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***Short Communication***

# Trend of reference evapotranspiration under climate change in Himalayan region, India

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Climate change is occurring globally (IPCC, 2007) and is alleged to cause changes in climatic variables, such as relative humidity, precipitation, air temperature, and solar radiation and in the hydrological cycle by affecting precipitation and evaporation (Yu *et al.,* 2013). These changes also affect crop evapo-transpiration and have major implications for irrigation management and crop production (Zhang *et al.,* 2011; Li *et al.,* 2016). The cryospheric processes and the hydrology of headwater catchments are immensely affected by changes in precipitation (Immerzeel *et al.,* 2012; Kesava Rao *et al.,* 2013; Lone *et al.,* 2020). Climate variability impacts the hydrological cycle especially evapotranspiration (ET) and soil moisture, which plays a crucial role in determining water flux of an agriculture system (Tyagi *et al.,* 2019). Reference evapotranspiration (ETo) and soil moisture deficit are vital for understanding the hydrological processes, particularly in the context of sustainable water use efficiency in the globe (Srivastava *et al.,* 2017). Precise estimation of ETo is required for developing appropriate forecasting systems, in hydrological modeling and also in precision agriculture.

Evapo-transpiration is an important parameter to study the impact of the changing climate; it can easily reflect the effect of the changing dynamics of the meteorological parameters. Accurate estimation of evapotranspiration is generally constrained due to lack of required hydro meteorological data sets (Srivastava *et al.,* 2020; Purnadurga *et al.,* 2019). The main objectives of the study to estimate trends in reference evapo-transpiration (ETo) using Mann–Kendall (non-parametric) test, and obtain the magnitudes of trends through linear regression test.

In the present study two Himalayan regions (Kashmir and Ranichauri) were considered. The Srinagar city is located at an attitude of 1585 m, 34.50$^{0}$N latitude and 74.40 $^{0}$E longitudes and Ranichauri is located at 30.3$^{0}$N latitude and 78.4$^{0}$E longitudes. Meteorological data was obtained from the Division of Agronomy Sher-e-Kashmir Agricultural Sciences and Technology of Kashmir (SKUAST-Kashmir) for the period of 20 years (1995-2014) for Kashmir and for the period of 28 years (1985-2012) for Ranichauri. Trend analysis of the different parameters was carried out on monthly, seasonal and annual basis.

### *Reference evapo-transpiration (ETo)*

The most reliable and universally accepted method, i.e. the Penman-Monteith FAO-56 (P-M), was used to calculate ETo (Allen *et al.,* 1998):

$$ET_0 = \frac{0.408\Delta(R_n - G) + \frac{900}{T+273}u_2(e_s - e_a)}{\Delta + y(1+0.34u_2)} \quad (1)$$

where ETo is the reference evapo-transpiration (mmday$^{-1}$); Rn is the net radiation at the crop surface (MJ m$^{-2}$ 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); $e_s$-$e_a$ is the saturation vapour pressure deficit (kPa); Δ is the slope of vapour pressure versus temperature curve at temperature T (kPa°C$^{-1}$); and y is the psychometric constant (kPa°C$^{-1}$).

Mann Kendall test was used for deciphering trend of climate time series. It is a nonparametric test and does not require the data to be normally distributed and has low sensitivity to abrupt breaks due to inhomogeneous time series (Kendall, 1975)

### *Estimation of magnitude of trends*

The magnitude of identified trends in a meteorological parameter was obtained through the parametric linear

**Table 1:** The value of test statistics (Z) obtained through Mann-Kendall test on monthly and annual bases

| Months | Kashmir ETo (mm) | Ranichauri ETo (mm) |
|---|---|---|
| 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)* |
| 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. Italic values are cases of no trends at 5% level of significance

**Table 2:** Test statistics (Z) values obtained through the Mann-Kendall test on a seasonal basis

| Seasons | ETo(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

regression test. The linear line

$$y = mx + c \quad (2)$$

It gives the linear relationship between two variables represented by a straight line, where x denotes the time variable, m is the slope of regression line, and c is the intercept.

***Stepwise regression analysis***

To identify dominant variables among independent variables associated with changes in the dependent variable, the stepwise regression method was applied. In this study, ETo rate is the dependent variable and various meteorological parameters are the independent variables.

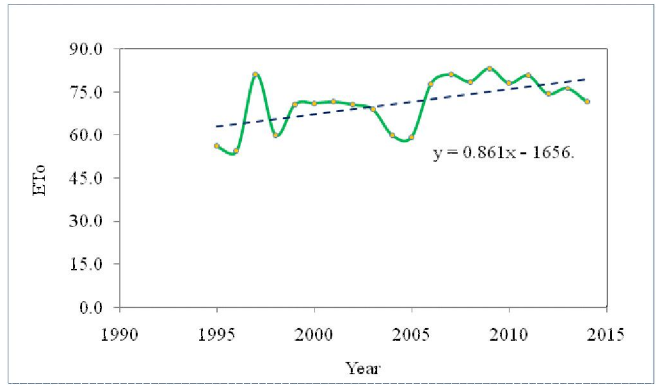


**Fig. 1:** Time series of $ET_0$ on an annual basis with linear trend lines for Srinagar

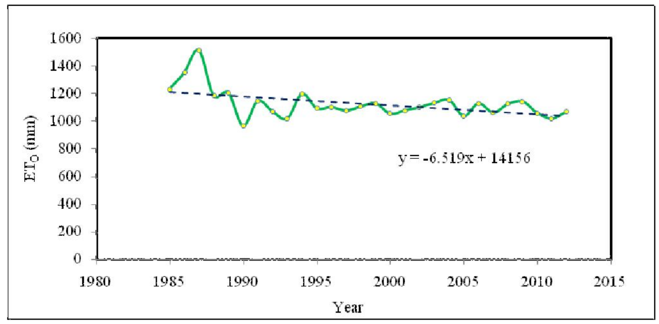


**Fig 2:** Time series of $ET_0$ on an annual basis with linear trend lines for Ranichauri

Regression was performed between dependent variable (ETo) and meteorological parameters that influenced the dependent variable i.e. maximum and minimum temperatures, sunshine duration, relative humidity, and wind speed. XLSTAT2014 and SPSS 16.0 were used for performing the statistical Mann-Kendall test. The null hypothesis was tested at 95% and 90% confidence levels.

***ETo for Srinagar (Kashmir)***

Trends in monthly, seasonal and annual ETo were performed using the Mann-Kendall test. The maximum value of ETo was found to be 150.9 mm in the month of July and minimum value of 17.8 mm in the month of December. Overall, in each month ETo increased gradually from 1995 to 2014. The statistically significant increasing trends were found in ETo at the rate of 3.84, 11.94, 17.84, 13.58, 9.87, 8.23 and 4.27mm/decade, for January, March, June, July, October, November, and December, respectively, at 5% level of significance as the values of Z (test statistics) obtained through the MK test were more than 1.96. The values of Z statistics with p-value in parenthesis obtained by Mann Kendall test on monthly and annual time scales are summarized in Table 1. Similarly, statistically significant increasing trend in ETo at the rate of 6.87mm/decade was witnessed in September at 10% significance level as the Z value was more than 1.65 and less than 1.96.

The trend was also analyzed on an annual basis (Fig. 1). It is evident from Table 1 that ETo witnessed statistically significant increasing trend at 5% significance level as the value of Z statistics was greater than 1.96 (Kashmir). The values of Z statistics with p-value in parenthesis obtained by Mann Kendall test on a seasonal basis is given in Table 2.The time series of ETo on a seasonal basis showed a linear trend. Trend analysis on a seasonal basis revealed that ETo at the rate of 8.32 mm/decade showed a significant trend in autumn and at the rate of 8.63 mm/decade in winter. On a seasonal basis the maximum of ETo with an average of 117.3mm was found in summer and the minimum value with an average of 56.3mm was in autumn. On an annual basis the highest and lowest values of ETo were found to be 998 mm in 2009 mm and 654.2 mm in 1996, respectively.

***Ranichauri***

The ETo value for Ranichauri station was determined on a monthly basis, is summarized in Table 1. It is evident that the maximum of ETo was found to be 185.7 mm in the month of May and the minimum value of 33.9 mm in the month of December. The ETo value of different seasons was also determined which is illustrated in Table 2. On a seasonal basis, maximum value of ETo were found to be in summer season with an average of 120.2 mm and the minimum value with an average of 59.9 mm in winter. On an annual basis, the highest value of ETo was found to be 1514 mm in 1987 and the lowest value was 966.6 mm in 1990. Over the annual time scale, the average of total ETo was found to be 1127.6 mm.

***Trend and slope analysis***

The MK test revealed statistically significant decreasing trend at the rate of 10.63 mm/decade in January, at the rate of 11.03 mm/decade in February, and at the rate of 15.39 mm/decade in November at 5% significance level (Table 1). On an 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 was more than 1.96 (Fig. 2). No statistically significant trends were witnessed in any season for ETo and evaporation as the Z values are between +1.96 and -1.96 (Table 2).

***Most dominating meteorological variables affecting ETo***

On analyzing the causal meteorological parameters responsible for the observed ETo trends, it was found that for Kashmir, wind speed, sunshine and maximum temperature dynamically influenced the observed ETo changes at the monthly and annual time scale, whereas sunshine and wind speed were main factors affecting ETo at the seasonal time scale in Kashmir region (Table 3). In case of Ranichauri data analysis revealed, wind speed was the main meteorological parameter effecting ETo (Table 4). It was observed that the maximum relative humidity had a negligible influence on the observed trends in ETo for the annual duration and for all the months for Kashmir and Ranichauri regions of Himalayas.

It is concluded that the trends were investigated using the non-parametric MK test. The magnitude of trends was analyzed by linear regression and stepwise linear regression to identify the dominant variables associated with ETo. On an annual basis it was found to be maximum in 2009 and minimum in 1996 in Kashmir whereas in Ranichauri it was found to be maximum in 1987 and minimum in 1990. Wind speed followed by sunshine duration, and temperature were found to be the main causes of observed changes in ETo over Kashmir and wind speed in Ranichauri on the annual time scale. The study revealed that a change in the water demand of various sectors, like agriculture, reservoir operation is expected to take place in most parts of the Himalayas.

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**Table 3:** Results of stepwise linear regression for Kashmir region

| Time scale | Tmin | Tmax | Sunshine | Wind | RHmax | Evaporation | Rainfall |
|---|---|---|---|---|---|---|---|
| January | - | 1 | - | - | - | - | - |
| February | - | - | 1 | - | - | - | - |
| March | - | 1 | - | - | - | - | - |
| April | - | - | 1 | 2 | - | - | - |
| May | - | 3 | 1 | 2 | - | - | - |
| June | - | - | 1 | 2 | - | - | 1 |
| July | - | - | - | - | - | 1 | - |
| August | - | 3 | 4 | 2 | - | 1 | - |
| September | - | 3 | 2 | 1 | - | - | - |
| October | - | 3 | 1 | 2 | - | - | - |
| November | - | 2 | - | 1 | - | - | - |
| December | - | - | - | - | - | - | - |
| Annual | - | 3 | 1 | 3 | - | - | - |
| Spring | - | - | 1 | 2 | - | - | - |
| Summer | - | - | - | - | 2 | - | 1 |
| Autumn | - | - | 2 | 1 | - | - | - |
| Winter | - | - | 1 | - | - | - | - |

**Table 4:** Stepwise linear regression for Ranichauri region

| Time scale | Tmin | Tmax | Sunshine | Wind | RHmax | Evaporation | Rainfall |
|---|---|---|---|---|---|---|---|
| January | - | - | - | 2 | 1 | - | - |
| February | - | 3 | - | 2 | 1 | - | - |
| March | - | - | - | 1 | - | - | 2 |
| April | - | 1 | - | - | - | - | - |
| May | - | - | 2 | 1 | - | - | - |
| June | 3 | 2 | - | 1 | - | - | - |
| July | - | 1 | - | - | - | - | - |
| August | - | - | - | 1 | - | - | - |
| September | - | 2 | - | 1 | - | - | - |
| October | - | - | 1 | - | - | - | - |
| November | - | - | 1 | - | - | - | - |
| December | - | - | 1 | - | - | - | - |
| Annual | - | 3 | 2 | 1 | - | 4 | - |
| Spring | - | - | - | 1 | - | - | - |
| Summer | - | - | - | - | - | 1 | - |
| Autumn | - | 2 | 1 | - | - | - | - |
| Winter | - | - | - | 1 | 2 | - | - |

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