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Study of Trends in Reference Evapotranspiration in the Himalayan Environment of Kashmir and Ranichauri, India

Zeenat Farooq[1], Rohitashw Kumar[1] and Deepak Jhajharia[2]

[1] Division of Agricultural Engineering, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Shalimar Campus, Srinagar-190025, Jammu and Kashmir, India

[2] Department of Agricultural Engineering, North Eastern Regional Institute of Science and Technology, Nirjuli, Itanagar-791109, Arunachal Pradesh, India.

ABSTRACT

As water resources are sensitive to climate change therefore climate change is receiving great attention. The main aim of this study was to explore changes in the Reference Evapotranspiration using the monthly, annual and seasonal data of Kashmir for the period of 20 years (1995-2014) and Ranichauri for the period of 28 years (1985-2012), site situated in Himalayas. In this study ET_0 was calculated by Penman Montieth Method on different time scales and trends analyses were performed with non-parametric statistics proposed by Mann-Kendall at different time scales. In Kashmir, on monthly basis, it is witnessed that statistically significant increasing trends are witnessed in ET_0 in the month of January, March, June, July, October, November and December (at the rate of 3.84, 11.94, 17.84, 13.58, 9.87, 8.23 and 4.27mm/decade, respectively) at 5% level of significance. Similarly, statistically significant increasing trend was witnessed in ET_0 in September (at the rate of 6.87mm/decade) at 10% significance level. Trend analysis on seasonal basis revealed that ET_0 in autumn season at the rate of 8.32 mm/decade and in winter season at the rate of 8.63 mm/decade witnessed statistically significant increasing trends only at 5% level of significance and on annual basis significant increasing trend was witnessed at 5% significance level at the rate of 8.61mm/decade. In case of Ranichauri, MK test revealed that statistically significant decreasing trend was witnessed in the month of January at the rate of 10.63 mm/decade, February 11.03 Mm/decade at the rate of, and November at the rate of 15.39 mm/decade at 5% significance level. On annual ETO at the rate of 65.1 mm/decade showed statistically decreasing trends at 5% significance level.

Keywords: Reference evapotranspiration; Penman-Monteith method; Mann-Kendall; trend; Kashmir; Ranichauri.

I.INTRODUCTION

Climate change is impacting every aspect of our life. These changes are not uniform but vary with space and time. As far as Himalayan regions are concerned, climate change has a direct impact on glaciers and snowmelt, thus need to be taken into consideration. ET_0 changes have direct impact influence on agriculture water use planning, irrigation system design and management. It is an important parameter for irrigation scheduling and water allocation. Many studies have been carried out in trend analysis of climate data. Jain and Kumar (2012) reviewed studies related to trends in rainfall, rainy days and temperature over India. They concluded that the Sen's non-parametric estimator of the slope has been frequently used to estimate the magnitude of the trend, whose statistical significance was assessed by the Mann–Kendall test. Jain *et al.* (2012) found rising trend in mean maximum temperature and mean minimum temperature for most of the stations over North east India. Falling trend in annual mean temperature is observed at some stations located in the North and Northeastern India. Chakraborty *et al.* (2013) analyzed trends for rainfall analysis over the Seonath basin during 1960 – 2008 using Mann Kendall and Spearman correlation trend detection tests. Both tests revealed decreasing trend in annual and seasonal rainfall series for the whole Seonath river basin. Changing trends were analyzed in rainfall over Nethravathi river basin, located in coastal region of Karnataka state by Babar and Ramesh (2013). Mann-Kendall (MK) test and Sens's slope estimator was used to determine trend and slope magnitude. Long-term analysis (1971 to2010) was carried out for both regions and results have been compared. Monthly precipitation trend has been identified hereto accomplish the objective which shows 40 years of data. From the analysis, it is found that there are decreasing trend of precipitation in some months and increasing trend in some other months. The statistical tests which are used in the study indicative of overall changes in precipitation trend during the south west monsoon.

Nenwiini and Kabanda (2013) analyzed trends and variability in rainfall of Vhembe District South Africa by Mann-Kendall trend analysis and Sen's slope estimator. They found that the direction of rainfall trend was, in general, downward and statically significant across the semi-arid zone. Statistically significant (downward) trends (95% to 99%) were observed in densely populated areas affected by urban sprawl, depleted vegetation cover, or other human development such as large-scale farming and construction.

Jhajharia *et al.* (2014) identified, trends in RET over Bikaner located in the Thar Desert (Rajasthan) in India using the non-parametric Mann–Kendall (MK) test. The results of this study revealed that the evapotranspiration decreases over Bikaner are controlled mainly by trends in the aerodynamic component, *i.e.* by the effects of significant wind speed decreases on RET, than the changes in the radiative component over the arid site located in the Thar Desert. Jhajharia *et al*. (2014) identified trends in pan evaporation (E_{pan}) and temperature was identified through the Mann-Kendall test over Jaisalmer to probe the existence of evaporation paradox in arid environments of Thar Desert, northwest India. Trends in rainfall, relative humidity, wind speed, and sunshine duration in the context of climate change were also identified. Decreasing trends in E_{pan} were witnessed over Jaisalmer in the months of January, June, October and November in the range of -2.04 to -4.1 mm $year^{-1.}$ Significant rainfall decreases were witnessed in the three crucial months of monsoon season, *i.e.*, July, August and September, in range of -0.23 to -1.25 mm $year^{-1}$. Increasing trends in mean temperature were witnessed corresponding to annual and monthly (January, April, September, October and November) time scales in the range of 0.03 to 0.07 °C $year^{-1}$. The simultaneous E_{pan} decrease and temperature rise at Jaisalmer confirmed the existence of evaporation paradox in the months of winter and post-monsoon seasons, which may be due to decreases in wind speed and bright sunshine hours. The increase in temperature along with decreases in E_{pan}, rainfall, sunshine duration, and wind speed over Jaisalmer may have far reaching consequences for the fragile ecosystem of the Thar Desert.

As there has been no previous study on trends of reference evapotranspiration rates for Himalayan region of

S.NO	REGION	LATITUDE	LONGITUDE	M.S.L
1	Kashmir	34.1	74.5	1524
2	Ranichauri	30.3	78.4	2200

Table 1: Location of study area

Kashmir and Ranichauri, the present study was carried out with the following objectives: (1) to estimate the reference evapotranspiration (ET_O) using the Penman-Monteith (PM) method in annual, seasonal and monthly time scales; (2) to investigate trends in the using the Mann–Kendall non-parametric test, and to obtain the magnitudes of trends through the linear regression test; (3) to identify the most dominating meteorological variables affecting the ET_O using the stepwise regression analysis

II.MATERIALS AND METHODS

Himalayas form the northern boundary of the country and covers an area of about 5 lakh km^2. Himalayas separate India, along its north-central and northeastern frontier, from China (Tibet), and extends between latitudes 26.20’ and 35.40’ North, and between longitudes 74.50’ and 95.40’ East.

In present study two Himalayan regions (Kashmir, Ranichauri) were taken into consideration. On the map of India, the State of Jammu and Kashmir is at the top and is 640 Km in length from north to south and 480 Km from east to west. The Ranichauri area located in Uttarakhand state is surrounded by Himachal Pradesh in the north-west and Uttar Pradesh in the south and shares its international borders with Nepal and China. The state of Uttarakhand covers twelve prominent ecological zones of the country. Uttarakhand has a total area of 53,483 km^2 of which 86% is mountainous and 65% is covered by forest.

METEOROLOGICAL DATA

The data sets used in the present study was obtained from Division of Agronomy Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir for the period of 20 years (1995-2014) and 28 years data (1985-2012) of Ranichauri.

METHODOLOGY

The present study focused on trend detection in RET using nonparametric test for the Himalayan region. The detailed methodology is given in following section.

Reference Evapotranspiration (RET)

The evapotranspiration rate from a reference surface, not short of water, is called the reference crop evapotranspiration or reference evapotranspiration and is denoted as ET_0. The concept of the reference evapotranspiration is introduced to study the evaporative demand of the atmosphere independently of crop type, crop development and management practices.

Many investigators have developed equations to estimate evapotranspiration. The most commonly used RET method, i.e. the Penman Monteith FAO-56, is selected for the present study, because it is physically based and explicitly incorporates both physiological and aerodynamic parameters (Xu et al. 2006), and is the most reliable and universally accepted method to estimate evapotranspiration under various types of climate. The PM FAO-56 model for computing the RET is given as (Allen *et al.*, 1998):

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_{2)}} \qquad (1)$$

where RET is the reference evapotranspiration ($mmday^{-1}$); Rn is the net radiation at the crop surface (MJm^{-2} $day^{-1)}$; G is the soil heat flux density (MJm^{-2} day^{-1}); T is the mean daily air temperature (°C); u_2 is the wind speed at a 2 m height above the ground ($m\ s^{-1}$); e_s is the saturation vapour pressure (kPa); e_a is the actual vapour pressure (kPa); es-ea is the saturation vapour pressure deficit (kPa); Δ is the slope of vapour pressure versus temperature curve at temperature T ($kPa°C^{-1}$); and is the psychrometric constant ($kPa°C^{-1}$).

Mann–Kendall methods for trend analysis

In the present study trend analysis was carried out using Mann Kendall test. It is a statistical test widely used for the analysis of trend in climate time series, because it is a non parametric test and does not require the data to be normally distributed and the test has low sensitivity to abrupt breaks due to inhomogeneous time series. According to this test, the null hypothesis H_0 assumes that there is no trend (the data is independent and randomly ordered) and this is tested against the alternative hypothesis H_1, which assumes that there is a trend.

The data values are evaluated as ordered time series. Each data value is compared to all subsequent data values.

The initial value of the Mann-Kendall statistic S is assumed to be 0. If a data value from a later time period is higher than a data value from an earlier time period, S is increased by 1. On the other hand, if the data value from the later time period is lower than a data valued sampled earlier, is decreased by 1. The net result of increments and

Let $x_1,x_2,x_3,\ldots\ldots,x_n$ represent n data points, then the Mann-Kendall test statistic S is given by;

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \mathrm{sgn}(x_j - x_i) \qquad (2)$$

Where n is the number of observations and x_j is the j^{th} observation and sgn (ɵ) is the sign function which can be defined as follows:

$$\mathrm{sgn}\,(\theta) = \begin{bmatrix} 1 \text{ if } \theta > 0 \\ 0 \text{ if } \theta = 0 \\ -1 \text{ if } \theta < 0 \end{bmatrix} \qquad (3)$$

Under the assumption that the data are independent and identically distributed, the mean and variance of the S statistic are given by (Kendall, 1975)

$$E(S) = 0 \qquad (4)$$

$$\frac{n(n-1)(2n+5) - \sum_{i=0}^{m} t_i(t_i - 1)(2t_i + 5)}{18} = V_S \qquad (5)$$

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

The Z-statistic can be computed as follows:

$$Z = \frac{S-1}{\sqrt{(\mathrm{var}(S)}} \quad \text{IF } S > 0 \qquad (6)$$

$$Z = 0 \text{ If } S = 0 \qquad (7)$$

$$Z = \frac{S+1}{\sqrt{(\mathrm{var}(S)}} \quad \text{if } S < 0 \qquad (8)$$

ESTIMATION OF MAGNITUDE OF TRENDS

In this study, the magnitude of the identified trends in the meteorological parameters was obtained through the parametric linear regression test, a commonly used parametric method.

The linear relationship between two variables is represented by a straight line, which is given as $y = m \times x + c$, where x denote the time variable, and m = slope of regression line and c = intercept. The slope obtained after plotting the graph of solar radiation and sunshine duration indicates the trend in the data, *i.e,* either positive or negative.

STEPWISE REGRESSION ANALYSIS

In order to identify the dominant variables among the independent variables associated with changes in dependent variable, in that case stepwise regression method is applied. In this study, reference evapotranspiration rate is the dependent variable and various meteorological parameters are the independent variables. Regression is performed between dependent variable (ET_0) and meteorological parameters that influence the dependent variable *i.e.* maximum and minimum temperatures, sunshine duration, relative humidity and wind speed.

In present study Addinsoft's XLSTAT2014 and SPSS 16.0 Software have been used for performing the statistical Mann-Kendall test. The null hypothesis is tested at 95% and 90% confidence level for all the parameters in all the three regions of Himalayas.

RESULTS AND DISCUSSION

The monthly data were used to compute seasonal and annual time series of Himalayan region. Four seasons of the study area were taken as Spring (March-April), Summer (May-August), Autumn (September-November), Winter (December-February).In this study, the trend analysis of RET (ET_0) determined by Penman Montieth method were analyzed using Mann Kendall (MK) and linear regression tests at 5% and 10% level of significance for all the three sites of Himalayan region. A brief summary of results is as follows:

REFERENCE EVAPOTRANSPIRATION (RET) FOR SRINAGAR (KASHMIR REGION)

Trend of different climatic parameters were carried out on monthly basis. The value of ET_0 during 1995 to 2014 was determined using Penman Montieth method. It is clear from Table 2 that the maximum and minimum valves of RET (ET_0) were found to be 150.9 mm in the month of July and 17.8mm in the month of December, respectively. Overall in each month ET_0 has increased gradually from 1995 to 2014. Over annual time scale, the average of total ET_0 was found to be 855.5mm. Overall gradual increase in ET_0 was witnessed. From Table 3 it is clear that on seasonal basis maximum and minimum value of RET (ET_0) was found to be in summer season with an average of 117.3mm and autumn season with an average of 56.3mm, respectively and on annual basis highest and lowest value of ET_0 was found to be 998mm in 2009 and 654.2mm in 1996, respectively.

Table 2: Values of ET0 on monthly and annual basis of Srinagar (Kashmir region)

YEAR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1995	*18.4*	*24.9*	*40.9*	*62.7*	*83.3*	*94.8*	*108.9*	*95.0*	*59.3*	*41.7*	*23.5*	*19.3*	*672.7*
1996	*19.1*	*25.8*	*42.6*	*63.2*	*77.7*	*92.8*	*101.3*	*85.5*	*67.7*	*38.2*	*22.7*	***17.8***	***654.2***
1997	*23.1*	*41.1*	*55.7*	*89.5*	*112.5*	*130.4*	***150.9***	*127.9*	*109.7*	*64.1*	*42.2*	*26.6*	*973.6*

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1998	*24.4*	*35.6*	*52.1*	*80.9*	*87.7*	*88.7*	*93.6*	*91.4*	*60.0*	*48.8*	*32.3*	*24.4*	*719.8*
1999	*19.8*	*27.6*	*49.1*	*81.5*	*109.5*	*130.8*	*129.3*	*112.0*	*87.0*	*52.1*	*28.8*	*22.3*	*849.6*
2000	*21.3*	*30.4*	*50.1*	*84.0*	*126.7*	*132.2*	*118.6*	*110.2*	*80.2*	*49.4*	*28.3*	*22.8*	*854.2*
2001	*24.4*	*31.7*	*54.4*	*78.1*	*127.8*	*123.6*	*125.5*	*113.9*	*79.8*	*49.8*	*28.9*	*21.6*	*859.4*
2002	*23.2*	*27.4*	*54.6*	*73.7*	*114.2*	*136.4*	*130.5*	*111.0*	*76.8*	*50.4*	*28.4*	*20.9*	*847.5*
2003	*23.2*	*29.2*	*50.1*	*77.8*	*98.6*	*128.4*	*138.5*	*103.2*	*78.7*	*51.2*	*27.1*	*21.9*	*827.7*
2004	*22.0*	*24.4*	*42.7*	*57.4*	*82.9*	*102.0*	*121.8*	*109.0*	*67.6*	*43.7*	*25.3*	*20.9*	*719.7*
2005	*21.4*	*24.3*	*45.8*	*65.2*	*88.1*	*101.9*	*115.9*	*99.8*	*68.4*	*40.7*	*22.9*	*18.4*	*712.7*
2006	*21.3*	*36.8*	*61.2*	*96.0*	*136.6*	*132.6*	*139.4*	*108.4*	*81.1*	*60.9*	*35.4*	*24.8*	*934.2*
2007	*32.4*	*35.5*	*62.7*	*111.9*	*121.0*	*133.3*	*136.1*	*118.3*	*84.6*	*68.6*	*39.6*	*28.9*	*972.8*
2008	*23.9*	*34.9*	*80.4*	*87.6*	*101.4*	*137.7*	*134.9*	*108.3*	*85.7*	*59.7*	*59.7*	*28.4*	*942.5*
2009	*29.2*	*38.8*	*64.5*	*91.3*	*128.7*	*133.7*	*142.9*	*137.0*	*97.9*	*66.7*	*38.1*	*29.4*	***998.0***
2010	*34.2*	*32.9*	*78.9*	*86.1*	*102.3*	*121.5*	*138.5*	*105.1*	*96.4*	*67.8*	*43.5*	*29.5*	*936.6*
2011	*27.5*	*32.1*	*69.0*	*81.6*	*138.3*	*151.7*	*131.9*	*118.6*	*88.1*	*62.7*	*35.9*	*30.7*	*968.0*
2012	*22.6*	*34.4*	*65.1*	*82.6*	*113.3*	*129.2*	*136.6*	*108.1*	*78.3*	*56.3*	*37.4*	*27.6*	*891.4*
2013	*29.8*	*34.1*	*68.4*	*78.2*	*114.8*	*139.4*	*143.6*	*105.8*	*85.0*	*61.8*	*28.7*	*25.5*	*915.1*
2014	*20.1*	*33.2*	*44.7*	*75.1*	*95.7*	*135.4*	*129.6*	*114.3*	*79.1*	*59.3*	*48.4*	*25.0*	*859.9*

Table 3: Values of ET0 on seasonal basis of Srinagar (Kashmir region)

Year	Spring	Summer	Autumn	Winter
1995	51.8	95.5	41.5	56.1
1996	52.9	89.3	42.9	54.5
1997	72.6	130.4	72.0	81.1
1998	66.5	90.4	47.0	60.0
1999	65.3	120.4	56.0	70.8
2000	67.1	121.9	52.6	71.2
2001	66.2	122.7	52.8	71.6
2002	64.2	123.0	51.9	70.6
2003	63.9	117.2	52.3	69.0

2004	50.1	103.9	45.5	60.0
2005	55.5	101.4	44.0	59.4
2006	78.6	129.2	59.1	77.9
2007	87.3	127.2	64.3	81.1
2008	84.0	120.6	68.4	78.5
2009	77.9	135.6	67.6	83.2
2010	82.5	116.9	69.2	78.0
2011	75.3	135.1	62.2	80.7
2012	73.8	121.8	57.3	74.3
2013	73.3	125.9	58.5	76.3
2014	59.9	118.8	62.3	71.7

TREND AND SLOPE ANALYSIS FOR SRINAGAR (KASHMIR REGION)

The statistical analysis of reference evapotranspiration was carried out using MK Test which is summarized in Table 4. The trends of different parameters are graphically represented during 1995-2014. It is witnessed from Fig. 1 (a-f) that statistically significant increasing trends are witnessed in ET_0 in the month of January, March, June, July, October, November and December (at the rate of 3.84, 11.94, 17.84, 13.58, 9.87, 8.23 and 4.27mm/decade, respectively at 5% level of significance as the values of Z (test statistics) obtained through the MK test are more than 1.96. The values of Z statistics with p-value in parenthesis obtained by Mann Kendall test for all the parameters on monthly and annual time scales are tabulated in Table 4. Similarly, statistically significant increasing trend was witnessed in ET_0 in September (at the rate of 6.87mm/decade at 10% significance level as the Z value is more than 1.65 and less than 1.96. However, the remaining months witnessed no statistically significant trends in ET_0 at 5% level of significance as the Z values are between +1.96 and -1.96 (or at 10% level of significance as the Z values are between +1.65 and -1.65).

Table 4: The value of test Statistics (z) obtained through Mann-Kendall test on monthly and annual basis

Months	ET0 (mm) Kashmir	Eto (mm) Ranichauri
January	2.142 (0.032)	-2.253 (0.024)
February	1.071 (0.288)	-3.557 (0.000)
March	2.823 (0.004)	-1.265 (0.206)
April	0.811 (0.422)	0.672 (0.502)

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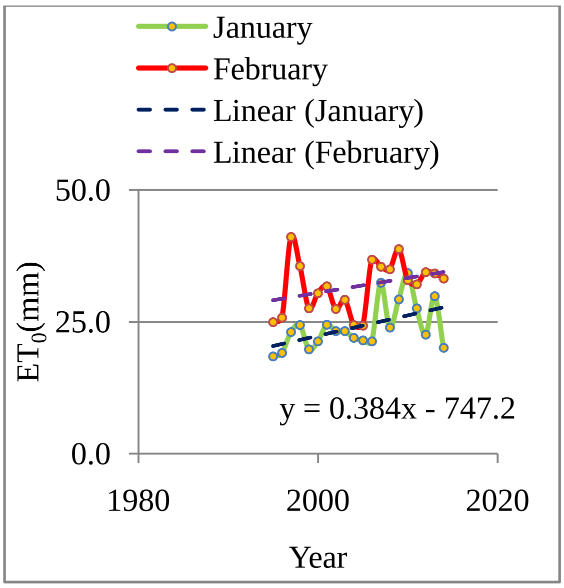
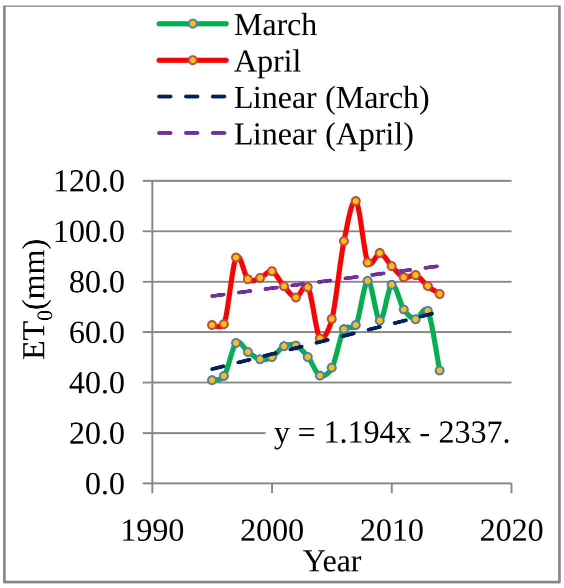
May	1.590 (0.113)	-1.166 (0.247)
June	2.758 (0.101)	0.593 (0.553)
July	2.272 (0.023)	0.217 (0.830)
August	0.876 (0.386)	-0.632 (0.527)
September	1.66* (0.098)	-1.127 (0.260)
October	2.433 (0.014)	-1.626 (0.105)
November	2.044 (0.040)	-4.011 (0.0001)
December	2.498 (0.011)	-1.067 (0.138)
Annual	2.478 (0.040)	-2.272 (0.189)

Note: Bold values denote statistically significant at 5% level of significance. Bold values with * denote statistically significant at 10% level of significance. Italic values are cases of no trends (statistically non-significant even at 10% level of significance).



(a)



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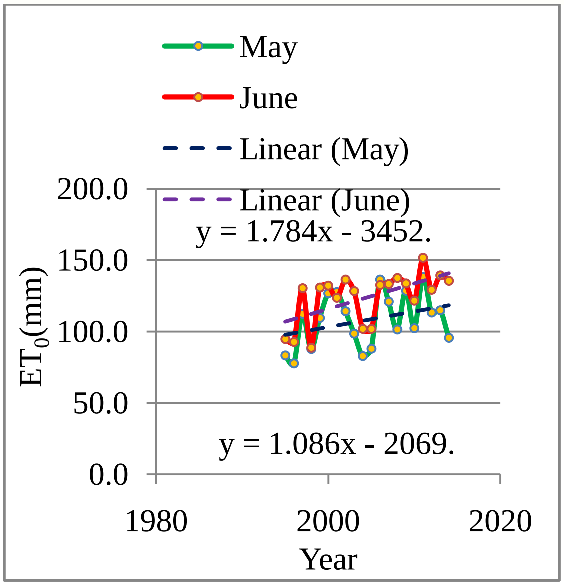

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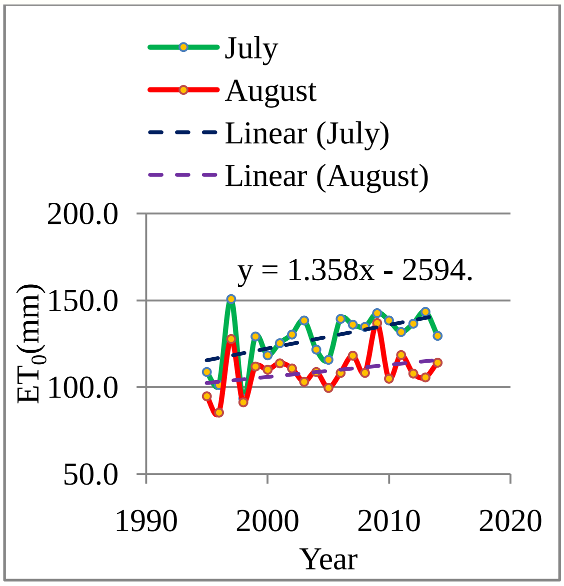

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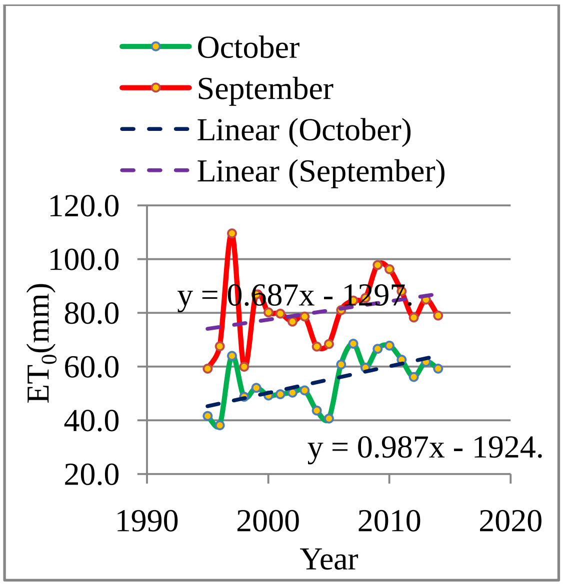

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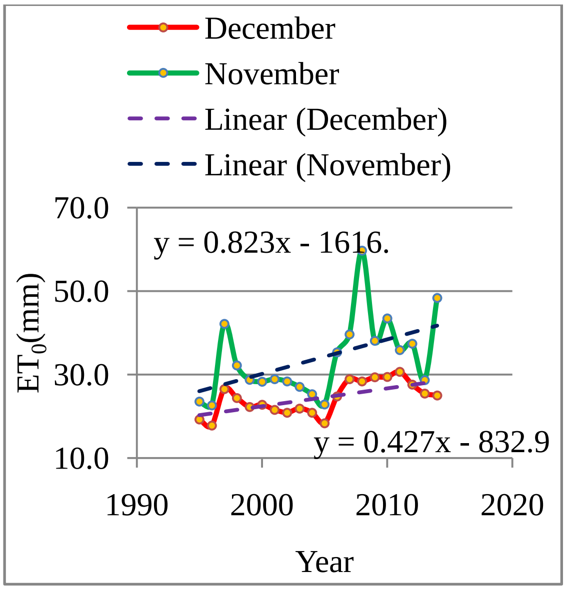

(f)

Fig 1 (a-f): Time series of ET_0 on monthly basis with linear trend lines of Srinagar

On annual basis the trend was analysis. It is evident from Table 4 that ET_0 witnessed statistically significant increasing trend at 5% significance level as the value of Z statistics is greater than 1.96. (Kashmir)

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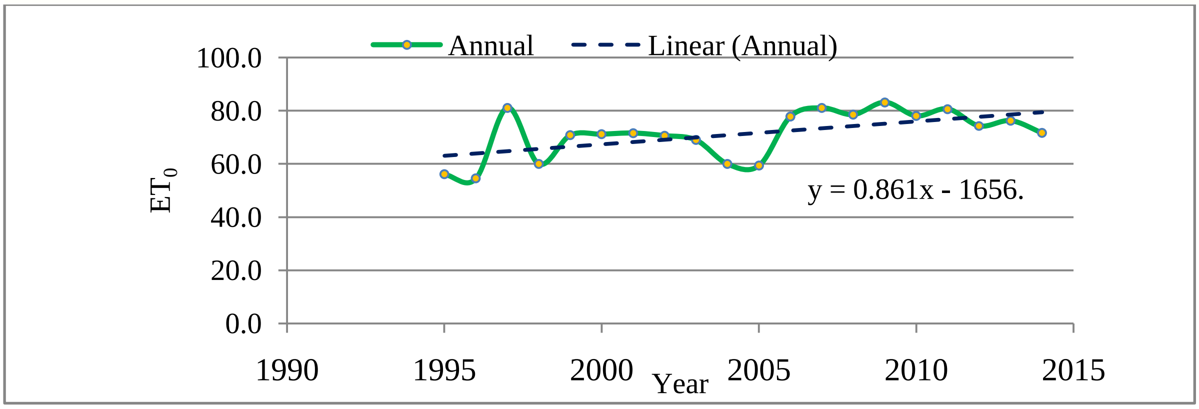


Fig. 2 (a-f): Time series of ET_0 on annual basis with linear trend lines of Srinagar

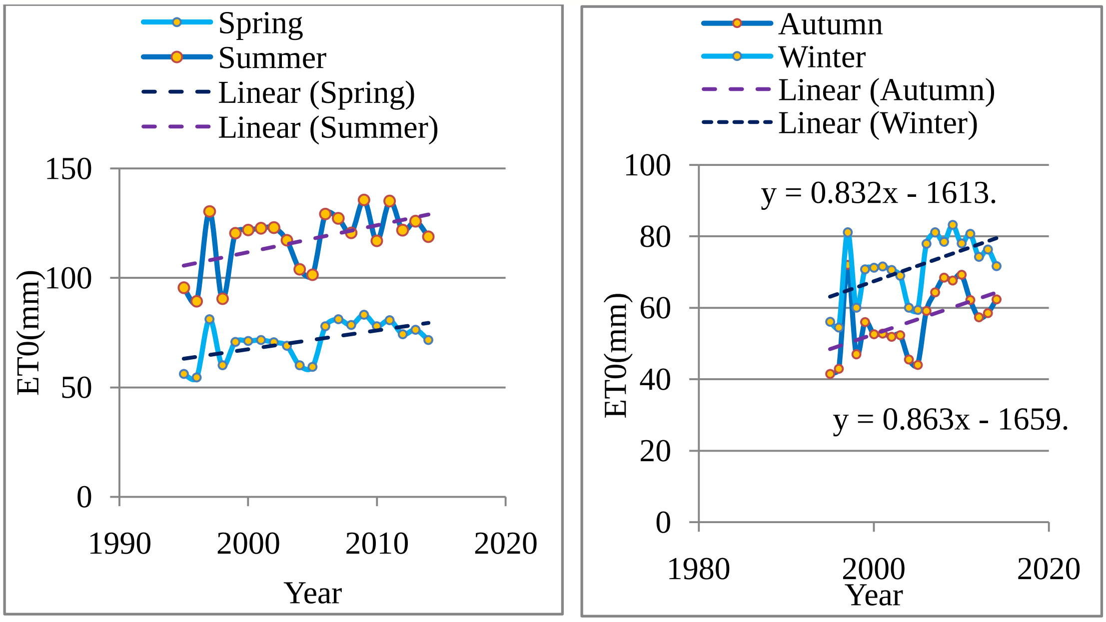
The statistical analysis on the basis of different seasons is also carried out. The values of Z statistics with p-value in parenthesis obtained by Mann Kendall test for all the parameters on seasonal basis are summarized in Table 5.

Table 5: Test statistics (Z) values obtained through the Mann-Kendall test on seasonal basis

Seasons	Et_0 (mm) Kashmir	Eto (mm) Ranichauri
Spring	*1.330* *(0.105)*	-1.442 (0.236)
Summer	*1.720* *(0.113)*	0.533 (0.730)
Autumn	***2.304*** ***(0.020)***	-0.257 (0.109)
Winter	***2.142*** ***(0.035)***	-0.790 (0.139)

Note: Bold values denote statistically significant at 5% level of significance. Italic values are cases of no trends at 5% level of significance

The time series of ET_0 on seasonal basis with linear trend lines is shown in Fig. 3 (a-b). Trend analysis on seasonal basis revealed increasing trend in ET_0 in autumn season at the rate of 8.32 mm/decade and in winter season at the rate of 8.63 mm/decade



(a) (b)

Fig. 3 (a-b): Time series of ET_0 on seasonal with linear trend lines

Ranichauri

The RET value determined on monthly basis is summarized in Table 6. It is evident from Table 6 that the maximum and minimum values of ET0 were found to be 185.7mm in the month of May and 34.1 mm in the month of December, respectively. Overall in each month ET_0 has increased gradually.

Table 6: Values of ET0 on monthly and annual basis of Ranichauri

YEAR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1985	*71.7*	*69.6*	*102.2*	*119.9*	*149.9*	*157.3*	*109.6*	*79.6*	*71.9*	*94.6*	*122.1*	*85.0*	*1233.4*
1986	*94.5*	*84.8*	*114.7*	*123.3*	*183.9*	*130.7*	*99.9*	*102.3*	*110.3*	*119.1*	*109.8*	*78.1*	*1351.4*
1987	*90.6*	*94.2*	*137.3*	*132.9*	***185.7***	*143.6*	*154.8*	*82.8*	*110.3*	*141.5*	*128.8*	*111.8*	***1514.3***
1988	*86.8*	*79.9*	*111.0*	*124.0*	*171.7*	*108.1*	*94.8*	*102.8*	*76.7*	*87.6*	*85.0*	*55.5*	*1183.9*
1989	*51.4*	*60.5*	*94.9*	*129.4*	*149.3*	*150.5*	*92.6*	*120.9*	*105.4*	*115.8*	*79.8*	*56.8*	*1207.3*
1990	*70.6*	*54.4*	*52.3*	*93.9*	*124.9*	*136.3*	*89.8*	*103.4*	*69.3*	*57.1*	*66.0*	*48.6*	***966.6***

1991	*93.4*	*82.4*	*131.9*	*110.3*	*112.4*	*98.1*	*76.8*	*89.8*	*115.2*	*89.2*	*79.4*	*68.2*	*1147.1*
1992	*69.3*	*76.3*	*102.8*	*116.3*	*98.3*	*117.1*	*88.5*	*76.8*	*102.8*	*77.5*	*74.3*	*71.5*	*1071.5*
1993	*44.9*	*59.0*	*87.7*	*119.5*	*132.7*	*155.8*	*84.9*	*103.1*	*73.4*	*64.9*	*58.6*	***34.1***	*1018.6*
1994	*58.9*	*52.9*	*112.3*	*128.2*	*166.6*	*161.7*	*114.2*	*84.2*	*89.3*	*99.7*	*73.8*	*56.7*	*1198.5*
1995	*46.1*	*51.6*	*89.0*	*118.9*	*163.2*	*130.7*	*105.4*	*82.0*	*88.7*	*92.3*	*71.2*	*54.4*	*1093.5*
1996	*48.8*	*57.7*	*91.1*	*128.4*	*166.0*	*133.9*	*105.7*	*91.0*	*79.5*	*86.1*	*69.5*	*44.1*	*1101.8*
1997	*51.8*	*58.1*	*89.5*	*108.2*	*150.1*	*154.2*	*102.5*	*86.6*	*83.8*	*77.1*	*51.9*	*63.6*	*1077.4*
1998	*48.7*	*53.5*	*80.8*	*126.6*	*160.0*	*138.2*	*108.5*	*99.6*	*85.4*	*79.3*	*69.0*	*56.6*	*1106.2*
1999	*50.1*	*58.3*	*113.7*	*154.2*	*156.7*	*116.1*	*106.4*	*80.5*	*77.2*	*88.3*	*69.3*	*59.3*	*1130.1*
2000	*50.0*	*43.0*	*88.2*	*136.1*	*144.6*	*116.5*	*92.0*	*94.8*	*85.1*	*88.9*	*60.4*	*54.8*	*1054.4*
2001	*53.6*	*62.3*	*93.0*	*117.2*	*143.1*	*137.6*	*106.1*	*84.0*	*98.4*	*69.3*	*57.2*	*57.3*	*1079.1*
2002	*47.2*	*47.7*	*94.2*	*123.3*	*157.6*	*116.1*	*129.5*	*93.0*	*86.8*	*90.2*	*65.4*	*50.4*	*1101.4*
2003	*56.3*	*49.0*	*86.7*	*127.7*	*154.8*	*154.2*	*112.0*	*91.3*	*77.6*	*96.7*	*65.2*	*61.5*	*1133.0*
2004	*58.4*	*51.3*	*99.4*	*122.4*	*167.3*	*158.6*	*118.8*	*97.8*	*70.2*	*83.4*	*62.3*	*63.4*	*1153.3*
2005	*43.9*	*42.0*	*88.3*	*129.0*	*151.5*	*100.3*	*92.9*	*96.7*	*79.1*	*83.0*	*70.9*	*60.1*	*1037.7*
2006	*77.7*	*75.3*	*104.2*	*126.4*	*117.3*	*135.4*	*87.9*	*107.1*	*89.9*	*83.2*	*66.1*	*59.1*	*1129.6*
2007	*61.4*	*48.9*	*90.0*	*128.9*	*139.5*	*104.4*	*108.0*	*85.9*	*88.8*	*79.4*	*63.4*	*63.5*	*1062.1*
2008	*46.5*	*51.4*	*102.8*	*120.2*	*138.6*	*168.0*	*93.7*	*105.3*	*91.8*	*83.9*	*66.8*	*56.2*	*1125.2*
2009	*60.1*	*64.0*	*97.2*	*139.2*	*147.1*	*148.1*	*116.2*	*78.2*	*85.1*	*87.0*	*64.1*	*56.8*	*1143.1*
2010	*62.6*	*57.4*	*105.3*	*140.8*	*156.0*	*108.5*	*96.6*	*79.4*	*66.6*	*79.7*	*64.0*	*41.6*	*1058.5*
2011	*48.7*	*47.7*	*92.2*	*108.6*	*138.8*	*161.6*	*85.0*	*76.8*	*79.4*	*79.8*	*49.8*	*52.8*	*1021.2*
2012	*33.9*	*40.2*	*72.9*	*103.8*	*158.5*	*168.3*	*104.2*	*91.2*	*82.6*	*87.0*	*64.8*	*63.9*	*1071.3*

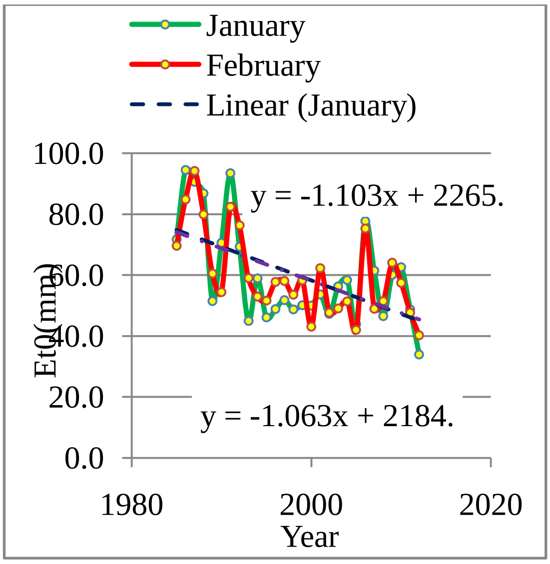
The RET value of different seasons are also determined and illustrate in Table 7. On seasonal maximum and minimum value of $ET_0$was found to be in summer season with an average of 120.2mm and in winter season with an average of 59.9mm respectively. And on annual basis highest and lowest value of ET_0 was found to be 1514mm in 1987 and 966.6mm in 1990 respectively. Over annual time scale, the average of total ET_0 was found to be 1127.6mm. Overall ET_0 varies ranging between 1000-1300mm.

Table 7: Values of ET0 on seasonal basis of Ranichauri

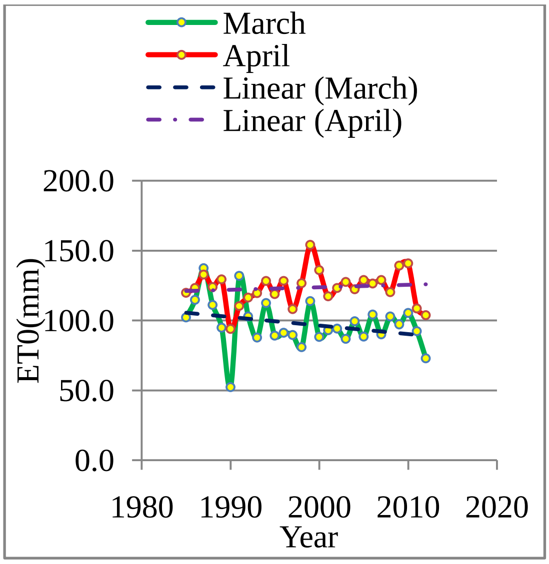
Year	*Spring*	*Summer*	*Autumn*	*Winter*
1985	*111.1*	*124.1*	*96.2*	*75.4*
1986	*119*	*129.2*	*113.1*	*85.8*
1987	*135.1*	*141.7*	*126.1*	*98.9*
1988	*117.5*	*119.4*	*83.1*	*74.1*
1989	*112.2*	*128.3*	*100.3*	*56.2*
1990	*73.1*	*113.6*	*64.1*	*57.9*
1991	*121.1*	*94.3*	*94.6*	*81.3*
1992	*109.6*	*95.2*	*84.9*	*72.4*
1993	*103.6*	*119.1*	*65.6*	*46*
1994	*120.3*	*131.7*	*87.6*	*56.2*
1995	*104*	*120.2*	*84.1*	*50.7*
1996	*109.8*	*124.2*	*78.4*	*50.2*
1997	*98.9*	*123.4*	*70.9*	*57.8*
1998	*103.1*	*126.6*	*77.9*	*52.9*
1999	*134*	*114.9*	*78.3*	*55.9*
2000	*112.1*	*112*	*78.1*	*49.3*
2001	*105.1*	*117.7*	*75*	*57.7*
2002	*108.8*	*124.1*	*80.8*	*48.4*
2003	*107.2*	*128.1*	*79.8*	*55.6*
2004	*110.9*	*138.6*	*72.5*	*57.7*
2005	*108.7*	*110.4*	*77.7*	*48.7*
2006	*109.5*	*111.9*	*79.7*	*70.7*
2007	*111.5*	*109.5*	*77.2*	*57.9*
2008	*118.2*	*126.4*	*80.8*	*51.4*
2009	*123.1*	*122.4*	*78.7*	*60.3*
2010	*100.4*	*110.1*	*70.1*	*53.9*
2011	*88.4*	*115.6*	*69.7*	*49.7*
2012	*89.3*	*130.6*	*78.1*	*46*

Trend and Slope Analysis

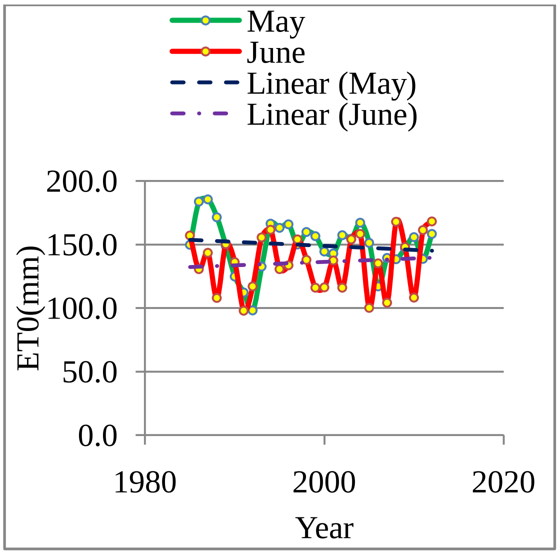
In case of ET_0 MK test revealed that statistically significant decreasing trend was witnessed in the month of January at the rate of 10.63 mm/decade, February 11.03 Mm/decade at the rate of, and November at the rate of 15.39 mm/decade at 5% significance level (Table 4). However no significant trends were observed in other months at 5 % significance level. Fig 4 represents time series of ET_0 with linear trend lines.



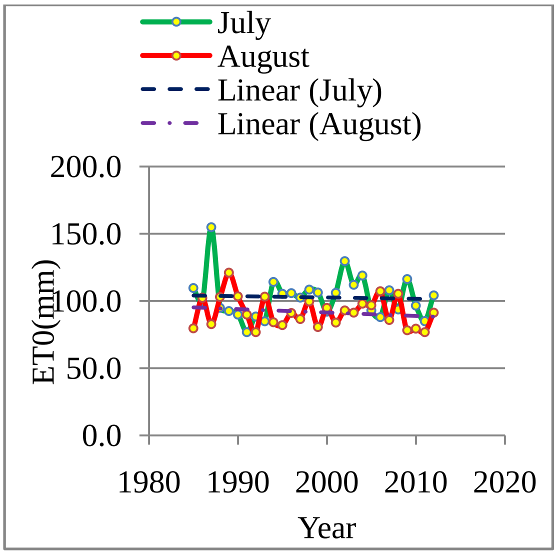
(a)



(b)



(c)



(d)

IJARSE
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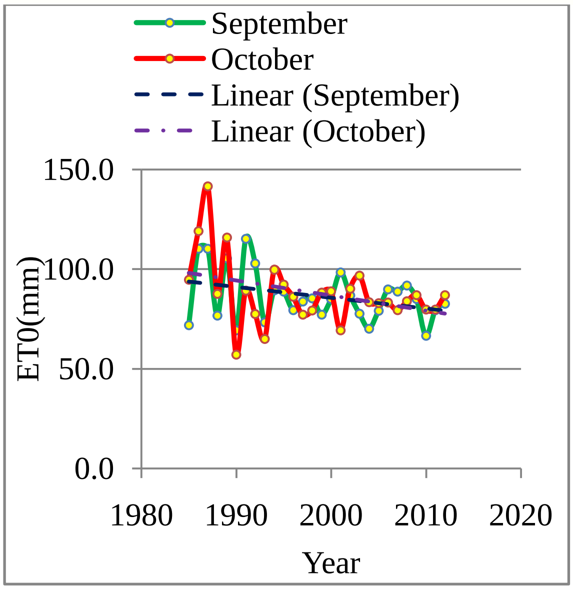
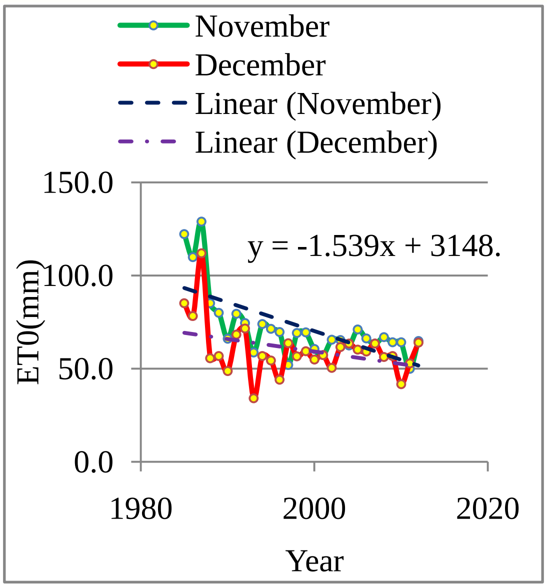


(e)

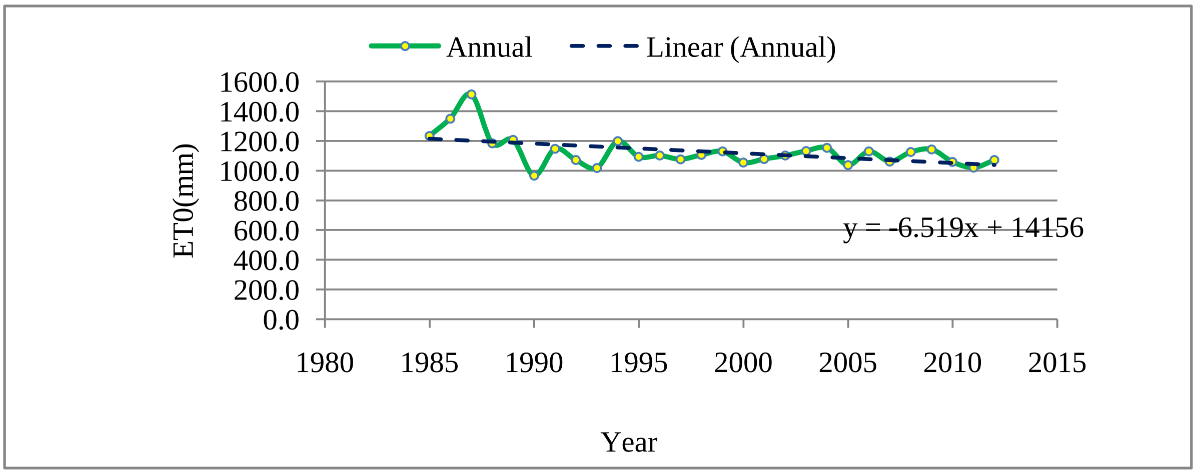


(f)

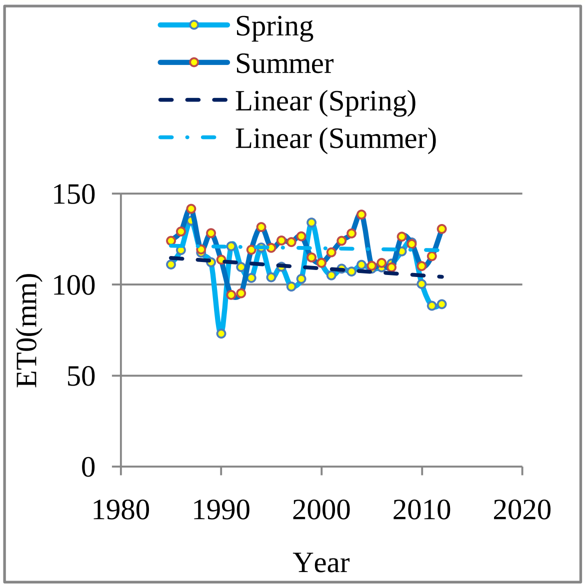
Fig.4 (a-f): Time series of ET_0 on monthly basis with linear trend line

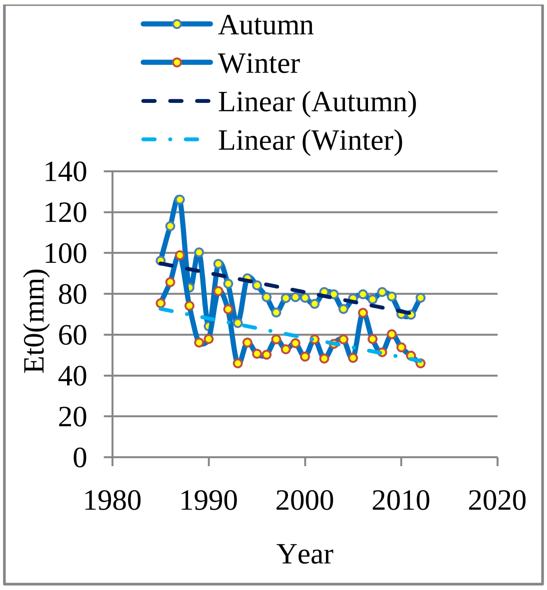
On annual basis, ETO at the rate of 65.1 mm/decade showed statistically decreasing trends at 5% significance level as the value of z statistic is more than 1.96

Fig 5 (a-f): Time series of ET_0 on annual basis with linear trend lines of Ranichauri



It is evident from Table 5 that no statistically significant trends are witnessed in any season in ET_0 and evaporation as the Z values are between +1.96 and -1.96 (Table 1.3).





(a) (b)

Fig 6 (a-b): Time series of ET_0 on seasonal with linear trend lines

IDENTIFICATION OF THE MOST DOMINATING METEOROLOGICAL VARIABLES AFFECTING ET_0

In order to identify the dominant variables associated with ET_O, the procedure of Stepwise Regression Analysis was used over both the Himalayan regions. Stepwise regression analysis was performed between ET_O and all the meteorological parameters for monthly, annual and seasonal time scales by using SPSS. While performing the stepwise regression analysis, ET_O was selected as a dependent variable and all the remaining climatic parameters as independent variables in order to look for the possible climatic parameters responsible for the ET_O changes in monthly, annual and seasonal time scales, and the results are shown in Table.8.

On probing the causal meteorological parameters responsible for the observed ET_O trends, it was found that for Kashmir, wind speed, sunshine and maximum temperature dynamically influenced the observed ET_O changes at the monthly and annual time scale whereas sunshine and wind speed are main factors affecting ETO at seasonal time scale in Kashmir region. In case of Ranichauri wind speed is the main meteorological factor effecting ET_0. It is interesting to note that the max relative humidity has negligible influence on the observed trends in ET_O for the annual duration and for all the months over Kashmir and Ranichauri regions of Himalayas.

Table 8: Results of stepwise linear regression for Kashmir region

Time scale	T_{min}	T_{max}	sunshine	Wind	RH_{max}	evaporation	rainfall
Jan	-	1	-	-	-	-	-
Feb	-	-	1	-	-	-	-
Mar	-	1	-	-	-	-	-
Apr	-	-	1	2	-	-	-
May	-	3	1	2	-	-	-
Jun	-	-	1	2	-	-	1
Jul	-	-	-	-	-	1	-
Aug	-	3	4	2	-	1	-
Sep	-	3	2	1	-	-	-
Oct	-	3	1	2	-	-	-
Nov	-	2	-	1	-	-	-
Dec	-	-	-	-	-	-	-
Annual	-	3	1	3	-	-	-
Spring	-	-	1	2	-	-	-
Summer	-	-	-	-	2	-	1
Autumn	-	-	2	1	-	-	-
Winter	-	-	1	-	-	-	-

Table 9: stepwise linear regression for Ranichauri region

Time scale	T_{min}	T_{max}	sunshine	Wind	RH_{max}	evaporation	rainfall
January	-	-	-	2	1	-	-
Febuary	-	3	-	2	1	-	-
March	-	-	-	1	-	-	2
April	-	1	-	-	-	-	-
May	-	-	2	1	-	-	-
June	3	2	-	1	-	-	-
July	-	1	-	-	-	-	-
August	-	-	-	1	-	-	-
Sepetember	-	2	-	1	-	-	-

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Octomber	-	-	1	-	-	-	-
November	-	-	1	-	-	-	-
December	-	-	1	-	-	-	-
Annual	-	3	2	1	-	4	-
Spring	-	-	-	1	-	-	-
Summer	-	-	-	-	-	1	-
Autumn	-	2	1	-	-	-	-
Winter	-	-	-	1	2	-	-

Summary and conclusion

5.1 GENERAL

In this study an attempt has been y to estimate the trends in reference evapotranspiration (calculated by Penman-Monteith FAO-56 method), on monthly, seasonal, and annual basis over different climatic conditions of Himalayas because of the importance of these parameters in water balance studies, irrigation planning, planning and operation of reservoirs. The trends in different climatic Parameters were investigated using the non parametric Mann-Kendall (MK) test. Magnitude of trends were analyzed by linear regression and stepwise linear regression which was performed to order to identify the dominant variables associated with reference evapotranspiration (ET_0), the procedure of Stepwise Regression Analysis was used to search for and possibly explain the underlying mechanisms of observed ET_0 changes under the Himalayan region. Stepwise regression analysis was performed between ET_0 and all the meteorological parameters for annual and seasonal time scales by using SYSTAT.

CONCLUSIONS

The conclusions drawn from the study are summarized as follows:

1. Overall trend in Et0 have been found to be minimum in January (winter) and then it gradually increases and reaches its peak value in July (summer) and then again decreases.

2. On annual basis it has found to be maximum in 2009 and minimum in year 1996 in Kashmir whereas in Ranichauri it has found to be maximum in year 1987 and min in 1990. Overall it has increased from 1985 to 2012.

3. An increasing trend has been witnessed in case of ET0 in seven months (January, March, June, July, October, November and December) at 5% significance level. In the month of September increasing trend was has been observed at 10% significance level.

4. Trend analysis on seasonal basis revealed that only ET_0 (autumn and winter season) witnessed statistically significant increasing trends only at 5% level of significance
5. In Ranichauri statistically significant decreasing trend has been witnessed in the month of January, February, and November at 5 % significance level.

On examining the results of stepwise regression to determine the meteorological parameters responsible for the observed ETO changes, wind speed followed by sunshine duration, and temperature were found to be the main causative variables of the observed changes in the ETO over Kashmir and wind speed in Ranichauri in the annual time scale. In this study, it has been found that the change in the aerodynamic component, i.e., wind speed, is the main factor responsible for the observed ETO changes than the radiative component in Ranichauri but in case of Kashmir wind and sunshine both are responsible for observed eto changes).

SCOPE FOR FUTURE RESEARCH

On the account of the observed trends in ET0 and other climatic parameters at various regions in Himalayas, a change in the water demand of various sectors, like, agriculture, reservoir operation, etc., expected to take place in most parts of Himalayas. It will become highly imperative for the irrigation planners in Himalayas to adopt some suitable policy for the future development of agriculture and water resources in Himalayas on the account of the anthropogenic-induced global warming.

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