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Micro-level spatial variability and temporal trends in reference evapotranspiration (ETo) at a semi-arid tropical station

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ABSTRACT

Micro-level spatial variability and temporal trends in annual and seasonal (weeks 23-39) reference evapotranspiration (ETo) were analyzed across three locations in Hyderabad. The mean ETo was highest (1694.2 mm) at ICRISAT and lowest (1489.0 mm) at Rajendranagar. It was 1555.7 mm at Hayathnagar. The coefficient of variability (C.V.) ranged between 6.8 to 8.7 % for annual and 8.3 to 12.3 % for seasonal ETo. The non-parametric (Mann-Kendall's 'ô') test showed significant decreasing trend across all three locations in Hyderabad on annual as well as on seasonal ETo basis. Parametric 't' test confirmed this as it brought out that the difference in mean reference evapotranspiration during 1975-1992 and 1993-2009 were highly significant (P=0.01) on annual basis and significant (P=0.05) on seasonal basis. The ETo on an average decreased between 9-10 mm per annum on yearly basis and between 1.9 to 3.1 mm per annum on seasonal basis during the period of analysis (1975-2009) at these three locations. The trends in governing weather parameters were also analyzed. The wind speed was the major parameter that showed significant decreasing trend both on annual and seasonal basis. Sunshine hours also showed significant decreasing trend on annual basis across all locations.

Key words: Variability, trends, reference evapotranspiration

Accurate estimation of crop water requirements is an important factor in efficient water management (Tyagi *et. al.,* 2000). For this reason, the knowledge of reference evapotranspiration rate in a region is a critical issue that allows managers to develop strategies for efficient utilization of water resources. India Meteorological Department (Anonymous, 1998) has brought out a publication on normal potential evapotranspiration and climatic water balance across 144 locations in India. But researchers (Bandhyopadhyay *et. al*., 1999 and Xu *et. al*., 2006) have reported significant trends in reference evapotranspiration across several locations encompassing temperate as well as the tropical climatic situations. They have reported decreasing trend in ETo. The relationships with governing weather parameters have been found to be location specific except those with wind speed. The wind shows decreasing trend causing similar and proportionate impact on the reference ETo depending upon other parameters. In recent years, there is abundant evidence to show that the more physically based FAO-56 Penman-Monteith combination method yields more accurate ETo estimates across a wide range of climates (Nandagiri and Kovoor, 2006). In this study we have also adopted the above mentioned P-M method for estimating the ETo. We have analyzed the spatial variability and quantified the decrease in ETo on annual and seasonal basis across three locations in Hyderabad. Trends in relevant weather parameters have also been analyzed. Non-parametric Mann-Kendall's 'ô' (Kendall, 1975 and Mann, 1945) test was carried out to find out the trends and significance thereof. Parametric (Student's 't') test was carried out to find out the significance of the difference in mean ETo values between 1975-1992 and 1993-2009 periods. This was necessary to ascertain that the trends were real and not because of the differences in variability between the past and the recent time periods. Least square regression equations were fitted by taking ETo as dependent parameter and time (years) as independent parameter. The significance of the slope was tested by 'F' test.

MATERIALS AND METHODS

Weekly data (1975-2009) on maximum and minimum temperature, relative humidity (0700 and 1400 hrs LMT), sunshine hours and wind speed (at 3 m height) across three locations namely Hayathnagar (17° 20' N, 78° 35' E, 515.5 m a.m.s.l.), Rajendranagar (17° 19' N, 78° 28' E, 534 m a.m.s.l.) and ICRISAT (17° 32', 78° 16' E, 545 m a.m.s.l.) situated in and around Hyderabad were collected from the respective research Institutions over a period of time. The wind speed measurements at 3 m height were transformed to wind speed at 2 m height by multiplying it with a wind profile factor of 0.933 used by Rao *et. al*. (1971). Incoming short wave solar radiation (Rs) was estimated by Angstrom's (1924) formula as modified by Prescot (1940). The coefficients **a** (percentage of Ra – Angot's value, reaching the earth's surface on a completely cloud covered day) and **b** (percentage of Ra absorbed by the clouds on a completely cloud covered day) in the above equation were taken as 0.14 and 0.55 respectively as estimated by Gangopadhyay *et.al.* (1970). Possible sunshine (N) hours were calculated using standard equations (Allen *et. al.,* 1998). Saturation vapour pressure was calculated by Teten's (1930) formula. Slope of the vapour pressure vs. temperature curve was worked out by differentiating Teten's equation (Srivastava *et. al.,* 2004).

The FAO-Penman-Monteith method has been proved to have global validity as a standardized reference for grass evapotranspiration and has found recognition by the International Commission for Irrigation and Drainage, by the World Meteorological Organization as well as by a large number of scientific studies.

By defining the reference crop as a hypothetical crop with an assumed height of 0.12 m having a surface resistance of 70 s m^{-1} and an albedo of 0.23, closely resembling the evaporation of an extensive surface of green grass of uniform height, actively growing and adequately watered, the FAO Penman - Monteith method was developed (Allen et. al., 1998) as given below:

$$ETo = \frac{0.408\ \Delta(Rn-G) + \gamma \dfrac{900}{T+273}\ U_2\left(e_s - e_a\right)}{\Delta + \gamma\ \left(1+0.34\ U_2\right)}$$

Where

ETo = reference evapotranspiration (mm day^{-1})

Rn = net radiation at the crop surface (MJ m^{-2} day^{-1})

G = soil heat flux density (MJ m^{-2} day^{-1})

T = mean daily air temperature at 2 m height (ÚC)

U_2 = wind speed at 2 m height (m s^{-1})

e_s = saturation vapour pressure (k Pa)

e_a = actual vapour pressure (k Pa)

$(e_s - e_a)$ = saturation vapour pressure deficit (k Pa)

Ä = slope of vapour pressure vs. temperature curve (k Pa $ÚC^{-1}$)

ã = psychrometric constant (k Pa $ÚC^{-1}$)

Ground heat flux G was neglected as advocated by Allen *et.al.* (1998) for short periods of 7 or 10 days. Psychrometric constant ã was worked out as 0.063 kPa $°C^{-1}$. Actual vapour pressure was worked out from maximum & minimum temperature and the relative humidity data recorded at 0700 and 1400 hrs LMT. The weekly reference evapotranspiration ETo was calculated by the above equation using meteorological data and other parameters as elaborated by Srivastava and Rao (2010). The calculations were done in an excel work sheet on mean daily weather parameters during respective standard meteorological weeks. The yearly and seasonal ETo was worked out from these daily values in respective weeks. Annual and seasonal ETo vs. years was plotted for all the locations (Fig. 1). Mann-Kendall (Kendall, 1975 and Mann, 1945) non parametric 'ô', Student's 't' and F distribution tests were conducted to ascertain the significance of decreasing or increasing trend in ETo as well as in the relevant weather parameters. Coefficient of variability (C.V.) of ETo was also worked out on yearly and seasonal basis for these three locations.

RESULTS AND DISCUSSION

The annual and seasonal estimated ETo values during 1975-2009 are plotted in Fig. 1. Mean values along with coefficient of variability (CV) are also presented. The mean (1975-2009) values of reference evapotranspiration were 1555.7, 1489.0 and 1489.0 mm at Hayathnagar, Rajendranagar and ICRISAT (International Crops Research Institute for the Semi-Arid Tropics) respectively. These values are lower than those published by India Meteorological Department (Anonymous, 2008) by 200-225 mm. The reason appears to be the difference in values of **a** and **b** coefficient used in the equation on short wave radiation estimation. If we use FAO recommended values of 0.25 and 0.50 for **a** and **b** respectively, we do get ETo on par with that reported by IMD. Since FAO values are to be used wherever estimated values are not available, we used those estimated by Gangopadhyay *et. al.*(1970). Moreover the trend in ETo is not to be affected by use of 0.14 & 0.55 in lieu of 0.25 & 0.50 for **a** and **b** coefficients.

The coefficient of variability of ETo was highest (8.7%) on the annual and seasonal (12.3 %) basis in respect to Rajendranagar. It was lowest on annual (6.8%) and seasonal (8.3%) basis at ICRISAT. The coefficient of variability's at Hayathnagar were 8.5 and 11.8 % on annual and seasonal basis. It is apparent that that the CV's were higher during the kharif season in comparison to the annual. Least square regression equations of ETo vs. years are also shown in Fig. 1. Significance of these equations was tested by F distribution test. The regression equations of ETo vs. years are highly significant (P=0.01) on annual basis. They are also significant (P=0.05) on seasonal basis for all the locations.

Regression equations for trends in average weather variables of wind speed, sunshine hours, temperature and relative humidity on yearly and seasonal basis are presented in Table 1. Decreasing trends in wind speed are highly significant on yearly and seasonal basis both. This finding is in conformity of Xu *et. al.* (2006) and Bandhyopadhyay *et. al.* (2009). Decreasing trend in sunshine hours was also highly significant on yearly basis. Temperature showed highly significant increasing trend at Rajendranagar. Increasing trend in relative humidity on annual basis was highly significant at ICRISAT. This may probably be due to development of water bodies and plantation crops on massive

Table 1 : Regression equations for trends in average weather parameters of wind speed, sunshine hours, temperature and relative humidity on yearly and seasonal basis across three locations at Hyderabad (1975-2009)

Weather Parameter	Hayathnagar		Rajendranagar		ICRISAT	
	Equation	R^2	Equation	R^2	Equation	R^2
Yearly						
Wind Speed	Y = -0.1278 X +9.8402	0.70**	Y = -0.1174 X +8.0765	0.53**	Y = -0.1175 X +11.369	0.90**
SSH	Y = -0.0393 X +7.9188	0.47**	Y = -0.029 X + 8.3166	0.44**	Y = -0.0143 X + 7.8834	0.21**
Temperature	Y = 0.0026 X + 25.702	0.002	Y = 0.012 X + 25.9522	0.17*	Y = -0.0129 X + 25.99	0.11*
Relative humidity	Y = 0.1464 X + 56.93	0.13	Y = 0.0354 X + 59.451	0.01	Y = 0.1641 X + 58.958	0.46**
Seasonal						
Wind Speed	Y = -0.2049 X +13.745	0.77*	Y = -0.1909 X +12.319	0.52**	Y = -0.1131 X +13.642	0.74**
SSH	Y = -0.0355 X + 5.7484	0.19**	Y = -0.0198 X + 5.9308	0.12*	Y = -0.0089 X + 5.4284	0.04
Temperature	Y = 0.0134 X + 26.075	0.04	Y = 0.0201 X + 26.593	0.24**	Y = -0.0055 X + 26.523	0.01
Relative humidity	Y = 0.0409 X + 70.387	0.02	Y = 0.0853 X + 68.65	0.04	Y = 0.095 X + 71.646	0.13*

N.B.: Y are respective average (daily) weather parameters and X are the corresponding years during 1975 – 2009 i.e. X = 1 represents 1975 and X = 35 represents 2009. * shows significance at P=0.01. ($R^2 > 0.1115$) and ** shows significance at P=0.05. ($R^2 > 0.1846$)

Table 2: Yearly and seasonal means of different weather parameters along with ‘ô’ and ‘t’ statistics for the periods 1975-1992 and 1993-2009 across three locations at Hyderabad

Location	Parameter	Yearly		Kendall's ‘τ’	Student's ‘t’	Seasonal		Kendall's ‘τ’	Student's ‘t’
		1975-92	1993-2009			1975-92	1993-2009		
HRF	ETo(mm)	1634.08	1472.64	-5.056^{++}	4.551**	510.33	467.79	-3.096^{++}	2.318*
	WS(km h^{-1})	8.58	6.43	-5.752^{++}	5.629**	11.72	8.29	-6.007^{++}	6.098**
	SSH(h)	7.53	6.88	-4.118^{++}	3.936**	5.37	4.84	-2.727^{+}	1.981
	TEMP(°C)	25.79	25.71	0.156	0.405	26.24	26.39	1.307	-0.644
	RH(%)	58.43	60.77	1.463	-1.705	69.96	69.33	-0.866	0.603
RNGR	ETo(mm)	1589.63	1382.36	-3.948^{++}	8.108**	527.67	451.93	-2.982^{++}	4.762**
	WS(km h^{-1})	7.22	4.63	-4.601^{++}	7.439**	10.93	6.72	-4.615^{++}	7.299**
	SSH(h)	8.06	7.52	-3.863^{++}	4.350**	5.78	5.36	-1.946	2.258*
	TEMP(°C)	26.06	26.28	-2.627^{++}	-2.301*	26.76	27.16	-2.968^{++}	-3.122**
	RH(%)	58.78	61.47	0.596	-2.138*	68.41	72.06	1.136	-2.395*
ICRISAT	ETo(mm)	1778.48	1604.93	-5.993^{++}	6.719**	511.27	483.53	-2.670^{+}	2.083*
	WS(km h^{-1})	10.24	8.21	-7.001^{++}	7.995**	12.52	10.63	-5.581^{++}	5.823**
	SSH(h)	7.75	7.49	-2.457^{+}	2.564*	5.38	5.15	-1.023	1.379
	TEMP(°C)	25.91	25.60	-2.215^{+}	2.460*	26.5	26.34	-0.298	0.865
	RH(%)	60.47	63.44	4.033^{++}	-4.413**	72.55	74.21	1.676	-1.853

Kendall's ‘ô’ 1.960 at 5 2.576 at 1 %
And Student's ‘t’ 2.034 at 5% 2.732 at 1%

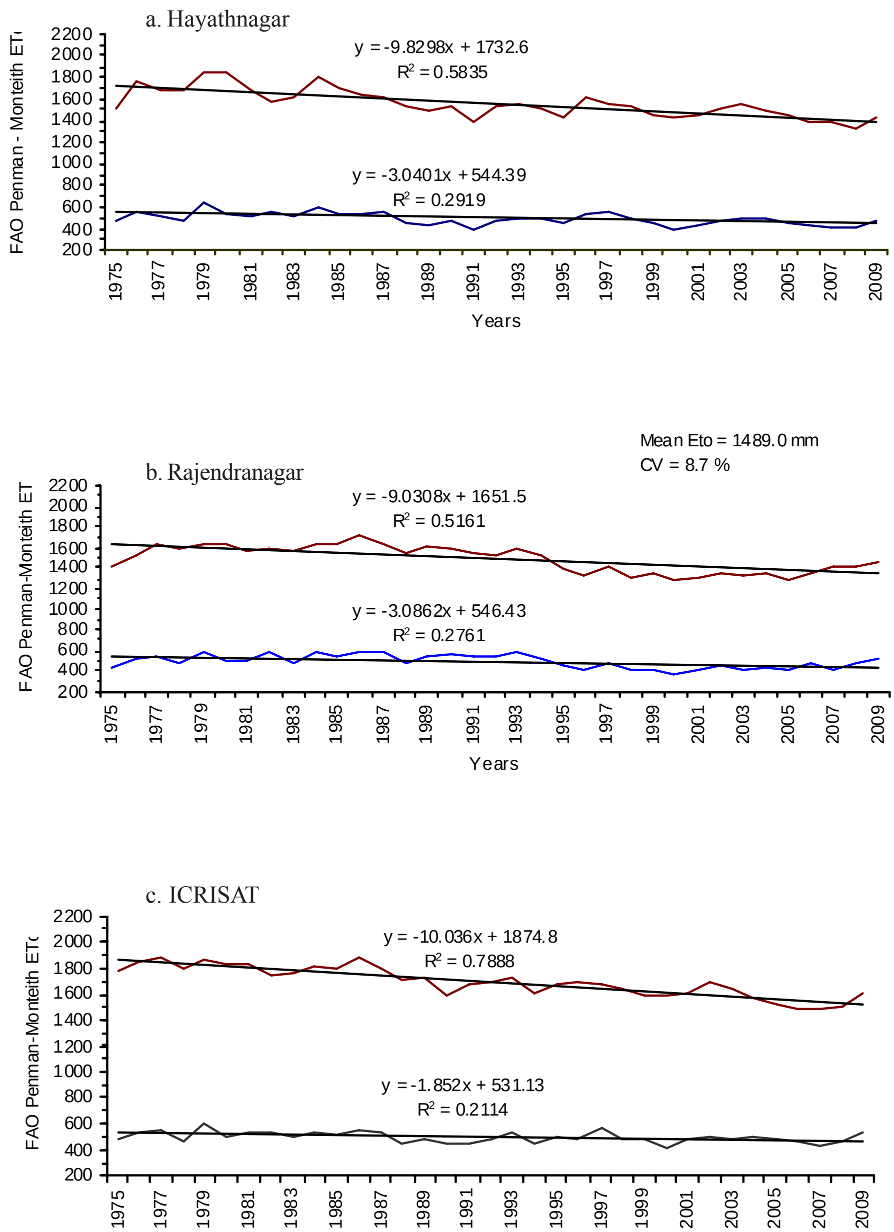

Fig. 1 : Variability as well the trends in yearly and seasonal (weeks 23-39) reference evapo- transpiration (ETo) at different locations in Hyderabad

scale nearby the observation site. Rest of the relationships were either non-significant or on the boundary of significance and were rejected/accepted depending upon other more sensitive tests. Kendall's 'ô' and Student's 't' statistics are presented in Table 2. Kendall's 'ô' statistics shows that the decreasing trend in ETo is highly significant on yearly and seasonal basis both. The 't' statistics shows that the difference in mean ETo during 1975-1992 and 1993-2009 are highly significant (P=0.01) on annual basis across all locations. At Hayathnagar the Mann-Kendall test shows highly significant trend in seasonal ETo. But 't' test shows only significant (P=0.05) difference between the two means. We have, therefore, conducted both - the parametric and the non-parametric tests to ascertain true nature and level of the trends in different climatic variables/parameters. If Mann-Kendall test shows significant trend, then the 't' test should also support it for its acceptance. At Hayathnagar sunshine hours show significant decreasing trend on seasonal basis by Mann-Kendall test (Table 2). But the't' test shows that there is no significant difference between the ETo means during 1975-1992 and 1993-2009 periods. Therefore, the trend shown may be due to variability in sunshine hours. Thus, we need to ignore such doubtful relationships.

CONCLUSIONS

Reference evapotranspiration (ETo) across three locations at a semi-arid tropical station (Hyderabad) has shown highly significant decreasing trend. The average annual decrease in ETo ranges between 9-10 mm on yearly basis and 1.9 to 3.1 mm on seasonal basis. Wind speed also shows highly significant decreasing trend on annual and seasonal basis across all three locations. Sunshine hours show similar decreasing trend uniformly only on yearly basis. Other weather parameters have localized significant /non-significant relationships. The decreasing trend in annual ETo is likely to be highly beneficial to the long duration as well to the perennial plantation crops at such locations.

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