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Trends in major and minor meteorological variables and their influence on reference evapotranspiration for mid Himalayan region at east Sikkim, India

Shweta YADAV[1] http://orcid.org/0000-0001-8192-8078; e-mail: shwtdv@gmail.com

Proloy DEB[2] http://orcid.org/0000-0002-2285-3560; e-mail: debproloy@gmail.com, Proloy.Deb@uon.edu.au

Sonu KUMAR[3] http://orcid.org/0000-0003-0829-4317; e-mail: snu4ucau@gmail.com

Vanita PANDEY[4] http://orcid.org/0000-0002-1033-6515; e-mail: vanita2@gmail.com

Pankaj Kumar PANDEY[3] http://orcid.org/0000-0002-5936-3565; e-mail: pandeypk@gmail.com

1 Water Engineering and Management, Asian Institute of Technology, Pathumthani 12120, Thailand

2 Centre for Water, Climate and Land-Use (CWCL), Faculty of Science and Information Technology, School of Environmental and Life Sciences, University of Newcastle, Callaghan, Newcastle 2308, Australia

3 Department of Agricultural Engineering, Northeastern Regional Institute of Science and Technology, Nirjuli, Arunachal Pradesh 791109, India

4 Department of Soil and Water Engineering, College of Agricultural Engineering and Post Harvest Technology, Ranipool, Sikkim 737135, India

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Abstract: Estimation of evapotranspiration (ET) for mountain ecosystem is of absolute importance since it serves as an important component in balancing the hydrologic cycle. The present study evaluates the performance of original and location specific calibrated Hargreaves equation (HARG) with the estimates of Food and Agricultural Organization (FAO) Penman Monteith (PM) method for higher altitudes in East Sikkim, India. The results show that the uncalibrated HARG model underestimates ET_o by 0.35 mm day^{-1} whereas the results are significantly improved by regional calibration of the model. In addition, this paper also presents the variability in the trajectory associated with the climatic variables with the changing climate in the study site. Non-parametric Mann-Kendall (MK) test was used to investigate and understand the mean monthly trend of eight climatic parameters including reference evapotranspiration (ET_o) for the period of 1985 - 2009. Trend of ET_o was estimated for the calculations done by FAO PM equation. The outcomes of the trend analysis show significant increasing ($p \le 0.05$) trend represented by higher Z-values, through MK test, for net radiation (Rn), maximum temperature (T_{max}) and minimum temperature (T_{min}), especially in the first months of the year. Whereas, significant ($0.01 \ge p \le 0.05$) decreasing trend in vapor pressure deficit (VPD) and precipitation (P) is observed throughout the year. Declining trend in sunshine duration, VPD and ET_o is found in spring (March - May) and monsoon (June – November) season. The result displays significant ($0.01 \le p \le 0.05$) decreasing ET_o trend between (June - December) except in July, exhibiting the positive relation with VPD followed by sunshine duration at the station. Overall, the study emphasizes the importance of trend analysis of ET_o and other climatic

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variables for efficient planning and managing the agricultural practices, in identifying the changes in the meteorological parameters and to accurately assess the hydrologic water balance of the hilly regions.

Keywords: Reference evapotranspiration (ET_0); Climatic variables; Trend analysis; Mann-Kendall's test; Monthly variation; East Sikkim hilly region

Introduction

Climate variability along with its consequence on hydrologic cycle and water distribution is of extreme concern, due to their conjoint relationship on each other and therefore it is being considered as the topic of interest in recent research trend (Schwartz and Randall 2003). Under global warming, climate change is expected to alter the hydrological cycle and all its components including evapotranspiration (ET_0) at both global and regional scale (Jung et al. 2010). In the past few decades, the global mean surface temperature has increased substantially up to 0.12°C in 2012 relative to mean temperature of 1951, furthermore it is projected to increase by 0.3 °C - 0.7°C in 2035 under different emission scenarios (Stocker et al. 2013). Consequently, climatic variables which have strong direct and implicit relation with the temperature such as vapour pressure deficit (VPD), sunshine duration, evaporation (E), evapotranspiration (ET_0), precipitation (P), wind speed and relative humidity (R_H) are also considerably affected. More than 50% of solar energy which is absorbed by earth surface is used for evaporating the water (Trenberth et al. 2009). Since ET_O is directly linked to these climatic variables, alteration in these variables along with increased temperature can significantly influence the trend and magnitude of ET_O (Irmak et al. 2012).

ET_O is an essential component in hydrologic water balance which plays a key role in estimation of crop water requirement, irrigation and drainage design, reservoir operation and potential rain-fed agricultural production (Dinpashoh 2006; Todorovic et al. 2013). Thus, an accurate estimation of ET_0 is crucial to investigate the changes in the meteorological variables as well as for better understanding and projecting the impact of these changes on the water resources. Several studies investigated the changes in climatic variables and their influence on the changing trend of ET_0 (Chattopadhyay and Hulme 1997; Zhang et al. 2007; Grundstein 2008; Elnesret al. 2010). Declining trend of ET_0 is attributed to decrease in maximum temperature and precipitation (Moonen et al. 2002), whereas sunshine duration and wind speed considered as the principle cause affecting ET in some studies (Gao et al. 2007).

A large number of empirical and semi-empirical methods have been used in calculating ET_O in various studies. However Penman-Monteith (PM) equation for estimating ET_0, proved well in numerous studies and has been applied globally (Smith 2000; Kashyap and Panda 2001; Temesgen et al. 2005; Allen et al. 2006; Irmak et al. 2012; Todorovic et al. 2013). The determination of ET_O using FAO PM method does not involve any regional or local calibration given that all physiological and aerodynamic parameters are available and also has been validated at different environments using accurate lysimeter measurements (Berti et al. 2014). It is a physical process based approach where the calculation requires numerous data including air temperature, humidity, wind speed, solar radiation and minor variables such as soil heat flux and vapor pressure deficit. No doubt that in the developing nations these data are not available and specifically in the mountain ecosystem it is incomprehensible to have a good network of meteorological stations. Considering all these factors, Allen et al. (1998) suggested the use of Hargreaves (HARG) equation for estimating ET_O in data sparse regions. The HARG equation (Hargreaves and Samani 1985) is a temperature based model which estimates the ET_O while considering the maximum and minimum temperature along with the extra-terrestrial solar radiation.

The HARG model has been applied at various regions of the world (Berti et al. 2014; Pandey et al. 2014; Murugappan et al. 2011; Hargreaves and Allen 2003; Droogers and Allen 2002) due to its simplicity however; the original HARG method has failed to perform well at many regions relative to the FAO PM method. For instance, in the cold humid regions, HARG method overestimated the ET_O over FAO PM method (Trajkovic 2007; Itenfisu et al. 2003). On contrary, for the hot and humid regions, ET_O was underestimated

(Sivaprakasam et al. 2011) along with the coastal regions (Bautista et al. 2009). Furthermore, literature suggests that a comprehensive study considering the comparison of the FAO PM and the original HARG method and local calibration has not been applied in the Himalayan ecosystem and therefore it is of utmost importance given the existence of data limited conditions in the region.

Despite the progress in studies indicating the changing trend and magnitude of climatic variables including ET_0, a precise understanding of the climatic characteristics of the mountain region is still limited. This is due to dearth of observations adequately distributed in time and space as well as insufficient theoretical attention given to the complex interaction of weather and climate phenomena in mountains at spatial scales (Beniston et al. 1994). For instance, Sikkim is a small mountainous state of North-East (NE) India, highly vulnerable to the water-induced disasters such as glacial lake outbursts resulting in devastating flash floods, because of its location in the eastern Himalayan periphery and its economic underdevelopment (Debnath et al. 2012; Jain et al. 2013). Studies also show an abrupt change in the climatic parameters in the hilly region (Gordon et al. 2008). Jhajharia et al. (2009) found the alteration in the pan evaporation due to changing sunshine duration and wind speed. Any changes to an already fragile environment may pose severe threat to the natural and social-economic system as well as affects the geomorphologic process of the region (Gautam et al. 2003; Marchenko et al. 2007; Hongfeng et al. 2009).Therefore, there is an urgent need for a special attention to be given, to these mountain ecosystems, in particular with respect to the possible impact of the climate change. In order to ascertain statistically significant trends in the climatic variables, Mann-Kendall (MK) test (Mann 1945; Kendall 1975) has been used progressively at various regions at global and regional scale (Yue and Hashino 2003; Burn et al. 2004; Hongfeng et al. 2009; Kumar and Jain 2011; Jain et al. 2013).

The present study focuses on the changing pattern of the climate in the hilly region with an objective to analyse the trend of the climatic variables, directly and indirectly influencing the trend of the ET_0. Furthermore, keeping in view the data limited estimation of ET_0, the present study also presents a comprehensive comparison of the uncalibrated and locally calibrated HARG equation with the FAO PM method. In particular, the trend of the meteorological parameter indicates the changing climate, which strongly governs the hydrologic cycle of the mountainous region and is highly important for the agricultural activities.

1 Materials and Methods

1.1 Study area description

The present study was conducted for East Sikkim district of Sikkim state of India with latitude and longitude ranging from 27°11' to 27°44'N and 88°29' to 88°48'E respectively. The selected meteorological station is located at a latitude and longitude of 27°37'N and 88°37'E in NE of India with an elevation of 1370 m above sea level (Figure 1). Due to its location in the Eastern Himalayas, the climate ranges between subtropical to high alpines. However, the region also experiences the humid hot summer, severe monsoon and mild winter at lower elevations. The mean annual temperature ranges between 9°C -

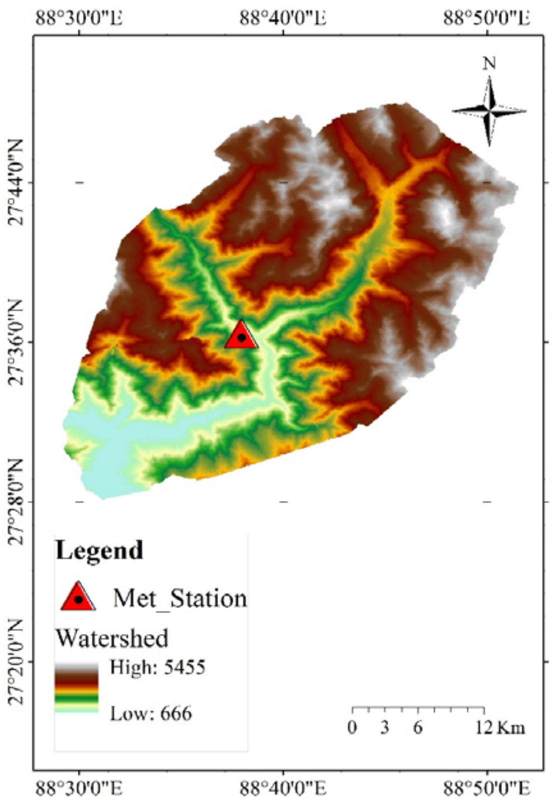


Figure 1 Map showing location of study area.

24°C and the rainfall varies from 2200 – 3900 mm in the region (Deb et al. 2015). The region is also drained by river Brahmaputra and its tributaries, with an average discharge of approximately 19,200 $m^3 s^{-1}$ (Jain et al. 2013).

Although, more than 60% of the land in NE India is covered by forests yet, agricultural activities dominate the region. The farmers of Sikkim generally grow the fruit crops in the upper elevations followed by cereal crops like rice and maize in middle and lower elevations respectively. The productivity of the crop also depends on the available moisture and nutrients in the soil. The soil texture varied from sandy loam to Clay, influencing the water holding and water retention properties of the soil in the study area (Deb et al. 2014).

1.2 Meteorological data

The climatic data was obtained from the Indian Council of Agricultural Research (ICAR) for NE hilly region of India. The daily time series of the meteorological data extending for the period of 25 years (1985-2009) includes eight variables namely, rainfall (*P*), relative humidity (R_H), maximum temperature (T_{max}), minimum temperature (T_{min}), sunshine duration (hr), net radiation (*Rn*), soil heat flux (*G*) and vapor pressure deficit (*VPD*). Missing data of all the meteorological variables ranging from January to October 2000 contributing to 3.33% of the total data for the station was filled by developing regression equations using Statistical Package for Social Sciences (SPSS) and Microsoft Excel among the observed values and the global gridded dataset obtained from National Oceanic and Atmospheric Administration (http://www.esrl.noaa.gov/psd/data/gridded/).

1.3 ETo estimation

The FAO PM equation was used to estimate the standard ET_o (mm day^{-1}) for the study station. The equation was given by Allen et al. (1998) as below;

$$ET_{O,PM} = \frac{0.408\Delta(R_n - G) + \gamma(\frac{900}{t + 273})u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (1)$$

Where, $ET_{O,PM}$ is the reference evapotranspiration in mm day^{-1}, Δ is the slope of the saturation vapor pressure function (kPa $°C^{-1}$), R_n is the net radiation at the crop surface (MJ m^{-2} day^{-1}), G soil heat flux density (MJ m^{-2} day^{-1}), T the air temperature at 2 m height (°C), u_2 the wind speed at 2 m height (m s^{-1}), e_s the vapor pressure of the air at saturation (kPa), e_a the actual vapor pressure (kPa) and γ is the psychrometric constant (kPa $°C^{-1}$), g may be ignored for daily time step computation. R_n was estimated from total incoming solar radiation measurements as given in Eq 2.

$$Rn = \frac{12(60)}{\pi} G_{sc} d_r [(\omega_2 - \omega_1) sin\varphi \times sin\delta + cos\varphi \times cos\delta \times (sin\omega_2 - sin\omega_1)] \quad (2)$$

Where, R_n is the extra-terrestrial radiation in the hour (or shorter) period in MJ m^{-2} $hour^{-1}$, G_{sc} is solar constant = 0.0820 MJ m^{-2} min^{-1}, d_r is inverse relative distance between earth and sun calculated as in Eq. 3, δ is solar declination as in Eq. 4, φ is the latitude of the location in radian, ω_1 and ω_2 are the solar time angle at the beginning and end of the period respective which is calculated as Eqs. 5 and 6.

$$d_r = 1 + 0.033 cos\left(\frac{2\pi}{365} J\right) \quad (3)$$

$$\delta = 0.409 sin\left(\frac{2\pi}{365} J - 1.39\right) \quad (4)$$

$$\omega_1 = \omega - \frac{\pi t_1}{24} \quad (5)$$

$$\omega_2 = \omega + \frac{\pi t_1}{24} \quad (6)$$

Where, ω is the solar time angle at midpoint of hourly or shorter period in radians and is calculated as in Eq. 7, t_1 is the length of the calculation period in hours

$$\omega = \frac{\pi}{12}[(t + 0.06667(L_z - L_m) + S_c) - 12] \quad (7)$$

Where, t is the standard clock time at the midpoint of the period in hour, L_z is the longitude of the centre of the local time zone [degrees west of Greenwich], L_m is longitude of the measurement site [degrees west of Greenwich], S_c is seasonal correction for solar time in hours and is calculated as in Eq. 8.

$$S_c = 0.1645 sin(2b) - 0.1255 cos(b) - 0.025 sin(b) \quad (8)$$

$$b = \frac{2\pi(J - 81)}{364} \quad (9)$$

Where, J is number of days in the year.

In this paper, FAO PM method was used as a replacement for the measured ET_o data and it is considered as the standard procedure in the absence of the lysimeter data (Trajkovic 2007).

The daily ET_O using HARG equation was calculated as following Eq. 10 given by Hargreaves et al. (1985).

$$ET_{0,Harg} = H_A \times R_e(T + 17.8) \times \Delta T^{H_E} \quad (10)$$

Where, $ET_{O,Harg}$ represents the reference evapotranspiration estimated by HARG method in mm day-1, H_A and H_E are the empirical parameters (standard values at global scale: H_A = 0.0023 and H_E = 0.5), R_e is the water equivalent of the terrestrial radiation (mm day-1), T is the mean temperature ($(T_{min}+T_{max})/2$°C) and ΔT is the difference between T_{max} and T_{min}. R_e was calculated according to Shuttleworth (1993) and is given in Eq. 11.

$$R_e = 15.392 d_r(\omega_s sin\emptyset sin\delta + cos\emptyset cos\delta sin\omega_s) \quad (11)$$

Where, d_r is inverse relative distance between earth and sun calculated as in Eq. 3, δ is solar declination as in Eq. 4, ϕ is the latitude of the site, ω_s is the sunset hour angle in radians and is calculated as in Eq. 12.

$$\omega_s = arc[cos(-tan\emptyset\ tan\delta)] \quad (12)$$

The first set of ET_o estimation by the HARG equation was done by the globally assessed values of H_A and H_E which are mentioned above. The regional calibration was done by manual calibration process in which 32 iterations were done considering the monthly average daily ET_O for the period of 1985 – 1999. The parameter values (H_A and H_E) were altered independently keeping one as constant and changing the other to obtain the best fit curve [linear with maximum coefficient of determination (Eq. 13)] with the outputs calculated by FAO PM method. The iteration was started from the standard global values of H_A and H_E.

The mean daily ET_O calculated from FAO PM method was compared with those of calculated from the original (uncalibrated) HARG model for the period of 1985 – 2009 whereas, for the site specific calibrated HARG method, the comparison was done for the period of 2000 – 2009 since the data ranging from 1985 – 1999 was used for model calibration.

1.4 Model output evaluation

The outputs of ET_o from the original and the calibrated HARG method was compared to that of calculated by PM method based on the coefficient of determination (R^2), mean bias error (MBE) and root mean square error (RMSE).

Coefficient of determination is defined as the square of correlation coefficient; it gives the proportion of variance of one variable that is predictable from the other variable as given by Willmott et al. (1985).

$$R^2 = \frac{\sum Si.Mi - \sum Si.\sum Mi}{\sqrt{\sum Si^2 - (\sum Si)^2} \times \sqrt{\sum Mi^2 - (\sum Mi)^2}} \quad (13)$$

MBE is used to indicate the over and underestimation of the model outputs given by Fekete et al. (2004) and is calculated as in Eq. 14.

$$MBE = \frac{1}{n}\sum_{i=1}^{n}(Si - Mi) \quad (14)$$

RMSE is used to test the goodness of fit and is dependent on the sample variance and sample size and is calculated as in Eq. 15.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(Si - Mi)^2} \quad (15)$$

Where Si and Mi are the simulated values of ET_O by HARG method and the PM method respectively; n is the number of months considered (12).

1.5 Trend analysis

The trends of eight meteorological variables were also investigated by using the non-parametric test method. Although both parametric and non-parametric tests are used most commonly in trend detection (Kundzewicz and Robson 2004; Zhang et al. 2007), but owing to the meteorological time series data that more often exhibit departure from the normality; the non-parametric tests are reasonably more suitable then parametric test (Khattak et al. 2011). Whereas, the parametric test generally assumes the normal distribution of data and whose power can be greatly reduced in case of skewed data. Hence, Mann-Kendall's test is considered as one of the most famous non parametric test for identifying the changing trend in the time series data of the meteorological parameters used in numerous case studies (Chen and Xu 2005; Pasquini et al. 2006; Burn and Hesch 2007). The test does not assume any prior knowledge of the distribution of the data, and is, therefore, more robust than the equivalent parametric tests (Honfeng et al. 2009). The Mann-Kendall test was performed to comprehend the trajectory of the mean monthly data of meteorological parameters and reference evapotranspiration of the station. The test mainly considers rank of the data and therefore, compares each value of the time series with the remaining values in the sequential order (Hirsch et al. 1982). The test statistic S is given by the Eq. 16.

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sign(x_j - x_k) = \begin{cases} +1 \ if \ (x_j - x_k) > 0 \\ 0 \ if \ (x_j - x_k) = 0 \\ -1 \ if \ (x_j - x_k) < 0 \end{cases} \quad (16)$$

Where x_j and x_k are the sequential data values, and n is the length of the dataset. For a time series $X = \{x_1, x_2, ..., x_n\}$, the null hypothesis H_0 states that there are a sample of n independent and identically distributed random variables (Yu et al. 1993). The alternative hypothesis H_1 of a two-sided test is that the distribution of x_k and x_j are not identical for all $k, j \leq n$ with $k \neq j$. However, a positive value of S indicates an upward trend, and a negative value indicates a down-ward trend. With the assumption that the data are independent and identically distributed, the mean and variance of the S statistic in Eq. 16 above are given by Eq. 17.

$$V_0(S) = \frac{n \times (n-1) \times (2n+5)}{18} \quad (17)$$

Where, n is the number of observations. The existence of tied ranks (equal observations) in the data results in a reduction of the variance of S to become Eq. 18.

$$V_0(S) = \frac{n \times (n-1) \times (2n+5)}{18} - \sum_{j=1}^{m} \frac{t_j \times (t_j - 1) \times (2t_j + 5)}{18} \quad (18)$$

Where, m is the number of groups of tied ranks, each with t_j tied observations.

Furthermore, the significance of the test was also tested by calculating the standardized statistic test (Z) in Eq. 19.

$$z = \begin{cases} \frac{S-1}{\sqrt{Var(s)}} \ if \ S > 0 \\ 0 \ if \ S = 0 \\ \frac{S+1}{\sqrt{Var(s)}} \ if \ S < 0 \end{cases} \quad (19)$$

Where, (Z) is the Mann-Kendall test statistic that follows a standard normal distribution with mean 0 and variance 1. The Z value can be related to a p-value of a specific trend. A p-value is a measure of evidence against the null hypothesis of no change thus smaller the p-value, the greater the strength of evidence against the null hypothesis (Khattak et al. 2011). Consequently, a two-sided test for trend, at a selected significance level (α), the null hypothesis of no trend is rejected if the absolute value of Z is greater than $Z\alpha/2$.

2 Results

2.1 FAO PM, original and calibrated HARG ETo

The average value to the ET_0 calculated by FAO PM method ranges from 1.34 to 3.29 mm day^{-1} and a mean value of 2.57 mm day^{-1}, with a maximum standard deviation of 0.45 mm day^{-1} for the month of November (Figure 2). On average, the uncalibrated HARG method underestimates the ET_0 by 12.9% of average daily value. On contrary, the regional calibration of the HARG method yields to overestimation of ET_0 by 4.1% on daily basis.

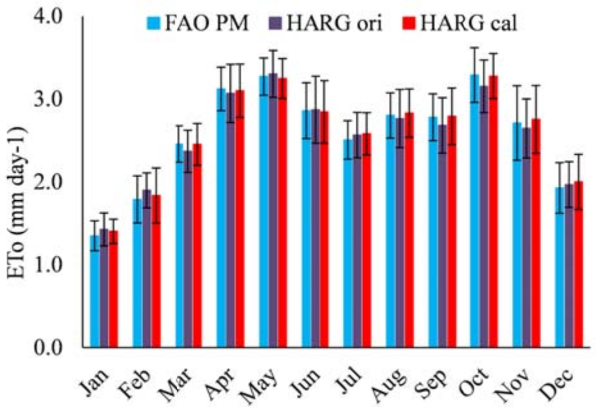


Figure 2 Average estimated daily reference ET_0 for all months using FAO PM, uncalibrated and calibrated HARG method for the study station.

In order to improve the estimation of the HARG equation, both parameters were calibrated for the study site. Calibration of H_A yields average value of 0.00201 whereas; the calibrated value of H_E reflects 0.521. The uncalibrated results obtained from HARG method illustrates very poor relation with R^2 ranging from 0.45 to 0.74 and maximum RMSE of 0.27 mm day^{-1} relative to the FAO PM method (Table 1). Furthermore, the ET_0 estimated by the original HARG method implies underestimation ranging from 0.01 to 0.11 mm day-1. It is also worth to note that the underestimation is mostly observed for the first half of the year followed by an overestimation ranging from 0.03 to 0.14 mm day-1 for the latter half. Similarly, the RMSE ranged from 0.15 to 0.27 mm day-1 with a repetition of 0.24 mm day -1 observed for February, March and April indicating the higher variability on ET_O estimation for the dry period. Also, lower R^2 is observed for the dry period (January to May) illustrating the inability of the model to capture the ET_O at good accuracy. However, a better R^2 is observed for the latter half of the year ranging from 0.60 to 0.75. This is probably due to the failure of the model to apprehend the low values of ET_O for the study site due to the physiological complexity of the area and the model structure simplicity. On contrast, the regional calibration resulted in modification of the ET_O estimates. Greater magnitudes of R^2 (0.77 to 0.89) along with low values of MBE (0.02 to -0.07 mm day-1) and RMSE (0.11 to 0.18 mm day-1) are observed for the present study.

Table 1 Performance evaluation of uncalibrated and calibrated HARG method of ET_O calculation at monthly mean daily time step

Month	Uncalibrated			Calibrated		
	MBE (mm day-1)	RMSE (mm day-1)	R^2	MBE (mm day-1)	RMSE (mm day-1)	R^2
January	-0.08	0.16	0.52	-0.05	0.15	0.79
February	-0.11	0.24	0.45	-0.05	0.18	0.77
March	0.09	0.24	0.56	0.01	0.13	0.84
April	0.05	0.24	0.56	0.02	0.15	0.79
May	-0.03	0.19	0.61	0.02	0.13	0.82
June	-0.01	0.15	0.74	0.01	0.13	0.87
July	-0.05	0.22	0.62	-0.07	0.12	0.82
August	0.03	0.18	0.75	-0.02	0.11	0.84
September	0.09	0.20	0.69	-0.01	0.14	0.84
October	0.14	0.25	0.60	0.01	0.12	0.87
November	0.06	0.27	0.66	-0.04	0.15	0.89
December	-0.04	0.17	0.71	-0.07	0.15	0.84

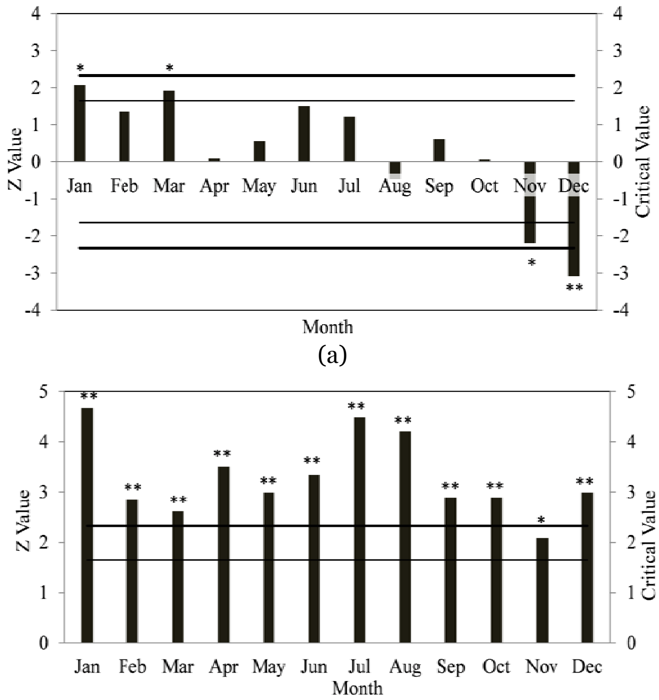
Notes: MBE = mean bias error; RMSE =root mean square error.

2.2 Trend analysis of major meteorological variables

The trend result of the climatic variables influencing the reference evapotranspiration (ET_O) of the NE hilly region situated in the humid state Sikkim is given in the following sections. The Z value of the non-parametric Mann-Kendall's test reveals the series of trends in the meteorological variables for the period of 1985-2009.

2.2.1 Trend of air temperature

The Z value of mean monthly maximum air temperature shows significant ($p \le 0.05$) increasing trend for the month of January and March. In contrast the significant declining trend is observed in the month of November ($p \le 0.05$) and December ($p \le 0.01$) with z value ranges between -2.0 to -3.5, while rest of the month does not show any significant trend for the remaining months of the year (Figure 3a). This implies that the trend of maximum air temperature shows a minor increasing trend for the winter months for the period of 25 years. However, the mean monthly minimum air temperature indicates a significant rising (positive) trend at $p \le 0.01$ for every month of the year, with the Z value above 2.0 (Figure 3b). Thus the mean



(a) (b)

Figure 3 The trend of Z statistics for the mean monthly (a) maximum and (b) minimum temperature for 25 years (1985-2009) (* indicates significance at $p \le 0.01$ probability level;** indicates significance at $p \le 0.05$ probability level).

monthly minimum air temperature illustrate increasing trend at the faster rate than the mean monthly maximum air temperature for the study site.

2.2.2 Trend of sunshine duration

The sunshine duration is often used to estimate the solar radiation from the extra-terrestrial radiation. The observed mean monthly sunshine duration for every month of the year shows a decreasing trend throughout the year except for an insignificant positive trend in the month of July and negative in September. The decreasing trend is highly significant for most of the months except for February and March at $p \leq 0.01$, whereas maximum Z values are observed for the month of June (-3.64), November (-4.07) and December (-3.22) at a significance level of $p \leq 0.05$. Figure 4 indicates the significant decreasing trend in sunshine duration for 25 year of the period with the Z values ranging from -1.5 to -4.0.

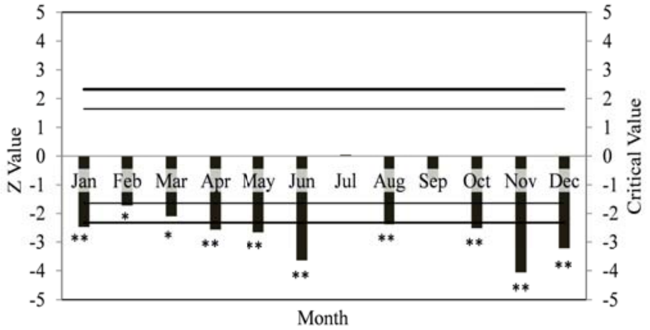


Figure 4 The trend of *Z* statistics for the mean monthly sunshine duration for 25 years (1985-2009) (* indicates significance at $p \leq 0.01$probability level;** indicates significance at $p \leq 0.05$ probability level).

2.2.3 Trend of relative humidity

The result for maximum and minimum relative humidity also show highly significant increasing trends for the month of April (*Z* value > 2.0) and highly significant declining trend for September (*Z* value < -1.5) at $p \leq 0.01$ for the minimum relative humidity; however for the maximum relative humidity no significant trend is observed. Figure 5a illustrates the non-significant increasing trend for most of the months except for April, October, November and December where a significant increasing trend is observed at a significance level of $p \leq 0.01$ and no trend is observed for July and August. On the other hand, the minimum relative humidity shows significant increasing trend for the month of April at significance level of $p \leq 0.05$ and decreasing trend at significance level of $p \leq 0.01$ for the month of September; whereas, the remaining does not display any significant trend (Figure 5b).

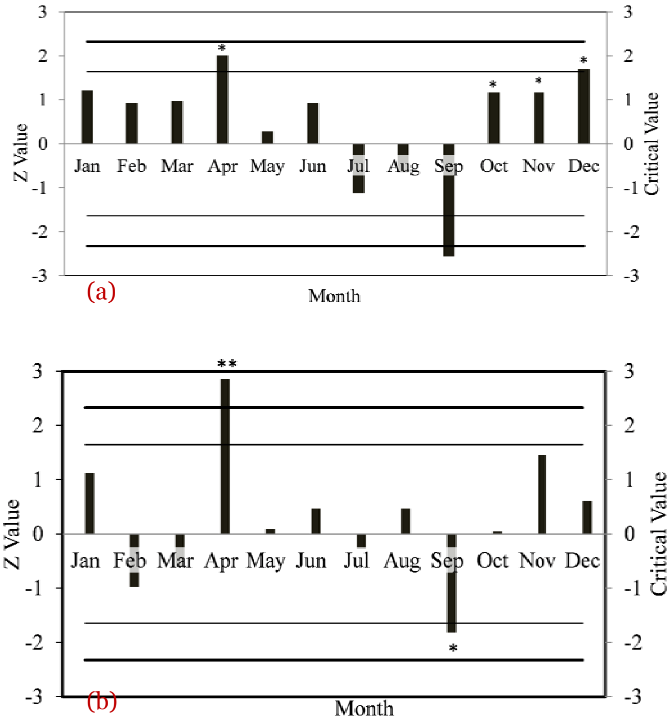


Figure 5 The trend of Z statistics for the mean monthly (a) maximum and (b) minimum relative humidity for 25 years (1985-2009) (* indicates significance at $p \leq 0.01$ probability level; ** indicates significance at $p \leq 0.05$ probability level).

2.2.4 Trend in precipitation (P)

Trend analysis of monthly precipitation indicates a significant ($p \leq 0.01$) decrease in the rainfall for the month of January and increase for the month of April with Z value greater 1.8. However, an insignificant declining trend is observed for the months of February, May and September with overall negative Z values (Figure 6). The month of March, June, July, August, October, November and December also exhibits the insignificant increasing trend (positive Z values). However, the Mann Kendall's test indicates the substantial increase and slight decrease in precipitation in the region whereas, the heavy precipitation received in the month of January and April.

2.3 Trend analysis of the minor meteorological variables

2.3.1 Trend of net radiation (R_n)

The net radiation, also known as the net flux shows the range of the difference in the incoming and outgoing radiation to and from the earth surface and the atmosphere. It is also termed as the total energy that can influence the climate of the region. In the present study, a significant declining trend in the net radiation is observed for most of the months in the latter half of the year (Figure 7). The declining trend is significant at $p \leq 0.05$ for the month of June and August to December at $0.01 \leq p \leq 0.05$. The area also exhibits the highly significant increasing trend ($p \leq 0.05$) of net radiation for the month of the January to March with their Z values greater than 3.0. Overall, the result indicates the decreasing trend in net radiation, consequently reducing the rate of evapotranspiration by altering the heat flux which has major contribution in altering evaporation of an area (Wales-Smith, 1980). This decrease in R_n also marks the onset of monsoon (south-west) from the month of May in the region. Although the area experiences cold and humid climate with rainfall throughout the year, the rainy season begins from the month of May and continues till October.

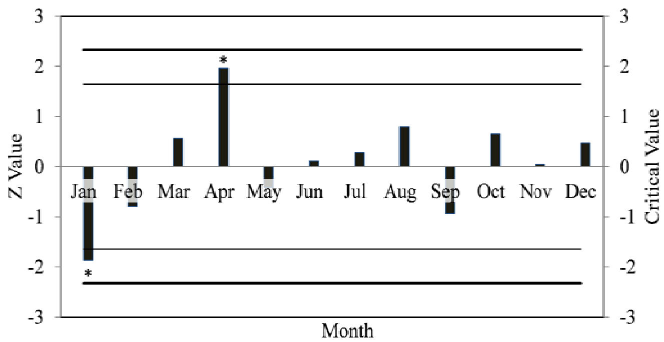


Figure 6 The trend of Z statistics for the mean monthly precipitation for 25 years (1985-2009) (* indicates significance at $p \leq 0.01$ probability level).

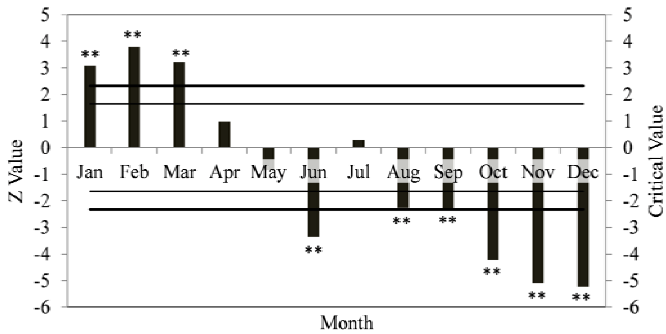


Figure 7 The trend of Z statistics for the mean monthly Net Radiation (R_n) for 25 years (1985-2009) (** indicates significance at $p \leq 0.05$ probability level).

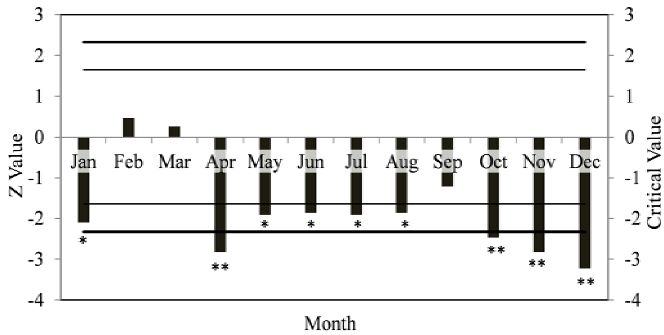


Figure 8 The trend of Z statistics for the mean monthly vapor pressure deficit for 25 years (1985-2009) (* indicates significance at $p \leq 0.01$probability level;** indicates significance at $p \leq 0.05$ probability level).

2.3.2 Trend of the Vapor Pressure Deficit (VPD)

The rate of evapotranspiration has explicit relationship with VPD (Eq. 1). Hence, the increase and decrease in the VPD also influence the upward and downward trend of evapotranspiration. In the present study, VPD shows declining trend throughout the year (Figure 8). The significant decreasing ($p \leq 0.05$) trend in VPD can be observed for most of the months except for February, March and September where no trend is observed. The substantial increase in the maximum relative humidity pragmatic at the meteorological station in East Sikkim can be attributed to the falling trend in the VPD since it represents the moisture holding capacity of the air implying at saturation, VPD is reduced.

2.3.3 Trend of the soil heat flux (G)

The soil heat flux (G) is a measure of the amount of energy moving into and out of the soil for a period of time. The obtained result illustrates the downward trend of G at $p \leq 0.01$, especially for the month of May and November (Figure 9).

However, no significant trend was observed for other months in the year. In general, the overall result implies the decreasing trend for most of the month with Man Kendall's Z value ranges between 0 to -1.7.

2.4 Trend analysis of reference evapotranspiration (ET0)

The study indicates a substantial decrease in the reference evapotranspiration (ET_O) in the later part of the year. The months of June and August to December reveals a significant falling trend (Figure 10). More specifically, August and September attributes to declining trend in ET_0 at 99% confidence level however, the months of June, October, November and December shows the declining trend at 95% confidence level. There are several contributing factors namely relative humidity, sunshine duration, net radiation, VPD, maximum and minimum temperature affects the ET_O trend as given in Eq. 1. In addition, the observed trend of precipitation affecting the water demand of the crops by altering the antecedent moisture content of the soil and therefore externally contributes to the observed trend of ET_O as observed in our case. Thus, changes in these factors directly and indirectly affects the reference evapotranspiration in general. Higher increase in the temperature and the declining trend of rainfall for the months of February and March can be attributed to the increasing trend of ET_O for the corresponding months.

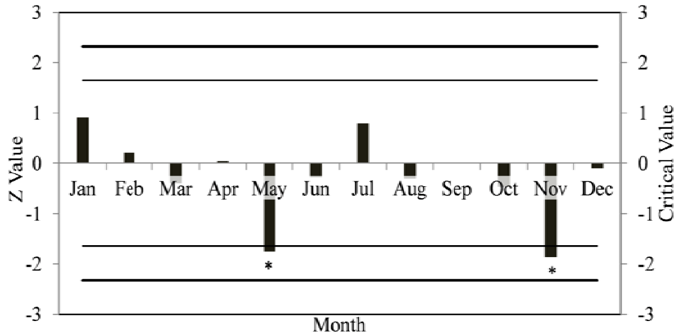


Figure 9 The trend of Z statistics for the mean monthly soil heat flux for 25 years (1985-2009) (* indicates significance at $p \leq 0.01$probability level).

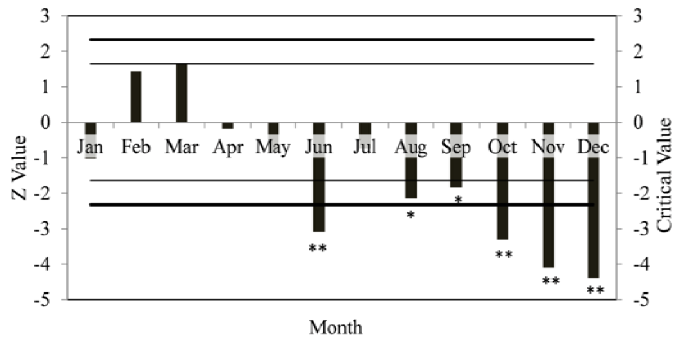


Figure 10 The trend of Z statistics for the mean monthly reference evapotranspiration for 25 years (1985-2009) (* indicates significance at $p \leq 0.01$probability level;** indicates significance at $p \leq 0.05$ probability level).

3 Discussion

Sensitivity of regional climate to climate change in the mountainous region (Hongfeng et al. 2009; Nogues-Bravo et al. 2007), attracts attention of researchers at a global scale to conduct climate studies in higher altitudes. Recent observations of the regional climate change at various parts of the world have brought into consideration the need of local scale studies and the dependence of climate on elevation (Khattak et al. 2011; Bolch 2007). Studies from different regions of the world has illustrated contrasting results at various mountain regions with certain mountains showing increasing temperature at higher elevations (Casimiro et al. 2012; Khattak et al. 2011), interestingly Giese and MoBig (2004), in their study determined the lowering trend of temperature at higher elevations (Bolch 2007).

Studies on comparison of different methods of ET_O estimation suggests with data limited conditions, simpler models can be used however, the reliability of the outputs are location specific where in some regions the daily computed ET_O is underestimated (Raziei and Pereira 2013) and overestimated (Berti et al. 2014) compared to either lysimeter or the FAO PM method of calculation. Therefore, in order to use a less data intensive model, extreme care is to be taken to represent the results for further impact assessment studies or management plans (Yoder et al. 2005). The present study reflects the combination of under and overestimation of ET_O for different months in the higher altitude of Himalayan Mountains where, regional calibration of the HARG method also yield to deviation in the magnitude of ET_0. However, better correlation is observed in the ET_o estimates using the calibrated HARG method compared to the uncalibrated case. Forcing the model to suit the target study site by calibrating the parameters definitely increases the R^2 however; it fails to improve the MBE significantly since the proportion of variance of the modelled estimate can be closer to the actual one however, the over and underestimation for a particular day can vary significantly. Similar results were also reported for Florida and South Bulgaria by Martinez and Thepadia (2010), Popova et al. (2006) respectively where adjustment of parameters in context of regional suitability yield into better estimates.

Previous studies on trend analysis for the regions with similar physiographic and climatic conditions shows a significant increasing trend in minimum temperature at annual scale with a rate of 0.07°C/year; however, at monthly scale both minimum and maximum temperature shows increasing trend for all months throughout the year. Furthermore, it was also concluded that the mean summer and monsoon rainfall shows a significant declining trend in magnitude (Rathore et al. 2013). In a separate study by Rahman et al. (2012), it was illustrated that the average number of rainy days and the magnitude of annual rainfall at the station has reduced to 0.72 days/year and 17.77 mm/year respectively for 2001-10 relative to 1991-2000. In addition, for mean annual temperature, the latter decade has experienced an increase of 0.81°C relative to the earlier implying the expected changes in local climate in the region in future.

A further study on rainfall at a coarser scale in the Northeast India by employing Sen's slope method and using meteorological data over 100 years illustrate a significant declination in the mean monthly rainfall for the month of June in whole Sikkim. Similarly for the months of March, August and September also a reduction in trend is observed however the shift is insignificant (Jain et al. 2013). Moreover, the annual analysis of the rainfall reveals that the region experiences insignificant trends. Nonetheless, all these studies indicate an illustrative region scale study and therefore limiting the station scale study which has not been applied before in the region.

Our study suggests, changes in the maximum and minimum temperature of the region, impacts various other climatic variables such as: VPD, evaporation from surface and vegetation, *ET*, *P* and *RH*. Although, T_{max} and T_{min} both shows slightly increasing trend especially in the beginning and middle of the year, but the trend of T_{min} is rising faster than T_{max} at the station. This can be due to the increase in cloudiness in the region caused by increase in quantity of aerosol in the atmosphere. Aerosol scatters and absorbs the incoming solar radiation thus directly influencing the earth's radiation budget and climate. Indirectly aerosols modify the size of cloud particle in lower atmospheres which lead to long wave surface warming at night and day time cooling due to aerosols-solar radiation interaction (Huang et al. 2006), attributing to increase in mean monthly minimum temperature (T_{min}) (Seetharam 2008). The mean monthly sunshine duration shows a significant declination due to mechanisms such as increasing aerosol, changes in cloud types and the presence of greenhouse gases, either generated locally or transported from elsewhere (Stanhill 1998). A significant decline in ET_o is also observed in most of the months, except in February and March. Increased R_n, T_{max}, T_{min} and VPD followed by slightly decreased P and sunshine hours, resulted in higher Z value of ET_o in the month of February and March. In addition, increased relative humidity also plays vital role in influencing the VPD as it reduces the moisture holding capacity of the air due to high saturation level. The declining trend in ET_o can be due to the significant increase in relative humidity in most part of the year at the observed station, which reduces the rate of evaporation from the atmosphere (Jhajharia et al. 2010). Evidently, ET_0 shows downward trend in the months with relatively low VPD indicating the direct relation of ET_0 with VPD. Irmak et al. (2012) also found the similar results in his study and states that generally ET_0 is highly sensitive to the increase and decrease in VPD. Increasing P reduces the driving energy (R_n, T_{max} and VPD), which is a primary source of evaporation and thus extensively affecting ET_0. Dwindling evaporative energy can be attributed to reduction in incoming short wave radiation (R_s) due to increased cloudiness, contributing to the reduced number of sunshine hours. On the other hand the significant decreasing trend in *G* can be attributed to the spatial and surface cover since an area with dense vegetation cover can significantly reduce the incoming solar radiation at the surface relative to a bare land. This further reduces the amount of energy (solar radiation) available to the soil thus also limiting the ability of transferring the energy to and from the soil surface (Yang et al. 1999). For instance, the magnitude of G varies from near 0 in dense crop cover on the daily basis in temperate zone, to nearly 50% of R_n (hourly) with no vegetation in a semiarid region (Lal 2006). Conversely, ET_O also demonstrates negative relation with R_{max} and R_{min} showing an increasing trend, owing to an increase in the air temperature and rainfall at the station, which augment the moisture in the atmosphere; this was also evident in some of the studies in India (Chattopadhyay and Hulme 1997).

4 Conclusion

The present study highlighted a critical comparison of the FAO PM method along with uncalibrated and calibrated HARG method of ET_O estimation. The uncalibrated HARG equation tends to underestimate the ET_O by 0.35 mm day^{-1} with maximum value of 0.83 mm day^{-1} relative to the FAO PM method. The regional calibration of the parameters H_A and H_E results in better estimation with an average underestimation of 0.16 mm day^{-1} and maximum of 0.28 mm day^{-1}. Although, this may lead to consistent underestimation of the irrigation needs for the crops, however; considering the results obtained by the calibrated HARG and FAO PM method of ET_O estimation, earlier one can be recommended for the mountain ecosystem in the absence of sufficient data.

In addition, the analysis of the monthly trend of eight climatic variables by using Man-Kendal's test implies four out of eight climatic parameters showing mild increasing trend in most of the months (T_{max}, T_{min}, R_H, P), especially in the winter (December-February) and monsoon (June - November). Conversely, a downward trend in sunshine duration, VPD and ET_O is observed in spring (March - May) and monsoon (June – November) in East Sikkim. However, R_n in the area is noted to increase between January to February and significantly ($p \leq 0.05$) decrease in the latter half of the year except for July. ET_O at the station displayed a significant ($0.01 \leq p \leq 0.05$) declining trend between June to December. Consequently, the area also displayed rising trend in ET_0 for the months of February and March. ET_O is also observed to exhibit positive relation with VPD following similar trend in the corresponding periods of the year. Although the climatic parameters in this study were locally analysed, however; the obtained results could be used extensively for better planning in agriculture areas, irrigation management and maintaining the hydrologic balance of the mountainous region.

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References

Allen RG, Pereira LS, Raes D, et al. (1998) Crop evapotranspiration: guidelines for computing crop water requirements. In: FAO Irrigation and Drainage Paper no. 56. FAO, Rome, Italy.

Allen RG, Pruit WO, Wright JL, et al. (2006) A recommendation on standardized surface resistance for hourly calculation of reference ET_0 by the FAO56 Penman-Monteith method. Agriculture Water Management 81: 1-22. DOI: 10.1016/j.agwat.2005.03.007

Bautista F, Bautista D, Delgado-Carranza C (2009) Calibration of the equations of Hargreaves and Thornthwaite to estimate the potential evapotranspiration in semi-arid and subhumid tropical climates for regional applications. Atmosfera 22(4): 331-348

Beniston M, Rebetez M, Giorgi F, et al. (1994). An analysis of regional climate change in Switzerland. Theoretical and Applied. Climatology 49: 135 - 159. DOI: 10.1007/BF00865530

Berti A, Gianmarco T, Chiaudani A, et al. (2014) Assessing reference evapotranspiration by the Hargreaves method in north-eastern Italy. Agricultural Water Management 140: 20-25. DOI: 10.1016/j.agwat.2014.03.015
Bolch T (2006) Climate change and glacier retreat in northern Tien Shan (Kazakhstan/Kyrgyzstan) using remote sensing data. Global and Planetary Change 56: 1-12. DOI: 10.1016/j.gloplacha.2006.07.009
Burn DH, Cunderlik JM, Pietroniro A (2004) Hydrological trends and variability in the Liard River Basin / Tendances Hydrologiques et Variabilité Dans Le Basin de La Rivière Liard. Hydrological Sciences Journal 49(1): 53-67. DOI: 10.1623/hysj.49.1.53.53994
Burn DH, Hesch NM (2007) Trends in evaporation for the Canadian Prairies. Journal of Hydrology 336(1-2): 61-73. DOI: 10.1016/j.jhydrol.2006.12.011
Casimiro WSL, Labat D, Ronchail J, et al. (2012) Trends in rainfall and temperture in the Peruvian Amazon-Andes basin over the last 40 years (1965-2007). Hydrological Processes 27: 2944-2957. DOI: 10.1002/hyp.9418
Chattopadhyay N, Hulme M (1997) Evaporation and Potential Evapotranspiration in India under Conditions of Recent and Future Climate Change. Agricultural and Forest Meteorology 87: 55-73. DOI: 10.1016/S0168-1923(97)00006-3
Chen Y, Zongxue Xu (2005) Plausible Impact of Global Climate Change on Water Resources in the Tarim River Basin. Science in China Series D: Earth Sciences 48(1): 65-73. DOI: 10.1360/04yd0539
Deb P, Debnath P, Pattannaik SK (2014) Physico-chemical properties and water holding capacity of cultivated soils along altitudinal gradient in south Sikkim, India. Indian Journal if Agricultural Research 48(2): 120-126. DOI: 10.5958/j.0976-058X.48.2.020
Deb P, Shrestha S, Babel MS (2015) Forecasting climate change impacts and evaluation of adaptation options for maize cropping in the hilly terrain of Himalayas: Sikkim, India. Theoretical and Applied Climatology 121(3): 649-667. DOI: 10.1007/s00704-014-1262-4
Debnath P, Deb P, Sen D, et al. (2012) Physico-chemical properties and its relationship with water holding capacity of cultivated soils along altitudinal gradient in Sikkim. International Journal of Agricuture, Environment and Biotechnology 5(1): 99-104
Dinpashoh Y (2006) Study of reference crop evapotranspiration in I.R. of Iran. Agricultural Water Management 84(1-2): 123-129. DOI: 10.1016/j.agwat.2006.02.011
Droogers P, Allen RG (2002) Estimating reference evapotranspitration under inaccurate data conditions. Irrigation and Drainage Systems 16: 33-45. DOI: 10.1023/A:1015508322413
Elnesr M, Alazba A, Abu-zreig M (2010) Analysis of evapotranspiration variability and trends in the Arabian Peninsula. American Journal of Envirnmental Sciences 6(6): 535-547. DOI: 10.3844/ajessp.2010.535.547
Fekete BM, Vörösmarty CJ, Roads JO, et al. (2004) Uncertainties in precipitation and their impacts on runoff estimates. Journal of Climate 17: 294-304. DOI: 10.1175/1520-0442(2004)017<0294:UIPATI>2.0.CO;2
Gao G, Chen D, Xu C, et al. (2007) Trend of estimated actual evapotranspiration over China during 1960-2002. Journal of Geophysical Research: Atmospheres 112: D11, 16. DOI: 10.1029/2006JD008010
Gautam AP, Webb EL, Shivakoti GP, et al. (2003) Land use dynamics and landscape change pattern in a mountain watershed in Nepal. Agriculture, Ecosystems and Environment 99(1-3): 83-96. DOI: 10.1016/S0167-8809(03)00148-8
Giese E, Moβig I (2004) Climate change in central Asia. Schriftenreihedes Center for International Development and Environmental Research, vol. 17. (In German)
Gordon JE, Haynes VM, Hubbard A (2008) Recent glacier changes and climate trends on south Georgia. Global and Planetary Change 60(1-2): 72-84. DOI: 10.1016/j.gloplacha.2006.07.037
Grundstein A (2008) Evaluation of climate change over the continental United States using a moisture index. Climatic Change 93(1-2): 103-115. DOI: 10.1007/s10584-008-9480-3
Hargreaves GH, Allen RG (2003) History and evaluation of Hargreaves evapotranspiration equation. Journal of Irrigation and Drainage Engineering 129(1): 53-63. DOI: 10.1061/(ASCE)0733-9437(2003)129:1(53)
Hargreaves GL, Hargreaves GH, Riley JP (1985) Irrigation water requirements for Senegal River Basin. Journal of Irrigationa and Drainage Engineering 111(3): 265-275. DOI: 10.1061/(ASCE)0733-9437(1985)111:3(265)
Hargreaves GH, Samani ZA (1985) Reference crop evapotranspiration from temperature. Applied Engineering in Agriculture 1(2): 96-99. DOI: 10.13031/2013.26773
Hirsch RM, Slack JR, Smith RA (1982) Techniques of trend analysis for monthly water quality data. Water Resources Research 18(1): 107-121. DOI: 10.1029/WR018i001p00107
Hongfeng Z, Zhiyun O, Hua Z, et al. (2009) Recent climate trends on the morthern slopes of the Tianshan Mountains, Xinjiang, China. Journal of Mountain Science 6(3): 255-265. DOI: 10.1007/s11629-009-0236-y
Huang Y, Dickson RE, Chameides WL (2006). Impact of aerosol indirect effect on surface temperature over east Asia. Proceeding of National Academy of Sciences of the United States of America 103(12): 4371-4376. DOI: 10.1073/pnas.0504428103
Irmak S, Kabenge I, Skaggs KE, et al. (2012) Trend and magnitude of changes in climate variables and reference evapotranspiration over 116-Yr period in the Platte River Basin, Central Nebraska–USA. Journal of Hydrology 420-421: 228-244. DOI: 10.1016/j.jydrol.2011.12.006
Itenfisu D, Elliott RL, Allen RG, et al. (2003) Comparison of reference evapotranspiration calculations as part of the ASCE standardization effort. Journal of Irrigation and Drainage Engineering 129(6): 440-448. DOI: 10.1061/(ASCE)0733-9437(2003)129:6(440)
Jain SK, Kumar V, Saharia M (2013) Analysis of rainfall and temperature trends in northeast India. International Journal of Climatology 33(4): 968-978. DOI: 10.1002/joc.3483
Jhajharia D, Shrivastava SK, Sarkar D, et al. (2009) Temporal characteristics of pan evaporation trends under the humid conditions of northeast India. Agricultural and Forest Meteorology 149(5): 763-770. DOI: 10.1016/j.agrformet.2008.10.024
Jung M, Reichstein M, Ciais P, et al. (2010) Recent decline in the global land evapotranspiration trend due to limited moisture supply. Nature 467(7318): 951-954. DOI: 10.1038/nature09396
Kashyap PS, Panda RK (2001) Evaluation of evapotranspiration estimation methods and development of crop-coefficients for potato crop in a sub-humid region. Agricultural Water Management 50: 9-25. DOI: 10.1016/S0378-3774(01)00102-0
Kendall MG (1975) Rank Correlation Methods. 4th ed. Charles Griffin & Company, London, UK.
Khattak MS, Babel MS, Sharif M (2011) Hydro-meteorological trends in the upper Indus River Basin in Pakistan. Climate Research 46(2): 103-119. DOI: 10.3354.cr00957
Kundzewicz ZW, Robson AJ (2004) Change detection in hydrological records — A review of the Methodology. Hydrological Sciences Journal 49(1): 7-20. DOI: 10.1623/hysj.49.1.7.53993
Lal R (2006) Encyclopedia of Soil Science. Available online at: http://books.google.co.th/books?id=sjNZ3LSUz80C&printsec=frontcover#v=onepage&q&f=false (Accessed on 20 July 2014)
Mann HB (1945) Nonparametric tests against trend. Econometrica 13: 245-259.
Marchenko SS, Gorbunov AP, Romanovsky VE (2007) Permafrost warming in the Tien Shan Mountains, central Asia.

Global and Planetary Change 56(3-4): 311-327. DOI: 10.1016/j.gloplacha.2006.07.023
Martinez CJ, Thepadia M (2010) Estimating reference evapotranspiration with minimum data in Florida. Journal of Irrigation and Drainage Engineering 136(7): 494-501. DOI: 10.1061/(ASCE)/IR.1943-4774.0000214
Moonen AC, Ercoli L, Mariotti M, et al. (2002) Climate change in Italy indicated by agrometeorological indices over 122 Years. Agricultural and Forest Meteorology 111(1): 13-27. DOI: 10.1016/S0168-1923(02)00012-6
Murugappan A, Sivaprakasam S, Mohan S (2011) Performance evaluation of calibrated Hargreaves method for estimation of Ref-ET in a hot and humid coastal location in India. International Journal of Engineering Science and Technology 3(6): 4728-4743.
Pandey V, Pandey PK, Mahanta AP (2014) Calibration and performance verification of Hargreaves Samani equation in a humid region. Irrigation and Drainage 63(5): 659-667. DOI: 10.1002/ird.1874
Pasquini AI, Lecomte KL, Piovano EL, et al. (2006) Recent rainfall and runoff variability in central Argentina. Quaternary International 158(1): 127-139. DOI: 10.1016/j.quaint.2006.05.021
Popova Z, Kercheva M, Pereira LS (2006) Validation of the FAO methodology for computing ET_o with limited data, application to South Bulgaria. Irrigation and Drainage Engineering 55: 201-215. DOI: 10.1002.ird.228
Rathore LS, Attri SD, Jaswal AK (2013) State level climate change trends in India. By India Meteorological Department, Ministry of Earth Sciences. Monograph no. ESSO/IMD/EMRC/02/2013.
Rahman H, Karuppaiyan R, Senapati PC, et al. (2012) An analysis of past three decade weather phenomenon in the mid-hills of Sikkim and strategies for mitigating possible impact of climate change on agriculture. In: Arrawatia ML et al. (eds.), Climate Change in Sikkim: Patterns, Impacts and Initiatives. Information and Public Relations Department, Government of Sikkim. Gangtok, India. pp 19-48.
Raziei T, Pereira LS (2013) Estimation of ET_o with Hargreaves-Samani and FAO-PM temperature methods for a wide range of climate in Iran. Agricultural Water Management 121: 1-18. DOI: 10.1016/j.agwat.2012.12.019
Schwartz P, Randall D (2003) An Abrupt Climate Change Scenario and Its Implications for United States National Security. In Diane Publishing, USA: Diane Publishing Co., 22. Available online at: http://www.futurebrief.com/dod-climate.pdf (Accessed on 25 July 2014)
Seetharam K (2008) Climate change scenario over Gangtok. Letter to the Editor. Meteorological Center, Gangtok. Indian Meteorological Department, India. Mausam 59(1): 361-366.
Shuttleworth WJ (1993) Evaporation. In: Maidment DR (ed.), Handbook of Hydrology. McGraw-Hill Inc., New York, NY, USA. pp 4.1-4.53.
Smith M (2000) The application of climatic data for planning and management of sustainable rainfed and irrigated crop production. Agricultural and Forest Meteorology 103(1-2): 99-108. DOI: 10.1016/S0168-1923(00)00121-0
Stanhill G (1998) Long-term trends in and spatial variation of solar irradiance in Ireland. International Journal of Climatology 18: 1015-1030. DOI: 10.1002/(SICI)1097-0088(199807)18:9<1015::AID-JOC297>3.0.CO;2-2
Stocker TF, Qin D, Plattner G-K, et al. (2013). IPCC Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, New York, USA.
Temesgen B, Eching S, Davidoff B, et al. (2005) Comparison of some reference evapotranspiration equations for California. Journal of Irrigation And Drainage Engineering 131(1): 73-84. DOI: 10.1061/(ASCE)0733-9437(2005)131:1(73).Todorovic M, Karic B, Pereira LS (2013) Reference evapotranspiration estimate with limited weather data across a range of Mediterranean Climates. Journal of Hydrology 481: 166-176. DOI: 10.1016/j.hydrol.2012.12.034
Trajkovic S (2007) Hargreaves versus Penman-Monteith under humid conditions. Journal of Irrigation and Drainage Engineering 133(1): 38-42. DOI: 10.1061/(ASCE)0733-9437(2007)133:1(38)
Trenberth KE, Fasullo JT, Kiehl J (2009) Earth's Global Energy Budget. Bulletin of the American Meteorological Society 90(3): 311–323. DOI: 10.1175/2008BAMS2634.1 (Accessed on 11 July 2014)
Wales-Smith BG (1980) Estimates of net radiation for evaporation calculations. Hydrological Sciences-Bulletin-des Sciences Hydrologiques 25(3): 237-242. DOI: 10.1080/02626668009491931
Willmott CJ, Ackleson SG, Davis RE, et al. (1985) Statistics for the evaluation of model performance. Journal of Geophysical Research: Oceans 90(C5): 8995-9005. DOI: 10.1029/JC090iC05p08995
Yoder RE, Odhiambo LO, Wright WC (2005) Evaluation of methods for estimating daily reference crop evapotranspiration at a site in the hunid southeast United States. Applied Engineering in Agriculture 21(2): 197-202. DOI: 10.13031/2013.18154
Yu YS, Zou S, Whittemore D (1993) Non parametric trend analysis of water quality data of rivers in Kansan. Journal of Hydrology 150(1): 61-80. DOI: 10.1016/0022-1694(93)90156-4
Yue S, Hashino M (2003) Temperature trends in Japan: 1900–1996. Theoretical and Applied Climatology 27: 15-27. DOI: 10.1007/s00704-002-0717-1
Zhang Y, Liu C, Tang Y, et al. (2007) Trends in pan evaporation and reference and actual evapotranspiration across the Tibetan Plateau. Journal of Geophysical Research 112: D12110. DOI: 10.1029/2006JD008161