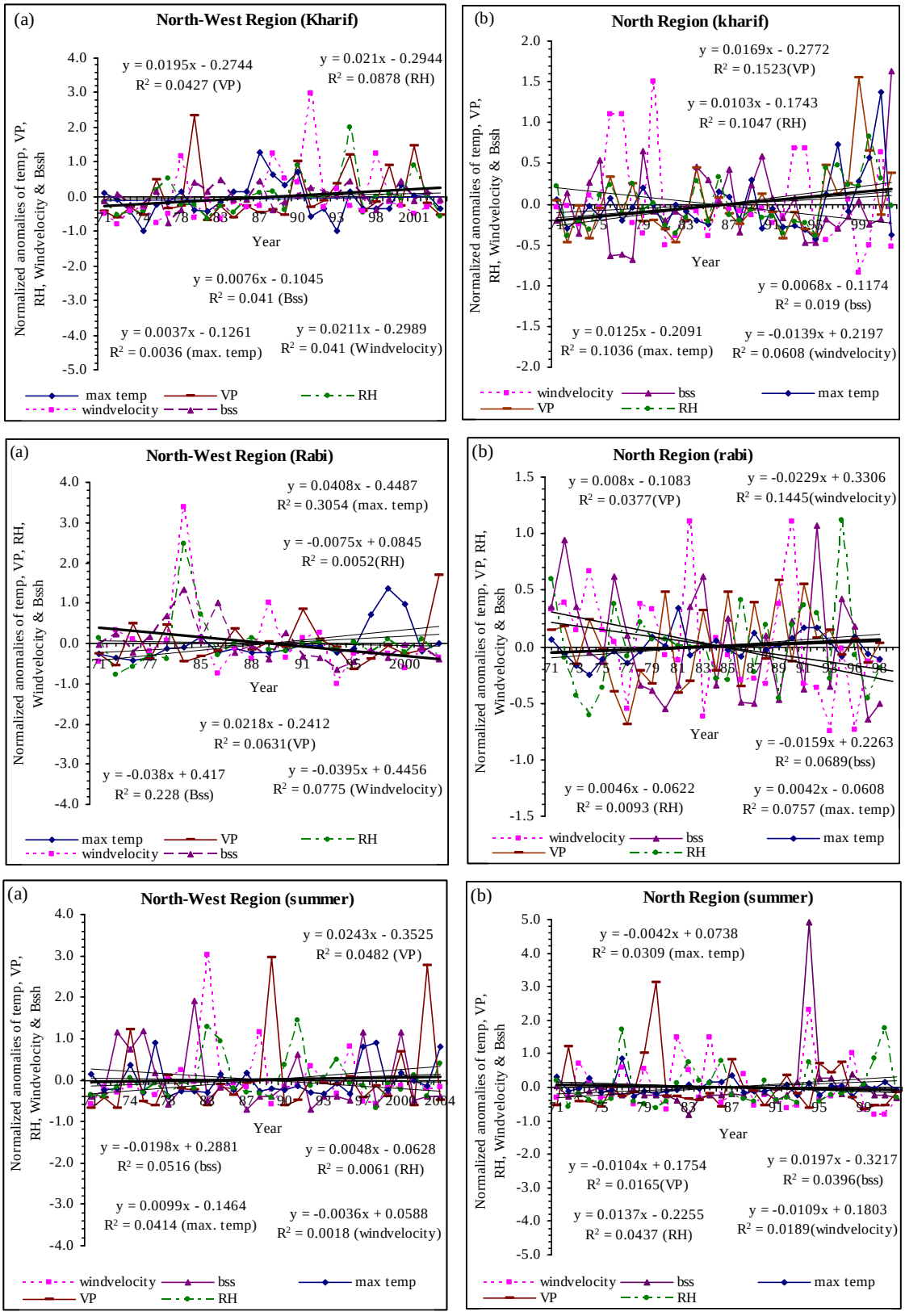
Linear and non-linear time trends in annual evaporation for 58 sites selected for the study during the period 1971-2004, 40 of the linear and 4 of the non-linear trends in annual evaporation were found statistically significant, 2 of these were increasing and 38 showed decreasing trend. The seasonal linear changes were normalized, so as to compare the spatial distribution of the trends. The time trends were examined as normalized anomalies, *i.e*., deviations from the median of each series divided by its standard deviation. Analysis of data for smaller and homogeneous region as well as for the smaller time period corresponding to crop growing seasons demonstrate trends which are either increasing or decreasing, but majority with non-significant correlation coefficient

3.2. *Precipitation*

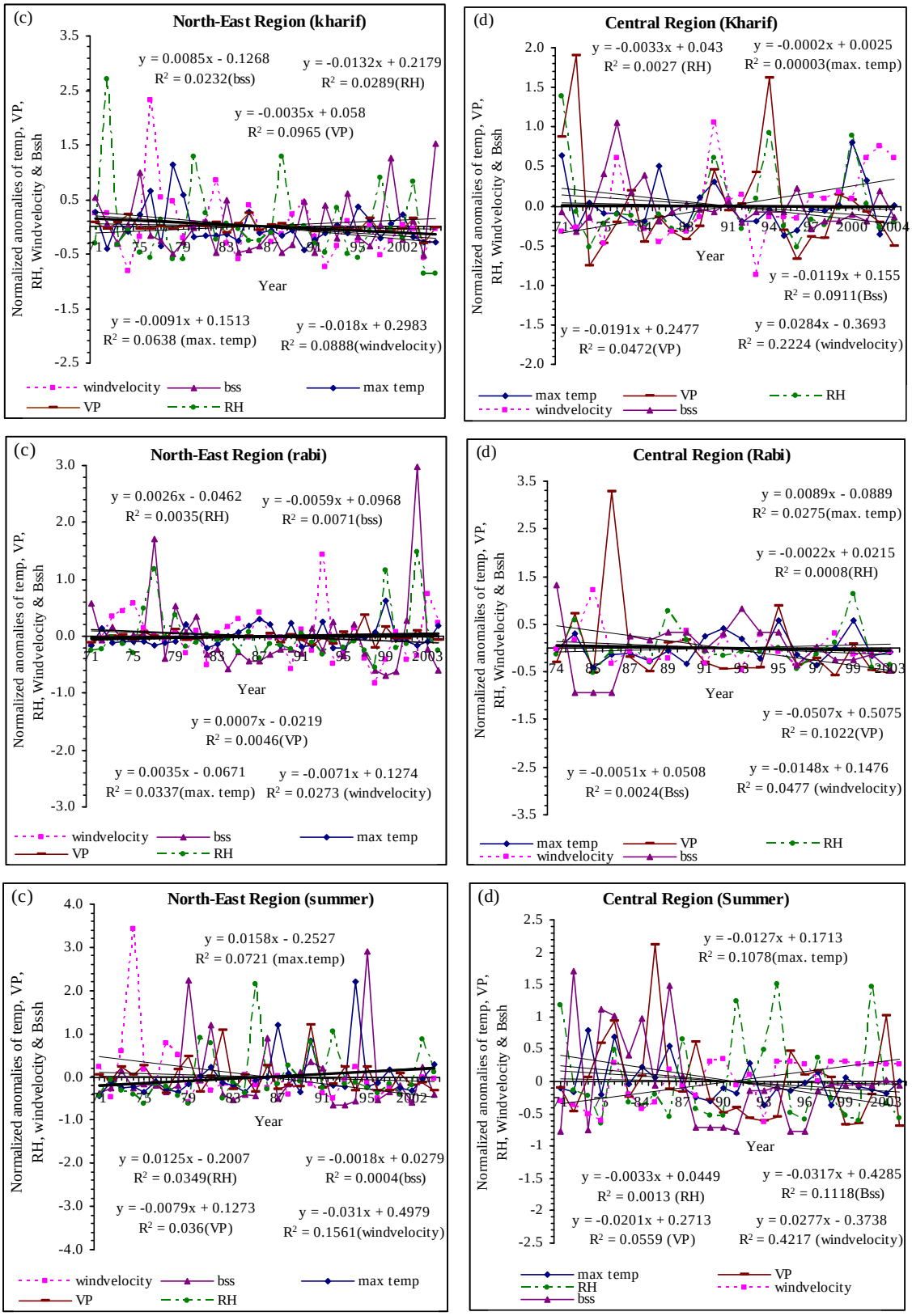
Linear and non-linear time trends in annual rainfall for different regions of India showed decreasing trends in all regions except in peninsular India where increasing trends were noticed [Fig. 3(b)]. However, the trends were found statistically not significant. Out of 58 stations selected for the study, 28 stations showed decreasing trend (2 were statistically significant) and 30 stations showed increasing trends (2 significant) (Table 1). Annual values of rainfall were inversely related to those of evaporation in all but 9 stations, however only 4 stations (Jobner, Tocklai, Agartala and Bangalore) were found statistically significant.



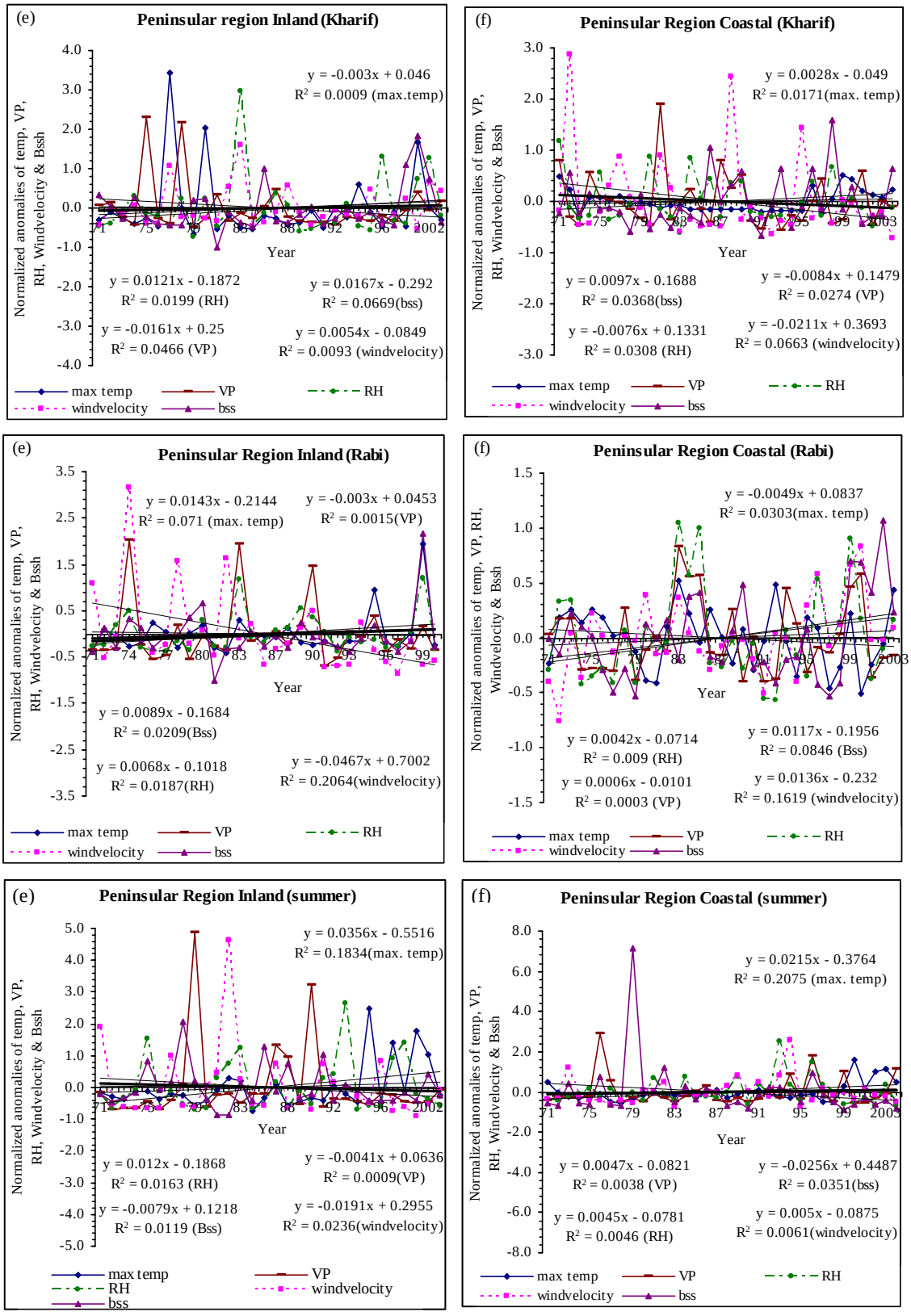
Figs. 1 (a-f). Trends in annual evaporation and rainfall in different regions of India



Figs. 2(a&b). Normalized anomalies of met. parameters for different crop seasons for different regions in India



Figs. 2(c&d). Normalized anomalies of met. parameters for different crop seasons for different regions in India



Figs. 2(e&f). Normalized anomalies of met. parameters for different crop seasons for different regions in India

TABLE 1

Time trends in annual evaporation (mm) and annual rainfall (mm) for different regions in India

Region		Annual evaporation (mm)		Annual rainfall (mm)	
		Equation	R^2	Equation	R^2
Northwest	Linear	y = -9.1273*x* + 2466.8	0.1484	y = -4.9504*x* + 934.73	0.0093
	Exponential	y = 2455.6 e $^{-0.0037x}$	0.1362	y = 986.47 e $^{-0.012x}$	0.0537
North	Linear	y = -4.0185*x* + 1306.4	0.0415	y = -0.4043*x* + 1624.8	0.0002
	Exponential	y = 1314.5 e $^{-0.0041x}$	0.0832	y = 1609 e $^{-0.0007x}$	0.0013
Northeast	Linear	y = -3.9207*x* + 936.67	0.0129	y = -0.7351*x* + 1267	0.0014
	Exponential	y = 930.48 e $^{-0.0073x}$	0.0371	y = -24.991Ln(*x*) + 1317.3 (log)	0.0155
Central	Linear	y = -11.807*x* + 1546.9	0.6509*	y = -4.8073*x* + 1669.8	0.0225
	Exponential	y = 1564.5 e $^{-0.0092x}$	0.6523*	y = 1608.3 e $^{-0.002x}$	0.0089
Peninsular (Inland)	Linear	y = -25.453*x* + 3294.2	0.6891*	y = 0.1852*x* + 513.09	0.00009
	Exponential	y = 3312.7 e $^{-0.0089x}$	0.6969*	y = 479.69 e $^{0.0006x}$	0.0002
Peninsular (Coastal)	Linear	y = 2.5008*x* + 1779.2	0.0284	y = 4.4492*x* + 1403.4	0.0206
	Exponential	y = 1770.6 e $^{0.0015x}$	0.0308	y = 1395.1 e $^{0.0022x}$	0.0115

* Significant at 5% level.

TABLE 2

Time trends in seasonal Evaporation (mm) for different regions in India for different crop growing season

Region	Station	Kharif		Rabi		Summer	
		Equation	R^2	Equation	R^2	Equation	R^2
North west	1. Bikaner	*y* = -5.0275*x* + 936.72	0.058	*y* = - 9.58*x* + 597	0.299	*y* = - 7.5419*x* + 1098.5	0.124
	2. Junagarh	*y* = -3.3467*x* + 470.6	0.159	*y* = -3.257*x* + 699.84	0.092	*y* = -3.1062*x* + 908.6	0.084
North	1. Delhi	*y* = -14.196*x* + 1090.1	0.313*	*y* = - 8.243*x* + 465.86	0.411*	*y* = - 2.8961*x* + 732.44	0.104
	2. Dehradun	*y* = -4.0254*x* + 526.09	0.452*	*y* = -1.544*x* + 206.55	0.554**	*y* = -3.0756*x* + 528.35	0.195
North East	1. Tocklai	*y* = - 1.652*x* + 392.6	0.249	*y* = 0.54*x* + 221.55	0.042	*y* = - 0.9738*x* +180.48	0.264
	2. Diphu	*y* = -0.9355*x* + 343.1	0.004	*y* = -3.482*x* + 270.87	0.067	*y* = 0.2985*x* + 228.28	0.001
Central	1. Nagpur	*y* = - 8.1138*x* + 803.64	0.221	*y* = - 6.5263*x* + 524.74	0.416*	*y* = - 8.7508*x* + 1040.8	0.323*
	2. Barrackpore	*y* = -2.367*x* + 484.01	0.189	*y* = -3.189*x* + 355.25	0.696**	*y* = -5.2483*x* + 590.02	0.573*
Peninsular(Inland)	1.Kovilpatti	*y* = - 10.255*x* + 1251.8	0.310*	*y* = - 8.8655*x* + 665.12	0.481**	*y* = - 6.8109*x* + 748.67	0.364*
	2. Bellary	*y* = -8.9758*x* + 1177.3	0.445*	*y* = -6.723*x* + 794.01	0.433*	*y* = -8.0129*x* + 1119.9	0.620**
Peninsular (Coastal)	1. Kasargod	*y* = - 2.318*x* + 443.8	0.273	*y* = - 1.5251*x* + 532.93	0.334*	*y* = 4.7883*x* + 167.14	0.055
	2. Bhubaneshwar	*y* = 6.2356*x* + 400.81	0.75**	*y* = 3.0334*x* + 896.68	0.112	*y* = -2.5261*x* + 372	0.310*

* Significant at 5% level.
** Significant at 1% level.

3.3. *Trends in seasonal evaporation and met. parameters for different crop growing seasons in the five regions of India*

3.3.1. *Northwest region*

Trends in seasonal evaporation and rainfall for Northwest region were worked out for each region 10 stations were selected as representative. The trends observed across the region, annually and during different crop seasons are as follows:

Trends in annual evaporation and rainfall showed decreasing trends in the Northwest region [Fig. 1 (a)].

Trends in seasonal evaporation and rainfall for Northwest region for two representative stations (Bikaner, Junagarh) are given in Table 2.

TABLE 3

Time trends in seasonal rainfall (mm) for different regions in India for different crop growing season

Region	Station	Kharif		Rabi		Summer	
		Equation	R^2	Equation	R^2	Equation	R^2
North west	1. Bikaner	$y = -5.9823x + 320.96$	0.097	$y = 0.1687x + 13.36$	0.006	$y = -0.868x + 55.504$	0.024
	2. Junagarh	$y = -1.3309x + 644.42$	0.001	$y = -0.981x + 24.09$	0.075	$y = 0.4752x + 2.4692$	0.025
North	1. Delhi	$y = -5.2061x + 723.91$	0.032	$y = 1.5174x + 32.434$	0.092	$y = -0.2596x + 50.721$	0.003
	2. Dehradun	$y = -6.9616x + 1413.2$	0.074	$y = 15.423x - 17.365$	0.221	$y = -0.6451x + 131.25$	0.006
North East	1. Tocklai	$y = -11.256x + 1274$	0.216	$y = -2.724x + 449.56$	0.020	$y = 2.0369x + 91.838$	0.092
	2. Diphu	$y = -3.0704x + 855.43$	0.040	$y = -0.073x + 82.102$	0.000	$y = 1.9528x + 254.17$	0.045
Central	1. Nagpur	$y = 3.4706x + 825.29$	0.034	$y = -0.285x + 63.204$	0.000	$y = 2.229x + 8.3092$	0.311*
	2. Barrackpore	$y = -7.4991x + 1278.3$	0.074	$y = 0.3178x + 73.065$	0.002	$y = -0.7767x + 244.76$	0.004
Peninsular (Inland)	1.Kovilpatti	$y = -1.7497x + 173.37$	0.040	$y = -2.971x + 291.27$	0.024	$y = -0.3431x + 151.99$	0.002
	2. Bellary	$y = -1.4719x + 305.55$	0.014	$y = 0.3969x + 45.065$	0.004	$y = -0.9794x + 86.496$	0.047
Peninsular (Coastal)	1. Kasargod	$y = -10.989x + 3025.6$	0.052	$y = -0.269x + 109.15$	0.000	$y = 4.7883x + 167.14$	0.054
	2. Bhubaneshwar	$y = -2.8024x + 1135.6$	0.011	$y = 1.9348x + 51.39$	0.056	$y = 3.2465x + 94.184$	0.060

* Significant at 5% level.
** Significant at 1% level.

(*i*) *Kharif season* : Linear and non-linear time trends in seasonal evaporation for 10 sites selected for NW region showed decreasing trend, out of which 5 stations namely Jodhpur, Jobner, Deesa, Ahmedabad and Jamnagar were statistically significant. Nine sites showed decreasing trend in seasonal rainfall out of which 1 station (Jodhpur) was found statistically significant and 1 station Ahmadabad showed increasing trend. Normalized anomaly analysis showed (Fig. 2) that maximum temperature though exhibited increasing trend, is not significant during the period. Seasonal mean VP and RH showed no trend while mean wind velocity showed slight increasing trend. Seasonal sunshine duration also showed no trend during the period.

(*ii*) *Rabi season* : During this season, seasonal mean evaporation in 8 representative stations across the region showed decreasing trend, 3 stations namely Jodhpur, Ahmedabad and Rajkot were statistically significant and 2 sites (Bikaner and Kota) showed increasing trend. Seasonal rainfall in 3 sites Jobner, Ahmadabad and Jamnagar showed decreasing trend and 7 sites showed increasing trend while it is interesting to note that maximum temperature showed significant increasing trend in all sites [Fig. 2(a)]. Seasonal mean VP showed small increasing trend during the period 1971-87 thereafter remained steady till 1992 and then showed increasing trend. Seasonal mean wind velocity and sunshine hours showed significant decreasing trend.

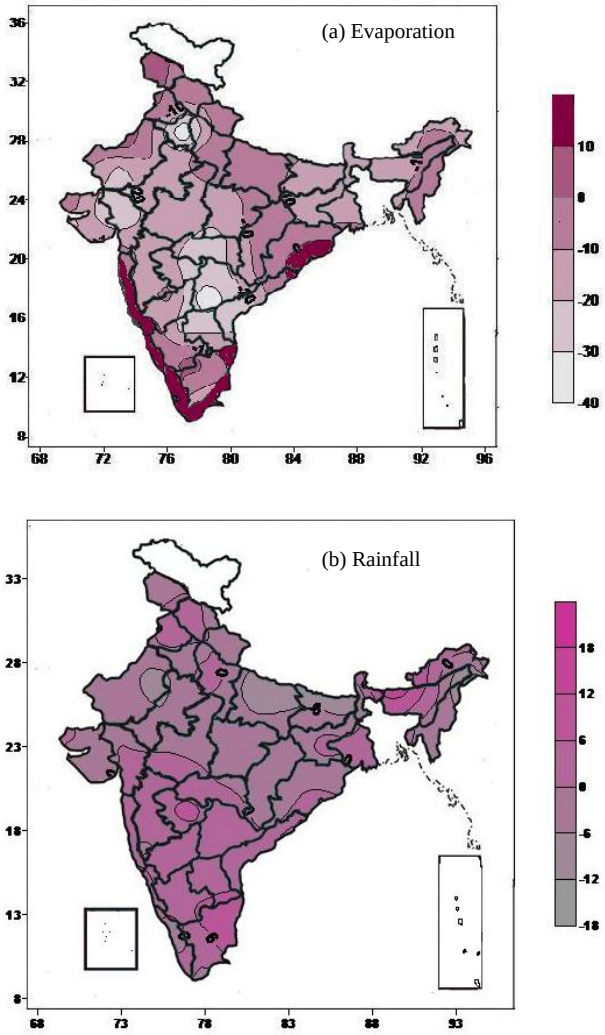
(*iii*) *Summer season* : Seasonal evaporation trends showed decreasing tendency in 9 locations out of which 4 stationst, *viz*., Jodhpur, Deesa, Bhuj and Ahmedabad were found statistically significant while 1 station (Bikaner) showed increasing tendency. Out of 10 stations data analysed, 6 stations showed decreasing trend while 4 stations showed increasing trend in seasonal rainfall. Maximum temperature showed significant increasing trend during this season. Seasonal RH and VP showed small in-significant increasing trend while mean wind velocity showed slight decreasing trend [Fig. 2(a)].

3.3.2. *North region*

Trends in annual evaporation and rainfall showed decreasing trends in this region [Fig. 1 (b)].

(*i*) *Kharif season* : Trend analysis of seasonal evaporation for 10 locations in North region during the period 1971-2004 showed decreasing trend in 6 locations out of which 4 (Chandigarh, Hissar, Karnal and New Delhi) were statistically significant while 4 stations trends were increasing. Trends in seasonal rainfall showed 5 stations exhibiting decreasing trends and 5 increasing trends. Normalized anomaly analysis showed [Fig. 2(b)] that maximum temperature showed increasing trend during the period. Seasonal mean VP and RH showed steady increase while mean wind velocity showed decreasing trend. Seasonal sunshine duration showed slight increasing trend during the period.

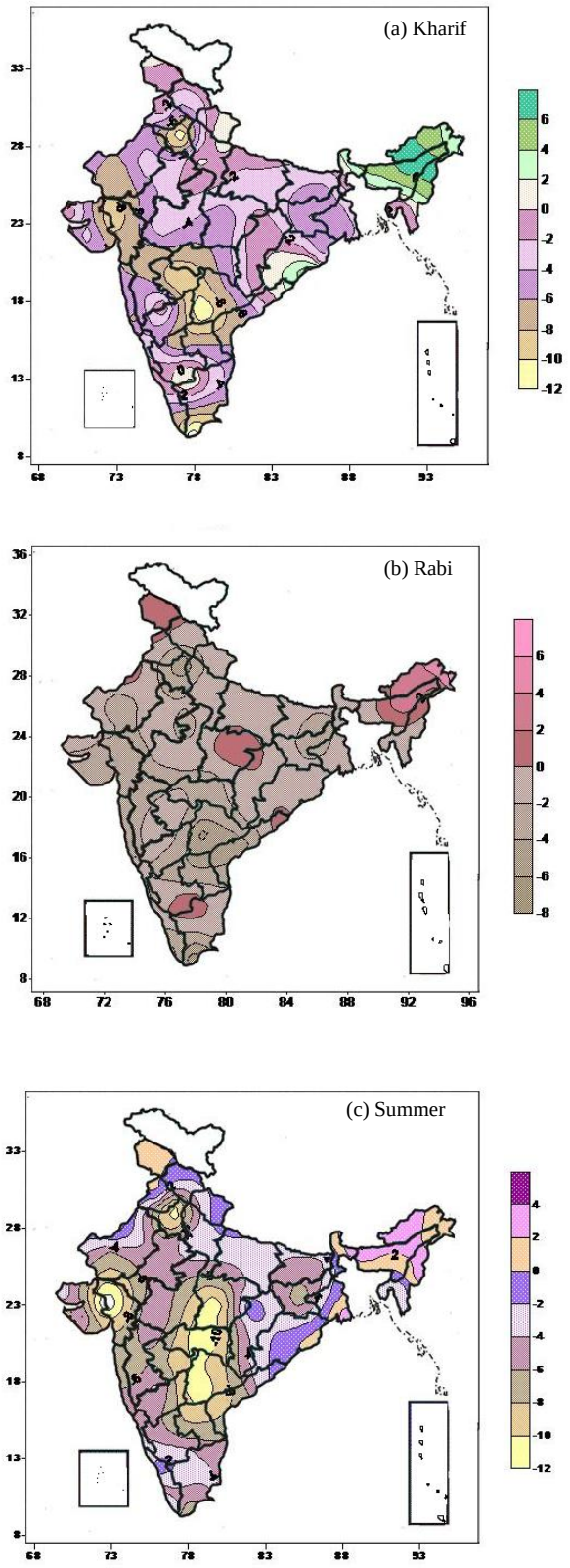
(*ii*) *Rabi season* : During this season, seasonal mean evaporation showed decreasing trends in all 10 sites out of which 3 (Dehradun, Pantnagar and New Delhi) were



Figs. 3(a&b). Annual evaporation and rainfall trends (mm/year) for different regions in India

found statistically significant and trends in seasonal rainfall showed 3 decreasing trends and 7 increasing trends, out of which 2 (Karnal, New Delhi) were found statistically significant. Maximum temperature, Seasonal mean VP and RH showed increasing trend while seasonal mean wind velocity and sunshine hours showed marked decreasing trend [Fig. 2(b)]. During this season evaporation exceeded seasonal rainfall.

(*iii*) *Summer season* : Seasonal evaporation trends were decreasing in 9 sites and 4 of this (Dehradun, Hissar, Karnal and New Delhi) were significant while in 1 site (Srinagar) the trends were increasing. In 6 locations seasonal rainfall trends were decreasing and at 4 locations it was increasing, however, seasonal evaporation exceeded seasonal rainfall. Maximum temperature showed



Figs. 4(a-c). Evaporation trends (mm/season) for different crop growing seasons in India

decreasing trend during this season. Seasonal RH and sunshine duration showed increasing trend while mean wind velocity showed slight decreasing trend [Fig. 2(b)].

3.3.3. *Northeast region*

Trends in annual evaporation and rainfall showed decreasing trends in this region [Fig. 1(c)].

(*i*) *Kharif season* : Trend analysis of seasonal evaporation during this season for 10 stations showed decreasing trend in evaporation in 6 stations and in 4 stations increasing trend, out of which 3 (Tocklai, Nagarkatta, Agartala) decreasing trends were statistically significant. Seasonal rainfall showed decreasing trend in 3 stations out of which, 1 decreasing trend (Tocklai) was statistically significant and in 7 stations increasing trend was found out of which 1 (Nagarkatta) was statistically significant. Normalized anomaly analysis showed that maximum temperature trends are slight decreasing during the period Fig. 2(c). Seasonal mean VP and RH remained more or less steady while mean wind velocity showed decreasing trend. Seasonal sunshine duration showed slight increasing trend during the period.

(*ii*) *Rabi season* : During this season, seasonal mean evaporation showed increasing trend in 3 stations (Tocklai, Dibrugarh, Guwahati) which are statistically significant and decreasing trend in 7 sites, out of which 1 (Nagarkatta) was statistically significant. Seasonal rainfall showed increasing trend in 5 stations and decreasing trend in 5 stations which were statistically not significant. Maximum temperature showed increasing trend while seasonal mean VP and RH showed no trend [Fig. 2(c)]. Seasonal mean wind velocity and sunshine hours showed slight decreasing trend. During this season seasonal rainfall exceeded evaporation in most of the years.

(*iii*) *Summer season* : Seasonal evaporation showed decreasing trend during this season in 8 sites out of which 5 (Nagarkatta, Kunjaban, Silchar, Agartala and Titabar) stations showed significant trend whereas Diphu and Guwahati showed increasing trend. Seasonal rainfall in 6 locations showed decreasing trend out of which 2 (Tocklai, Silchar) were statistically significant and in 4 sites increasing trends were noticed. It is observed that most of the year seasonal evaporation exceeded seasonal rainfall. Seasonal mean maximum temperature, RH showed increasing trend while mean wind velocity and VP showed decreasing trend. No trend was observed for sunshine duration [Fig. 2(c)].

3.3.4. *Central region*

Trends in annual evaporation and rainfall showed decreasing trends in this region [Fig. 1 (d)].

(*i*) *Kharif season* : Trend analysis of seasonal evaporation during the season in 10 locations of this region showed decreasing trend in evaporation, of which 5 (Nagpur, Ranchi, Sabour, Jabalpur, Kolkata) were statistically significant and seasonal rainfall showed increasing trend in 6 sites and decreasing trend in 4 sites. In most of the years seasonal rainfall exceeded seasonal evaporation. Normalized anomaly analysis showed [Fig. 2(d)] that maximum temperature showed slight decreasing trend during the period. Seasonal mean VP and sunshine hours showed decreasing trend while RH remained more or less steady. Mean wind velocity showed marked increasing trend.

(*ii*) *Rabi season* : During this season, seasonal mean evaporation showed decreasing trend in 8 locations out of which 5 stations (Nagpur, Ranchi, Barrackpore, Indore and Kolkata) showed significant trend and increasing trend in 2 sites. Seasonal rainfall showed increasing trend in 4 sites and decreasing trend in 6 sites. Seasonal mean maximum temperature, VP, RH and sunshine hours showed no trend [Fig. 2(d)], while seasonal mean wind velocity showed slight decreasing trend. During this season seasonal evaporation exceeded rainfall.

(*iii*) *Summer season* : Seasonal evaporation showed decreasing trend in all locations and 6 of them (Nagpur, Ranchi, Barrackpore, Jabalpur, Indore and Kolkata) were found statistically significant during this season while seasonal rainfall showed increasing trend in 6 sites out of which 2 sites Nagpur and Sabour were statistically significant and decreasing trend in 4 locations. It is observed that seasonal evaporation exceeded rainfall. Seasonal mean maximum temperature, VP showed decreasing trend while mean wind velocity showed marked increasing trend. No trend was observed in RH and sunshine duration showed decreasing trend Fig. 2(d).

3.3.5. *Peninsular region*

Trends in annual evaporation showed decreasing trends while rainfall showed slight increasing trends in the inland areas [Fig. 1(e)] and annual evaporation and rainfall showed increasing trends in the coastal regions [Fig. 1(f)] of Peninsular India.

(a) *Inland*

(*i*) *Kharif season* : Trend analysis of seasonal evaporation in 9 locations in this region during this season showed decreasing trend in evaporation (7 significant – Aduthurai, Anantpur, Bellary, Kovilpatti, Kottayam, Parbhani and Ramgundam) and seasonal rainfall trends showed decreasing trend in 4 locations and increasing trend in 5 locations (1 significant - Anantpur). Normalized anomaly analysis showed [Fig. 2(e)] that seasonal RH

showed slight decreasing trend during the period. Seasonal mean maximum temperature, wind velocity and sunshine hours showed no trend and remained more or less steady. Mean VP showed slight decreasing trend.

(*ii*) *Rabi season* : During this season, seasonal mean evaporation showed increasing trend in 2 locations and decreasing trend in 7 locations (3 significant- Bellary, Kovilpatti and Anantpur). Increasing trend in 6 locations (1 Aduthurai significant) and decreasing trend in 3 locations in seasonal rainfall was observed. Seasonal mean maximum temperature, VP and sunshine hours showed slight increasing trend. While seasonal mean wind velocity showed pronounced decreasing trend [Fig. 2(e)]. During this season stations particularly in Tamil Nadu, seasonal rainfall exceeded seasonal evaporation in most of the years and slight decreasing trend in seasonal rainfall was observed.

(*iii*) *Summer season* : Seasonal evaporation showed decreasing trend during this season in all locations (7 significant - Aduthurai, Anantpur, Bellary, Kovilpatti, Kottayam, Parbhani and Ramgundam) while seasonal rainfall showed decreasing trend in 8 sites and increasing trend in 1 (Parbhani) site. It was observed that seasonal evaporation exceeded rainfall. High increasing trend in seasonal mean maximum temperature was observed while wind velocity showed slight decreasing trend. No trend were observed in seasonal RH and sunshine duration and VP showed slight decreasing trend Fig. 2(e).

(b) *Coastal*

(*i*) *Kharif season* : Trend analysis of seasonal evaporation during the season in 9 locations in the region showed decreasing trend in 8 sites (5 significant – Pattambi, Tiruvanantapuram, Mumbai, Chennai and Cuttuck) and significant increasing trend in 1 (Bhubaneshwar) site while seasonal rainfall showed decreasing trend in 7 sites (2 significant - Chennai and Cuttuck) and increasing trend in 2 sites. During this season seasonal rainfall exceeded seasonal evaporation and seasonal rainfall showed slight decreasing trend. Normalized anomaly analysis showed [Fig. 2(f)] no trend in seasonal mean max. temperature, RH, VP and sunshine duration while wind velocity showed slight decreasing trend during the period.

(*ii*) *Rabi season* : During this season, seasonal mean evaporation showed decreasing trend in 7 sites (4 significant - Pattambi, Mumbai, Kasargod and Panjim) and increasing trend in 2 sites and seasonal rainfall showed increasing trend in 5 sites (1 Significant – Mumbai) and decreasing trend in 4 sites. Seasonal evaporation exceeded seasonal rainfall most of the years seasonal mean maximum temperature, wind velocity and sunshine hours showed slight increasing trend [Fig. 2(f)]. While seasonal mean VP showed slight increasing trend and RH remained steady during the season.

(*iii*) *Summer season* : Seasonal evaporation showed decreasing trend in 8 locations (6 significant - Pattambi, Tiruvanantapuram, Mumbai, Chennai, Panjim and Bhubaneshwar) and 1 Kasargod showed increasing trend while seasonal rainfall showed decreasing trend in 3 sites and increasing trend in 6 sites during this season. It is observed that in some years seasonal evaporation exceeded seasonal rainfall. Increasing trend in seasonal mean maximum temperature was observed while no trend was observed in seasonal RH, sunshine duration, VP and wind velocity [Fig. 2(f)].

3.4. *Relationship between Evaporation and Meteorological factors*

The linear correlations between evaporation and meteorological parameters, *viz*., maximum temperature, relative humidity (RH), vapour pressure (VP), wind velocity and bright Sunshine duration and rainfall were also worked out. Maximum temperature showed high significant positive correlation (cc 0.45 to 0.95) in all the regions in all the seasons at most of the stations. The high correlation reflected the basic dependence of evaporation on maximum temperature. Another factor, which represents insolation, *i.e*., bright sunshine hours showed positive significant (cc 0.32 to 0.80) correlation and wind speed showed positive significant (cc 0.35 to 0.82) correlation for most of the stations. Wind speed is one of the key factors in removing the evaporated water vapour from evaporating surface and altering the aerodynamic conditions and hence having a strong bearing on evaporation. Relative humidity and seasonal rainfall showed significant negative correlation with evaporation. High humidity suppresses evaporation rates by decreasing the vapour pressure near the water surface (Chowdhary *et al*., 1999). Gerald and Markus (2008) in their study found that difference in sunshine duration used as a proxy for global radiation were found to be the major factor explaining spatial as well as temporal changes in evaporation in the British Isles.

Multiple regression analysis with evaporation and maximum temperature, bright sunshine hours and rainfall for the selected stations in each regions also showed that maximum temperature and bright sun shine hours are strongly related to the increase in evaporation. Increase in humidity and decrease in bright sun shine hours were both important and found to be correlated with the decrease in evaporation.

4. Conclusions

(*i*) Trend analysis of annual evaporation across all the regions of the country showed significant decreasing trends at majority of locations.

(*ii*) Trends in evaporation in different regions of the country in three crop growing season, *viz*., kharif, rabi and summer season also showed decreasing trends except in northeast India where a few stations showed significant increasing trend during Kharif and Rabi seasons.

(*iii*) Maximum temperature, VP and RH showed increasing trend in Northwest regions and North during all the three seasons. Decreasing trend or no trend in wind velocity was observed in all the regions except in Central region where increasing trend was observed during Summer season.

(*iv*) Northeast region showed decreasing trend in maximum temperature during all the three seasons. In this region during Kharif and Rabi season seasonal rainfall exceeded seasonal evaporation.

(*v*) In Inland Peninsular regions seasonal evaporation during rabi season exceeded seasonal rainfall and in Coastal Peninsular regions seasonal rainfall exceeded seasonal evaporation during Kharif and Summer season. No significant trend was observed in the annual as well in the seasonal rainfall over the country though some stations showed increasing trend in the seasonal rainfall, which were not significant.

High positive correlation ranging from 0.45 to 0.95 was generally found between evaporation and maximum temperature in most stations. Correlation ranging from 0.35 to 0.82 was found between evaporation and wind speed. Mean relative humidity showed high negative correlation ranging from -0.31 to -0.94 for majority of stations.

These conclusions of declining trend of evaporation in different regions of India inspite of reported general increase in maximum temperature do raise a number of important points, which needs to be further examined. Changes in relative humidity appear to be closely related to the evaporation changes, both in annual as well as seasonal conditions. The apparent increase in relative humidity over India, which seems to have suppressed evaporation, may be related to the more general tendency in recent years of increased humidities in the lower troposphere over tropical oceans as reported by Flohn and Kappala (1989). A study of trends in observed evaporation in Australia during the period 1975-2004, reported decrease in daily average wind speed (termed as wind run) as an important cause of decreasing trends in evaporation (Rayner, 2007).

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