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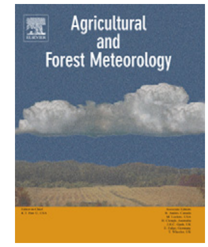

Temporal characteristics of pan evaporation trends under the humid conditions of northeast India

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ABSTRACT

This paper analyses the temporal characteristics of pan evaporation (E_{pan}) trends by using Mann–Kendall non parametric test and a parametric test under the humid conditions for eleven sites of northeast India. Decreasing E_{pan} trends have been observed mainly in pre monsoon and monsoon seasons. On examining total rainfall's relationship with E_{pan}, it is observed that almost all sites do not show a concurrent decrease in E_{pan} and an increase in rainfall. Trend analysis of other meteorological parameters indicates decreases in sunshine duration and wind speed in different seasons over most of the sites and an increase in relative humidity over four sites in winter and pre monsoon seasons. The likely causative meteorological parameters of E_{pan} changes by stepwise regression are also identified. The findings of this study suggest that mainly two parameters i.e. sunshine duration followed by wind speed strongly influenced E_{pan} changes at various sites from different regions in different seasons.

1. Introduction

Evaporation is an important climatic parameter that affects both plant and animal life. Pan evaporation (E_{pan}) changes are of great significance for water resource planning, irrigation control and agricultural production. It is routinely measured by various agencies in India because of its widespread applications. Several researchers (Sarkar and Thapliyal, 1988; Thapliyal and Kulshrestha, 1991; Kothyari and Singh, 1996; Arora et al., 2005) have carried out studies on changes in rainfall and temperature around India. In contrast a little attention has been given to changes in evaporation barring one study of Chattopadhyay and Hulme (1997).

Trends in E_{pan} have been analyzed for many regions resulting in differing conclusions. Increasing trends in E_{pan} have been reported in Israel's central coastal plain (Cohen et al., 2002) and in northeast Brazil (da Silva, 2004). However, decreasing trends were reported by Peterson et al. (1995) and Golubev et al. (2001) in the United States and former Soviet Union, by Roderick and Farquhar (2004) in Australia, by Jun et al. (2004) in Japan, by Liu et al. (2004) in China, by Tebakari et al. (2005) in Thailand and by Burn and Hesch (2007) in Canadian Prairies.

Northeast India has great economic dependence on crops like paddy, tea and forest products. Any major changes in the water budget may have major consequences on hydrologic processes. The studies relating to the evaporation over northeast India are very important for irrigation planning. Thus, this study was carried out with the objective of studying the temporal variation of E_{pan} on annual and seasonal basis over the humid climate of northeast India.

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Fig. 1 – Location of the sites selected for the trend analysis.

2. Methods and material

2.1. Details of study area

In this study, eleven sites (Agartala, Chuapara, Gungaram, Margherita, Nagrifarm, Nagrakata, Pasighat, Silcoorie, Thakurbari, Tocklai and Umiam) were selected (Fig. 1). Endowed with a sub tropical type of climate, the northeast region forms a distinct climatic zone within the Indian landmass with a remarkable variability of weather and climate. It is one of the heaviest rainfall regions in the world. The mean temperature over this region varies from 5 to 30 °C and the mean relative humidity remains in the range of 70 to 85% during most of the period. The data of eleven sites were collected from various governmental agencies like Tocklai Tea Research Station (Jorhat), India Meteorological Department (Pune) and Indian Council of Agricultural Research Complex for North Eastern Hill Region (Barapani, Meghalaya). The eleven sites have different record length of various meteorological parameters. The details of the eleven sites selected for this study and the duration of meteorological data used in the trend analysis are given in Table 1.

Table 1 – Details of sites.

S No.	Name of site	Region of site	Lat. (N)	Long. (E)	Alt., m amsl	Duration of data
1	Agartala	West Tripura, Tripura	23°53′	91°15′	16	1953–2000
2	Chuapara	East Dooars, N. Bengal	26°44′	89°28′	190.8	1980–2000
3	Gungaram	Terai, N. Bengal	26°38′	88°48′	123.6	1977–2000
4	Margherita	Upper Assam	27°16′	95°32′	183	1979–2000
5	Nagrifarm	Darjeeling, N. Bengal	26°55′	88°12′	1158.2	1965–1988
6	Nagrakata	Dooars, N. Bengal	26°54′	88°55′	228.6	1965–2000
7	Pasighat	East Siang, Arunachal Pradesh	28°06′	95°23′	155	1957–1991
8	Silcoorie	Cachar, Assam	24°50′	92°48′	39.6	1965–2000
9	Thakurbari	North Bank, Assam	26°48′	92°42′	92.45	1973–2000
10	Tocklai	Jorhat, Assam	26°47′	94°12′	96.5	1965–2000
11	Umiam	Barapani, Meghalaya	25°34′	91°53′	980	1984–2003

Lat, long, alt, m amsl denote latitude, longitude and altitude, metre above mean sea level, respectively.

Table 2 – Average pan evaporation in different durations of eleven sites.

Months	Agt	Chu	Gun	Mag	Nfm	Nag	Pas	Sil	Tha	Toc	Umi
Year	1316	943	936	649	830	1135	521	1015	969	867	1088
Winter	169	116	115	74	97	140	77	127	108	86	155
Pre Mon	432	313	329	186	295	395	129	309	322	267	382
Mon	456	315	313	258	261	378	175	368	365	362	336
Post Mon	259	199	179	131	177	222	140	211	174	152	215

Where Agt, Chu, Gun, Mag, Nfm, Nag, Pas, Sil, Tha, Toc, Umi, Mon denote Agartala, Chuapara, Gungaram, Margherita, Nagrifarm, Nagrakata, Pasighat, Silcoorie, Thakurbari, Tocklai, Umiam, and monsoon, respectively.

2.2. *Trend analysis on temporal basis*

Trends can be identified by using parametric or non-parametric methods. Parametric methods require the data to be independent and normally distributed. But, even for smaller departures from normality, non-parametric methods are sometimes better than parametric methods (Hirsch et al., 1991). Non-parametric methods use the ranks of observations rather than their actual values which relax the requirements concerning the distribution of the data. Non-parametric

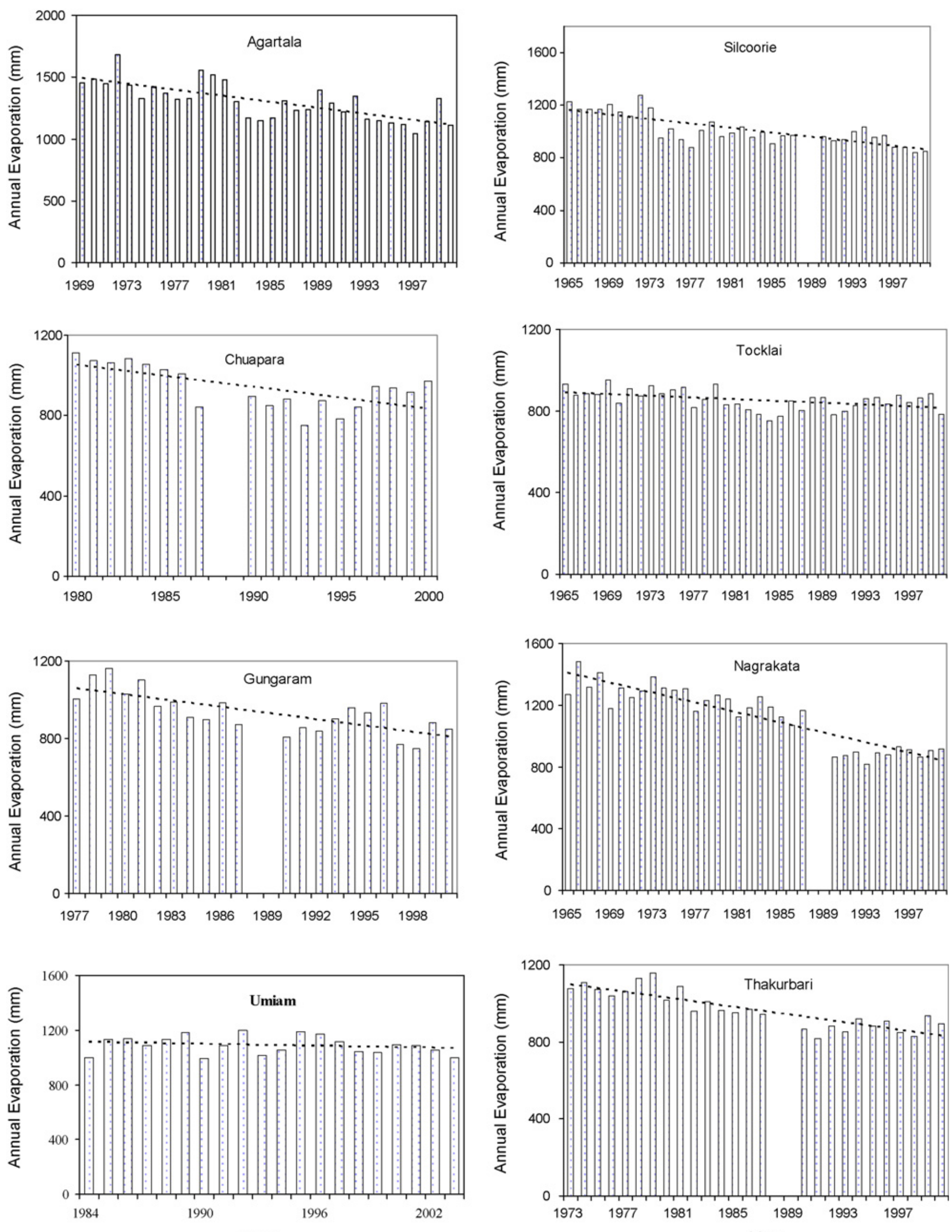

Fig. 2 – Annual evaporation series of sites from northeast India.

Table 3 – Trend analysis of E_{pan} by Mann–Kendall test in different durations.

Name of site	Duration of data	Year	Winter	Pre monsoon	Monsoon	Post monsoon
Agartala	1969–2000	a*	a*	a*	a*	c
Chuapara	1980–2000	a*	c	a*	a*	c
Gungaram	1977–2000	a*	c	a*	a*	b**
Margherita	1979–1992	c	c	c	c	c
Nagrakata	1965–2000	a*	a*	a*	a*	a*
Nagrifarm	1965–1988	c	c	c	b*	c
Pasighat	1977–1991	b*	c	c	b*	c
Thakurbari	1973–2000	a*	a*	a*	a*	a*
Tocklai	1965–2000	a*	c	a*	a**	c
Silcoorie	1965–2000	a*	a*	a*	a*	c
Umiam	1984–2003	a**	c	c	a*	c

Where a = decreasing trend, b = increasing trend and c = no trend.
* Denote statistically significant trend at the 5% level of significance.
** Denote statistically significant trend at the 10% level of significance.

Table 4 – Trend 'a' (mm/year) of E_{pan} in different durations calculated through linear regression test.

Name of site	Year	Winter	Pre monsoon	Monsoon	Post monsoon
Agartala	−12.1	−1.8	−6.3	−3.2	n.s.
Chuapara	−12.1	−1.7	−2.9	−5.4	−2.1**
Gungaram	−12.4	−1.2	−5.9	−6.5	+1.2**
Margherita	n.s.	n.s.	−3.9**	n.s.	n.s.
Nagrakata	−17.2	−2.6	−7.3	−5.7	−1.7
Nagrifarm	n.s.	n.s.	−3.0**	+1.9**	n.s.
Pasighat	+8.7	n.s.	n.s.	+4 (n. s.)	n.s.
Thakurbari	−11.0	−1.4	−4.0	−4.6	−1.0
Tocklai	−2.2	n.s.	−1.5	−0.7**	n.s.
Silcoorie	−9.3	−1.6	−3.4	−4.0	n.s.
Umiam	−4.4**	n.s.	n.s.	−2.05	n.s.

Where '−' = decreasing trend, '+' = increasing trend, n.s. = not significant. Bold letter and bold letter** denote statistically significant trends at the 5% and 10% level of significance, respectively, determined by t-test.

methods are less sensitive to outliers in data. Thus, it is preferable to use non-parametric tests for hydrologic time series as hydrologic data are highly non-normally distributed.

The trend present in the data was quantified using Mann–Kendall test (Mann, 1945; Kendall, 1975). The description of Mann–Kendall test is as follows: let us assume the sample (x_1, $x_2 \ldots\ldots x_N$) be a random sample of N independent, identically distributed variables. For a decreasing trend, x_i has continuous cumulative distribution function F_i such that $F_i(x) < F_{i+k}(x)$ for every i, every x and every $k > 0$. The value of the test statistic denoting the trend is determined and the significance of the test statistic is assessed by comparing the values of standard normal variate. In a two-sided test for the trend, the alternative hypothesis should be accepted if $|Z| > Z_{\alpha/2}$, where α is the significance level (Kothyari and Singh, 1996).

The positive and negative values of test statistics indicate increasing and decreasing trends, respectively. E_{pan} trends were also determined through linear regression test, a commonly used parametric method. The linear trend is expressed as $y(t) = a \times t + b$, where t is the time and a and b are constants. The trend determined, a, are tested in terms of its statistical significance using the t-test, where $t = (a/\sigma_a)$ with σ_a the expected standard deviation of a. If $|t| > t_{(1-\alpha/2;n-2)}$, there is a trend in the data at α% of significance level.

Yu and Neil (1993) demonstrated the validity of supplementing linear regression test with a non-parametric method. Suppiah and Hennessy (1998) also used linear regression to determine magnitude of trend, while statistical significance of change was given by Kendall test. In this study, Mann–Kendall and linear regression tests were selected to establish E_{pan} trends and the magnitude of trend is determined by linear regression test. The seasons are winter: January–February; pre monsoon: March–May; monsoon: June–September and post monsoon: October–December.

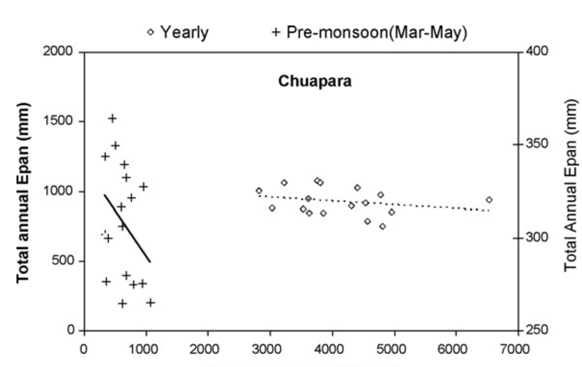

Fig. 3 – Relationship between total E_{pan} and total rainfall.

3. Results and discussion

In this study, the trend analysis of E_{pan} and other meteorological parameters was carried out by Mann–Kendall and linear regression tests at 5% and 10% level of significance for eleven sites. A brief summary of results is as follows:

3.1. Annual trends in E_{pan}

Table 2 lists the average E_{pan} values and these annual values range from 1316.0 mm for Agartala to 521.0 mm for Pasighat. The yearly time series of E_{pan} at eight sites are shown in Fig. 2. Table 3 enlists increasing and decreasing trends in annual E_{pan} by Mann–Kendall test. E_{pan} trends and their magnitude (in mm/year) obtained by linear regression are given in Table 4. E_{pan} trends by linear regression are almost similar to E_{pan} trends by Mann–Kendall test. Decreasing trends in annual E_{pan} for yearly duration were observed at the following eight sites: Agartala, Chuapara, Gungaram, Nagrakata, Thakurbari, Tocklai, Silcoorie and Umiam. The magnitude of decreasing trends in annual E_{pan} varied from (−)17.2 mm/year for Nagrakata to (−)2.2 mm/year for Tocklai. Only one increasing annual E_{pan} trend at the rate of (+)8.7 mm/year was observed over Pasighat. The remaining two sites displayed no statistically significant annual E_{pan} trends.

3.2. Seasonal trends in E_{pan}

At each location, E_{pan} is lowest in winter season and highest in either monsoon or pre monsoon season. Decreasing E_{pan} trends by Mann–Kendall test were observed mainly in pre monsoon and monsoon seasons at seven and eight sites, respectively. The decreasing trends varied between (−)7.3 mm/year in pre monsoon season for Nagrakata and (−)0.7 mm/year in monsoon season for Tocklai (Table 4). Increasing E_{pan} trends were also observed over Gungaram and Nagrifarm at the rate of (+)1.2 mm/year and (+)1.9 mm/year, respectively. In terms of geographical distribution, nine sites

Table 5 – Trend analysis of temperature by Mann–Kendall test.

Name of site	Different durations									
	Year		Winter		Pre monsoon		Monsoon		Post monsoon	
	T_{mx}	T_{mn}	T_{mx}	T_{mn}	T_{mx}	T_{mn}	T_{mx}	T_{mn}	T_{mx}	T_{mn}
Agartala	c	c	c	c	c	c	b*	b*	c	c
Chuapara	c	b*	c	c	c	b**	a**	b*	c	b*
Gungaram	b*	b*	c	c	b*	b*	b*	b*	b*	b*
Margherita	c*	b*	c	b*	c	b*	c	c	b*	c
Nagrifarm	c	a*	c	c	c	a*	c	c	c	c
Nagrakata	b*	b*	c	c	c	c	b*	b*	b*	b*
Pasighat	c	c	c	c	c	c	c	c	b*	c
Silcoorie	b*	c	c	c	c	c	b*	c	b*	c
Thakurbari	c	c	c	c	c	a**	c	c	b*	c
Tocklai	c	b*	c	c	c	c	c	b*	c	c
Umiam	b*	c	b**	c	c	c	b*	c	c	c

Where a = decreasing trend, b = increasing trend, c = no trend, T_{mx} and T_{mn} = maximum and minimum temperature.
* Denote statistically significant trend at 5% level of significance.
** Denote statistically significant trend at 10% level of significance.

Table 6 – Trend analysis of meteorological parameters by Mann–Kendall test.

Name of site	Different durations														
	Year			Winter			Pre monsoon			Monsoon			Post monsoon		
	Sun	Wind	RH	Sun	Wind	RH	Sun	Wind	RH	Sun	Wind	RH	Sun	Wind	RH
Agartala	a	a	b	a	a	b	a	a	b	c	a	a	c	a	c
Chuapara	a	a	a	c	a	c	a	a	a*	a	a	a	c	a	a*
Gungaram	c	a	b	a	a	c	c	a	b	c	a	c	a	a	c
Margherita	a	a	a	a*	a	c	a	a	c	c	a	c	c	a	a
Nagrifarm	c	c	c	c	c	c	c	a	c	c	c	c	c	c	c
Nagrakata	a	c	b	a	c	b	a	a*	b	a*	c	c	a	c	b
Pasighat	NA	a	NA	NA	a	NA	NA	a	NA	NA	a	NA	NA	a	NA
Silcoorie	a	a	c	a	a	b	a	a	c	c	a	c	c	c	c
Thakurbari	a	a	c	a	a	c	a	a	c	a	a	c	a	a	c
Tocklai	a	a	b	a	a	b*	c	a	b	c	a	c	a	a	c
Umiam	NA	c	c	NA	c	c	NA	a*	c	NA	c	c	NA	a	a

Where a and b are statistically significant decreasing and increasing trends at 5% level of significance, respectively. c, NA, Sun, Wind, and RH denote no trend, data not available, sunshine duration, wind speed and relative humidity, respectively.
* Denote statistically significant trend at the 10% level of significance.

i.e. four each from Assam and north Bengal and one from Tripura, showed decreasing E_{pan} trends in pre monsoon season. Similarly, eight sites i.e. three each from Assam and north Bengal and one each from Tripura and Meghalaya, showed decreasing E_{pan} trends in monsoon season.

3.3. *Trends in rainfall and its relationship with E_{pan}*

Trends using Mann–Kendall test were obtained for total rainfall in the same way as for E_{pan}. No statistically significant trend in any of yearly and seasonal rainfall was observed at eight sites (Gungaram, Margherita, Nagrifarm, Pasighat, Silcoorie, Thakurbari, Tocklai and Umiam). Increasing trends were observed at Agartala in winter and at Chuapara in yearly and pre monsoon rainfall. However, at Nagrakata, decreasing trends were observed in yearly and monsoon rainfall. For the rest of rainfall series, no statistically significant trends were observed.

The concurrent occurrences of E_{pan} decreases and rainfall increases were found at Agartala in winter season and at Chuapara in yearly and pre monsoon season. Only these two sites supported a finding by Lawrimore and Peterson (2000) of concurrent decreases in E_{pan} and increases in rainfall throughout the United States. The relationship between E_{pan} and rainfall, as shown in Fig. 3, indicates a decrease in E_{pan} with rainfall at Chuapara. The lines are E_{pan} trends with total rainfall for yearly duration and the pre monsoon season. However, no such concurrent occurrence of E_{pan} decrease and rainfall increase was observed at other sites of northeast India.

3.4. *Trends in temperature, sunshine duration, wind speed and relative humidity*

Table 5 lists the trends in maximum and minimum temperatures using Mann–Kendall test. This table supports a general view of rise in temperature over India as reported by Kumari et al. (2007). Five and six sites of northeast witnessed increasing trends in maximum temperature in monsoon and post monsoon seasons, respectively (Table 5). Both decreases and increases in diurnal temperature ranges (DTR) were observed. Three sites (Nagrakata, Chuapara and Tocklai) observed decreasing trends in DTR in monsoon season. The decrease in DTR is possibly due to increased cloud cover which may have caused a decrease in sunshine duration and eventually, it may have led to E_{pan} decreases in monsoon season.

The increasing or decreasing trends of sunshine duration, wind speed and relative humidity are shown in Table 6. Almost all sites showed decreasing trends in sunshine duration in winter and pre monsoon seasons. Similarly, all the sites showed decreasing wind speed trends in the pre monsoon season. Increasing trends in relative humidity were witnessed in winter and pre monsoon seasons at Agartala and Nagrakata. The potent combination of decrease in wind speed, rise in relative humidity and decrease in sunshine duration has led to higher number of decreasing E_{pan} trends in pre monsoon season.

3.5. *Influence of meteorological variables on E_{pan} changes*

Regional anomalies persist over a few sites of northeast India where E_{pan} declined while temperatures have increased. In order to identify the dominant variables associated with E_{pan} changes, stepwise regression method was applied. Regression was performed between E_{pan} and meteorological parameters that influence evaporation i.e. maximum and minimum temperatures, sunshine duration, relative humidity and wind speed by using SPSS (Norusis, 1988), a commercial software for statistics. For yearly series, sunshine duration appears to be the most important variable contributing to E_{pan} changes, followed by wind speed, relative humidity and minimum

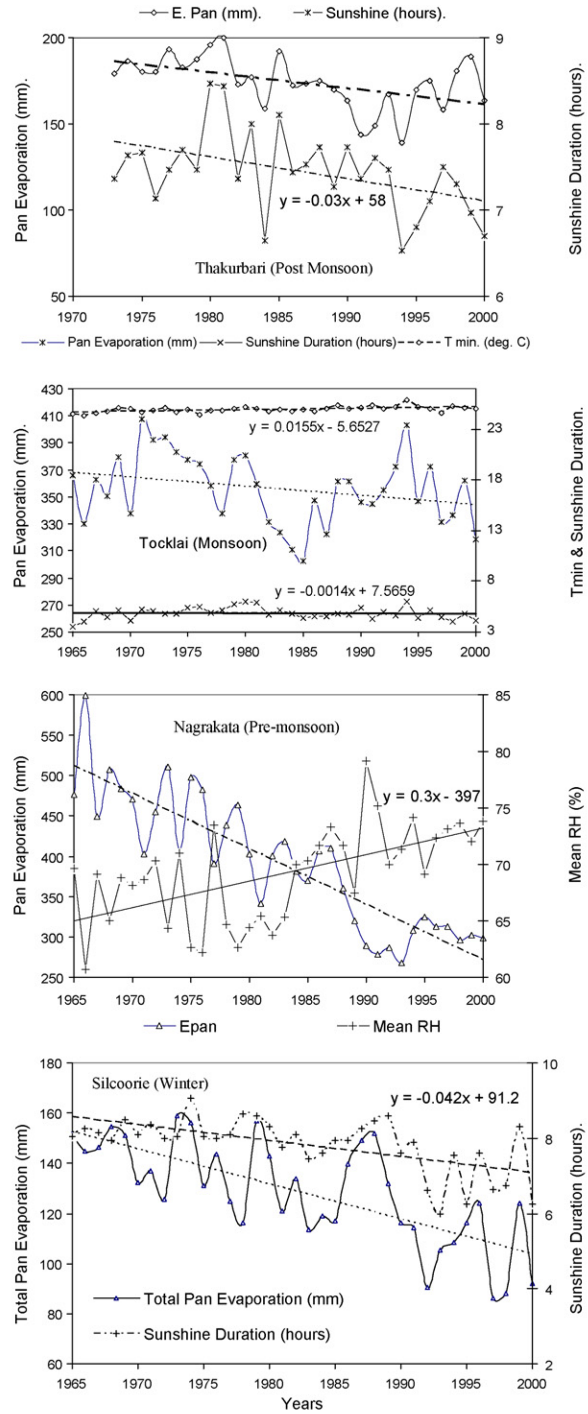

Fig. 4 – Influence of meteorological parameters on E_{pan} in different seasons.

Table 7 – Number of times meteorological variables, in order of dominance (i–iii), were significantly related to E_{pan} in stepwise regression method.

Meteorological variable	Different durations														
	Year			Winter			Pre monsoon			Monsoon			Post monsoon		
	i	ii	iii	i	ii	iii	i	ii	iii	i	ii	iii	i	ii	iii
Sun	3	1	–	5	–	–	3	1	1	4	–	–	2	–	–
RH	2	1	–	3	1	1	2	–	–	–	1	–	1	–	–
Wind	2	1	–	1	1	–	3	–	1	4	2	–	1	2	–
T_{max}	–	–	1	–	–	–	1	4	–	–	1	–	–	–	1
T_{min}	1	–	–	–	1	–	–	–	–	1	2	–	1	–	–

i, ii and iii indicate the step at which the meteorological variable was selected in the stepwise regression method (i first, i.e. most dominant variable; iii third). Sun, RH, Wind, T_{max} and T_{min} denote, respectively, sunshine duration, relative humidity, wind speed, maximum and minimum temperatures.

temperature. Thus, decreases in sunshine duration and wind speed and increase in relative humidity collectively led to offsetting the effect of rise in temperature on E_{pan}.

Fig. 4 shows the influence of the dominating variables on E_{pan} changes in four different seasons. The lines and the related equations in the figures indicate the signs and magnitudes of trends in the meteorological parameters. The figures for winter and post monsoon seasons clearly show that trend lines of sunshine duration follow very closely to E_{pan} trend lines over Silcoorie and Thakurbari, respectively. This is in total agreement with the result of stepwise regression analysis which shows sunshine duration as only meteorological parameter influencing E_{pan} over these two sites. Similarly, relative humidity at Nagrakata and sunshine duration followed by minimum temperature at Tocklai are the main dominating variables influencing E_{pan} in pre monsoon and monsoon seasons, respectively.

Sunshine duration is strongly related to E_{pan} changes in winter and monsoon seasons over almost all sites of Assam. Similarly, wind speed appear to be the most dominant variable influencing E_{pan} in monsoon season over all the four sites of north Bengal. Also, wind speed and maximum temperature were two factors influencing E_{pan} in pre monsoon season at Chuapara, Gungaram and Thakurbari. Wind speed, being the dominant factor, caused the decrease in E_{pan}. Relative humidity is a major factor in winter season at Agartala and Nagrakata. Sunshine duration, wind speed and relative humidity were the main factors influencing E_{pan} at three sites in post monsoon season (see Table 7).

A close inspection of the contribution of the meteorological variables to E_{pan} changes has shown that sunshine duration and wind speed appear to be the two important variables contributing to E_{pan} changes in three different durations: the year, the winter, and the monsoon seasons. In humid climates such as northeast India, solar radiation supplies most of the energy required to change water from its liquid to vapor form. Sunshine duration can be considered as a substitute of solar radiation in the absence of global solar radiation data. Overall, sunshine duration shows a decreasing trend and E_{pan} is also decreasing over most of the sites, as reported by Roderick and Farquhar (2002). Kumari et al. (2007) also reported solar dimming during winter, pre monsoon and monsoon seasons over Indian region. Regarding wind speed trends, at least eight sites observed decreasing trends in all the seasons. Regression shows that wind speed is strongly related to E_{pan} changes in pre monsoon and monsoon seasons. Burn and Hesch (2007) reported that warm season wind speed decreasing trends had more of an influence on decreasing E_{pan} trends over Canadian Prairies.

4. Conclusions

The results of this study indicate a broad general pattern of decreasing pan evaporation trends in the northeast India. Eight sites observed decreasing E_{pan} trends in the yearly duration. However, an increasing E_{pan} was also observed over Pasighat. Eight and nine sites showed decreasing E_{pan} trends in the monsoon and pre monsoon seasons, respectively. Chattopadhyay and Hulme (1997) also reported E_{pan} decreases mainly in pre monsoon and monsoon seasons. They observed decreasing E_{pan} trends in winter and post monsoon seasons for less number of sites.

No statistically significant trend in total rainfall was observed at most of the sites in any of the duration: the year and the four seasons. The concurrent occurrence of E_{pan} decrease and rainfall increase was not observed at the majority of the sites analyzed in this study. The results do not support a finding of concurrent decreases in pan evaporation and increases in rainfall in the United States.

Rise in maximum and minimum temperatures over almost half of the total sites analyzed are reported in monsoon and post monsoon seasons. The trends in sunshine duration were also examined at nine sites. Seven and six sites observed decreasing trends in sunshine duration in winter and pre monsoon seasons, respectively. The yearly and seasonal wind speed changes were also examined at all the eleven sites. At least eight sites witnessed decreasing wind speed trends in the yearly duration and in all the four seasons. Increasing trends in relative humidity were observed over four sites in three different durations: the year, the winter and the pre monsoon season.

On examining the results of stepwise regression to find the causal mechanisms of E_{pan} changes, sunshine duration appears to be the most influencing variable mainly in winter, monsoon and pre monsoon seasons. Wind speed is also strongly related to E_{pan} decreases in pre monsoon and monsoon seasons. However, relative humidity is a major meteorological parameter influencing E_{pan} at Agartala and Nagrakata stations.

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