***Original Research Article***

**Assessment of Climate Change Impact on Potential Evapotranspiration Trends in Sirsa and Hisar Districts of Haryana, India**

***ABSTRACT***

Potential evapotranspiration (PET), which is crucial for irrigation planning, influences crop water requirements in part. Thus, patterns in PET were discovered over Hisar and Sirsa in Haryana (India) in the current study utilizing the non-parametric Mann-Kendall (MK) test. First, PET values were first estimated for different time periods using the Thornthwaite method, employing meteorological data spanning 35 years from 1985 to 2019. Over the annual, kharif, rabi, pre-monsoon, monsoon, and post-monsoon time frames, PET was shown to climb significantly at Hisar and Sirsa. After evaluating the underlying meteorological parameters responsible for the reported PET trends in the Hisar and Sirsa, it was found that wind speed had a dynamic effect on the observed PET fluctuations at the yearly time scale and during all seven seasons. The results of the study support the hypothesis that evapotranspiration increases over Sirsa and Hisar.

**KEY WORDS:** E*vapotranspiration, trend, PET, meteorological parameters, Sirsa and Hisar*

***Introduction***

Water supply has become a critical concern for development and planning, encompassing flood control and food production. There may be serious consequences from climate change because of the reduction in water availability in many parts of the world. As per Kothawale and Rupa Kumar (2002), over the last century, the average yearly temperature of India has risen at a pace of 0.05 °C per decade−1. This can be attributed mainly to a rise in the maximum temperature (0.07 °C per decade−1) instead of a rise in the minimum temperature (0.02 °C per decade−1). The consensus is that rising temperatures frequently result in higher evapotranspiration rates. Based on research by Doorenbos and Pruitt (1975, 1977), which are generally recognized for evapotranspiration calculation, the Food and Agriculture Organisation (FAO) included the notion of reference evapotranspiration (RET) in the FAO standards for crop water requirements. Evapotranspiration is one of the essential elements of the hydrologic cycle, according to the FAO.

According to Luo *et al*. (2014), Yan *et al*. (2020), and Yin *et al*. (2020), evapotranspiration (ET) is a significant factor in the meteorological and hydrological cycles and is recognised as critical metric representing climatic fluctuations. Precipitation, ET and other climatic factors have varied throughout the various regions due to the rising probability of heat wave occurrences and their persistence in the recent past (Lyakaremye *et al*., 2021 and Ullah *et al*., 2022). It is crucial to comprehend the spatiotemporal characteristics of ET and the contributing components in the context of continuing climate change, as ET may be directly utilised as an input variable in many hydrodynamic and water quality modelling systems. Additionally, a deeper comprehension of ET is helpful for assessing hydrodynamics and water quality, particularly when it comes to elucidating the causes behind fluctuations in water quality, such as shifts in the salinity balance and changes in pollutant concentrations. By using the reference evapotranspiration (ET0), ET may be calculated. Water resource management benefits from the estimation and forecasting of ET0 since it is commonly acknowledged to be a significant factor in water balance and conversion (Traore *et al*., 2016 and Yan *et al*., 2021). For instance, calculating crop water demand is a crucial step in designing agricultural water conservation projects and scheduling irrigation (Tang *et al*., 2011 and Roy *et al*., 2020). This estimation of crop water demand is mostly dependent on the computation of ET0. PET, or the phase shift of water, is energy-intensive. Planning and scheduling irrigation will benefit considerably from knowledge of the water requirements of various crops under a particular set of region-specific climate variables. Measurements of radiation, vapour pressure, air temperature, relative humidity, and wind velocity over the evaporating surface are the main sources of data for RET. Planning and managing water resources more effectively requires a thorough grasp of the spatiotemporal fluctuations in ET0. The “evaporation paradox” (Liu, 2012) refers to the contentious behaviour wherein ET0 has been seen to decrease in several places with increasing temperature, defying intuitive assumption (Burn and Hesch, 2007). Numerous scholars have been drawn to examine the spatiotemporal variations in ET0 and the contributing climatic conditions as a result of the “evaporation paradox”, which essentially offers clear evidence that the variations are products of changes in multiple variables rather than any one component.

Several studies (Dinpashoh *et al*., 2011 and Jhajharia *et al*., 2012) have used data of varying lengths at varying places under varying types of climate to assess trends in evapotranspiration under warmer climates worldwide. According to Lawrimore and Peterson (2000), Golubev *et al*. (2001), and Roderick and Farquhar (2004), there have been notable reductions in pan evaporation (Epan) or potential evapotranspiration (PET) over different regions of Russia and the US, over India, over different US regions, over a few US-USSR sites, and over Australia, respectively.

Comparably, Epan was shown to be declining in northeast India, the Chao Phraya River basin (Thailand), and throughout all of China by Zhang *et al*. (2014) and Jhajharia *et al*. (2009), respectively. Jhajharia *et al*. (2012) observed significant declining trends in evapotranspiration over different portions of northeast India for other studies from the Indian subcontinent. Crop productivity may be directly impacted by patterns in PET, so it's critical to recognise changes in RET as a result of climate change in order to comprehend how agriculture will be affected by these changes.

During the last few decades, Bikaner, one of the most famous locations in the Thar Desert, has seen a number of changes brought about by urbanisation and the widespread construction of irrigation canal networks of the Indira Gandhi Canal, which carries waters of the Satluj and Vayas Rivers through the states of Himachal Pradesh, Haryana, and Punjab into the vast dry lands of the Thar Desert in the western part of Rajasthan. The last 58 years, from 1951 to 2008, have seen Bikaner see notable increases in minimum, maximum, and mean temperatures at the yearly time scale in the range of 0.1–0.4 °C decade−1 (Choudhary *et al*., 2009). Researchers were motivated to investigate whether the arid climates of Hisar and Sirsa will see any increases in evapotranspiration under global warming scenarios because of the temperature increases that were recorded in the region during this time period. Since there is no information available regarding trends in PET over Hisar and Sirsa, the current study was carried out with the following objectives: (1) compute the potential evapotranspiration (mm/day) in Hisar and Sirsa using the Thornthwaite formula; (2) compute the evapotranspiration at Hisar and Sirsa under arid climatic conditions; and (3) use the Mann–Kendall (MK) non-parametric test to investigate PET trends.

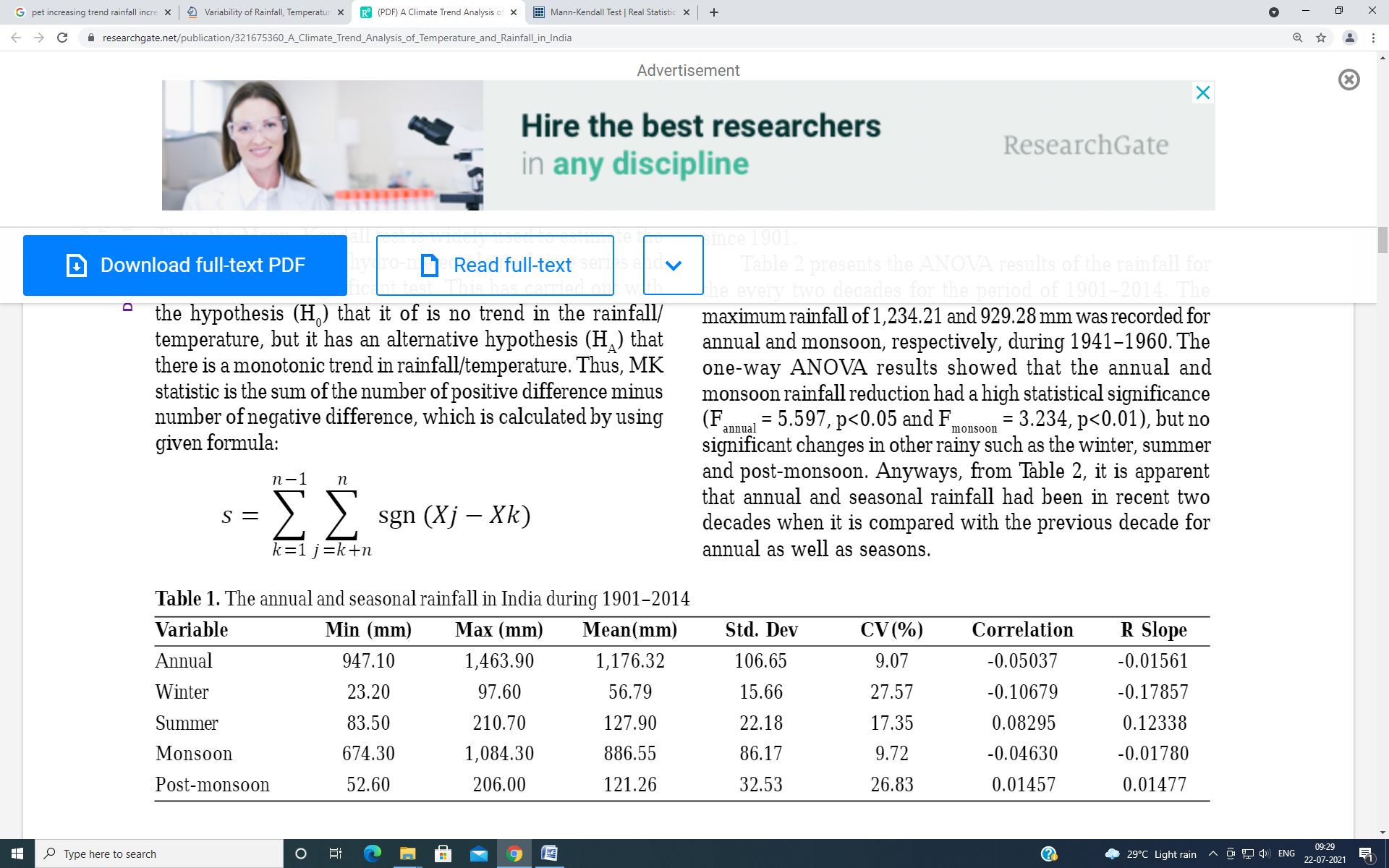
**MATERIALS AND METHODS**

**Study area and meteorological data**

The aim of the present study was to estimate the evapotranspiration's spatiotemporal trend analysis at two discrete Haryana locations—Hisar and Sirsa—that are situated in various agroclimatic zones. The study was carried out at CCS HAU, Hisar's Department of Agricultural Meteorology. The agro-met section of CSSRI, Karnal in Hisar, IMD, provided the highest and lowest temperatures, or meteorological data, between 1985 and 2019.

**Mann-Kendall techniques for analysing trends**

The non-parametric MK technique was used in this work to find trends in evapotranspiration and other climatic indicators since it is less impacted by the existence of outliers in the data and is better suitable for non-normally distributed and censored data (Mann, 1945; Kendall, 1975). The Mann-Kendall test, which is commonly used to assess the monotonic trend of the hydro-meteorological time series, is applied here to find trends in PET. The alternative hypothesis (HA), which states that the variable has a monotonic trend, and the hypothesis (H0), which states that the variable has no trend, have been used in this process. Therefore, the formula to calculate the MK statistic is as follows: it is equal to the sum of the positive differences minus the sum of the negative differences. The MK Test employs the subsequent statistic for the time series x1..., xn:



Where,

Sgn (Xj-Xk) = 1 ifXj-Xk> 0

Sgn (Xj-Xk) = 0 ifXj-Xk = 0

Sgn (Xj-Xk) = -1 ifXj-Xk< 0

An anormalized test statistic was utilised as well to evaluate the statistical significance of the trend tendency of the mean temperature and rainfall at the 0.1, 0.05, and 0.001 significance levels. Data on the spatial distribution of PET for the entire state of Haryana are obtained through the interpolation process using Geographic Information Systems (GIS). The Department of Agriculture Meteorology's Arc GIS 10.4 software from CCSHAU Hisar is utilised for this.

The monthly mean temperature has been concealed from the daily temperature data of the long-standing sire. The monthly PET was calculated using the Thornthwaite method, with the monthly mean temperature as the input data.

Thornthwaite method for ET,

E = 1.6 (10T/I)a

The Thornthwaite method (1948) yielded an additional formula for calculating ET.:

E = 1.6 (10T/I)a(D/12) (N/30)

Where, E = unadjusted PET, cm

T = mean monthly air temp, 0C

I = annual or seasonal heat index. It is the summation of 12 values of monthly heat indices.

i = (T/5)1.514

a = an empirical exponent

= 0.675 \* 10-6 I3- 0.771 \* 10-4 I2 + 1.79 \* 10-2 I + 0.4924

Temperature data spanning more than 30 years was analysed in order to assess the ET. Daily temperature data spanning 35 years was used to create the results of a study on seasonal and yearly ET patterns in the states of Hisar and Sirsa, Haryana.

**RESULTS AND DISCUSSION**

**Hisar**

Table 1 displays the potential evapotranspiration of the Hisar station, which peaked in June 2012 at 11.69 mm/day and reached its minimum in January 2003 at 0.23 mm/day. The typical potential evapotranspiration was in June at 10.03 mm/day and reached its minimum in January at 0.36 mm/day. For the Hisar area, the annual average PET of 4.55 mm/day was noted. PET was five times higher during the *kharif* season than it was during *rabi* season. PET was typically 7.65 mm/day during the *kharif* season and 1.46 mm/day during the *rabi* season. In the pre-monsoon, monsoon, post-monsoon, and winter seasons, the normal PET was 0.56, 5.25, 8.03, and 1.88 mm/day, respectively.

In *rabi*, the lowest and maximum values were 1.23 in 1997 and 1.83 in 2010, respectively, while in *kharif,* the lowest and maximum values were 6.38 in 1997 and 9.37 in 2002. Table 3 and Fig 1 shows the range of PET values for each climatic season: 0.38 to 0.9 mm/day in winter, 4.1 to 7.71 mm/day in pre-monsoon, 6.69 to 10.31 in monsoon, and 1.47 to 2.20 in post-monsoon. Pre-monsoon and monsoon are the two meteorological seasons with the highest PET, respectively.

In the months of January and July, respectively, the minimum and maximum monthly potential evapotranspiration in Hisar were measured to be 0.23 and 12.11 mm/day. The statistical parameters, namely Mean, Standard deviation (SD), Coefficient of Variation (CV), Skewness, and Kurtosis, varied between 0.36 and 10.03 mm, 0.08 to 1.19 mm, 8.23 to 24.26%, -0.63 to 2.90 mm, and -0.96 to 12.03 mm, as indicated by the tabulated results, as presented in Table 5. The months of December through March have a higher CV.

With the exception of January, June, and December, trend analysis showed a non-significantly positive trend in most of the months. At the 0.5 threshold of significance, a noteworthy upward trend was seen in October at a rate of 0.18 mm per day. Table 6 indicates that a non-significant positive trend was also noted in the annual PET at Hisar. Sen's slope estimate for January indicated a strong -ve trend in PET, with a daily decrease of 0.003 mm. The *rabi* and *kharif* seasons had a non-significant positive trend, according to Table 7. Table 7 illustrates that, among the meteorological seasons from 1985 to 2019, only the post-monsoon season exhibited a significant positive trend. All other seasons showed a non-significant trend.

Hisar, which has a dry climate, is a representative station for the Western Agroclimatic Zone. According to the evapotranspiration values from the previous chapter, June had a high ET (10.03 mm/month) during the *kharif* season, which dropped until September (5.98 mm/day) as a result of the temperature dropping. In the Rabi season, October had a high PET (3.57 mm/day) that was consistently reduced until January (0.36 mm/day) as a result of a falling trend in temperature. From February to March, PET climbed as a result of rising temperatures or summer solstices.

In Hisar, Gurgaon, Rohtak, Bhiwani, Haryana, between 1998 and 2008, Singh and Bala (2012) calculated seasonal potential evapotranspiration and discovered that it was 1.5 to 2 times higher in the *kharif* season than in the *rabi* season. In the current study, variance was seen to be smaller, or roughly 1.3 times, even if the observation remained the same—that is, that *kharif* PET was greater than *rabi* PET.

The monthly PET trend revealed a less variable pattern, with significant trends only in two months-the trend in October and the substantial negative trend in January at the 0.5 level of significance-while the other months, with the exception of June and December, displayed non-significant positive trends. With the exception of winter, seasonal PET trend showed a non-significant upward trend across all seasons. With the exception of the winter season, the research shows that the Hisar region had less volatility in PET during the 35-year period, with the post-monsoon showing a positive significant trend (0.1 level of significance) in the meteorological season.

**Sirsa**

The state's western region, where Sirsa is situated, experiences a dry climate. The maximum recorded evapotranspiration for the Sirsa station was 13.80 mm/day in June 1998, while the minimum was 0.19 mm/day in January 2001. According to Table 2, the average potential evapotranspiration was at its highest point in June, or 11.62 mm/day, and at its lowest point in January, at 0.34 mm/day.

The yearly average for the Sirsa location was found to be 5.05 mm/day for PET. The *rabi* season was 1.52 mm/day, and the *kharif* season was 8.57 mm/day. The usual PET values for the winter, pre-monsoon, monsoon, and post-monsoon seasons were 0.56, 6.00, 8.89, and 1.95 mm/day, respectively. For the *kharif* season, the lowest and maximum values were 6.82 in 1997 and 9.75 in 2010, respectively; for the *rabi* season, the values were 1.23 in 1997 and 1.82 in 2008. According to Table 4 and Fig 2, PET values varied by meteorological season from 0.39 to 0.96 mm/day in winter, 4.18 to 8.22 mm/day in pre-monsoon, 6.34 to 10.31 mm/day in monsoon, and 1.44 to 2.45 mm/day in post-monsoon.

Pre-monsoon and monsoon are the two meteorological seasons with the highest PET, respectively. Because it was winter, the PET value was significantly lower than the other two seasons. The lowest and greatest monthly potential evapotranspiration over this study period (1985–2019) were reported in the months of January and June, respectively, to be 0.19 and 13.80 mm/day. The statistical parameters, namely the mean, standard deviation (SD), coefficient of variation (CV), skewness, and kurtosis, varied from 0.34 to 11.62, 0.07 to 1.55, 8.92 to 22.95%, -1.09 to 2.42 mm, and -0.76 to 9.76 mm, respectively, according to tabulated values displayed in Table 5. Similar to every station in the study, Sirsa's PET varied greatly during the cold months of December, January, and February.

The state's most western region, Sirsa, has a markedly positive trend in annual PET, which Sen's slope estimations show is growing at a rate of 0.010 mm each day. PET showed a markedly increasing trend in the months of January, September, and October. In April, there was likewise a highly significant positive correlation (0.002), and PET revealed an increasing trend of 0.02 mm/day. Except for January, February, November, and December, which displayed a -ve non-significant trend or a decreasing trend as indicated in Table 6, the following months likewise had a non-significant positive trend.

Table 7 indicates that there was a noteworthy positive trend throughout the *kharif* season. *Rabi* season, however, had a non-significant +ve trend. Pre-monsoon and post-monsoon meteorological seasons had a substantial increasing trend, but the monsoon season showed a non-significant +ve trend. Winter showed a non-significant decreasing tendency in contrast to all other seasons (Table 7).

The summers in Sirsa, which is in the westernmost region of the state, are hot and dry. Additionally, a seasonal river called Gagger flows alongside it. According to seasonal analysis based on monthly PET interpretation, June had high ET (11.62 mm/day) during the *kharif* season. October had the highest ET (3.77 mm/day) throughout the Rabi season, while January had the lowest (0.34 mm/day). Using rainfall data from 1970 to 2000, Goparaju and Ahmad (2019) calculated seasonal potential evapotranspiration and demonstrated that ET was high in arid and semi-arid regions of India. The current study revealed the same thing: Sirsa had a higher PET than the other stations in Haryana.

According to a seasonal trend analysis, April, September, and October experienced favourable trends during the *kharif* season. The overall *kharif* season showed notable increases in PET trends. Pre-monsoon and post-monsoon seasons also showed similar trends; the winter season had a non-significant lowering trend, but January saw a significant decreasing trend, with PET falling at a rate of 0.003 mm/day according to Sen's slope estimate. October's positive, non-significant growing trend in the *rabi* season was caused by a rise in the minimum temperature. With the exception of the monsoon, the meteorological seasons' post-monsoon and pre-monsoon showed positive significant trends, whereas the winter season's declining trend was non-significant because of the drop in temperature.

**CONCLUSION**

In the present investigation, an attempt has been made to estimate potential evapotranspiration (PET) using the Penman–Monteith (PM) method across Hisar and Sirsa, taking into consideration the significance of PET in water balance studies, irrigation planning, reservoir planning, and operation. After PET was estimated using the PM approach, the trends in RET in the arid areas of Sirsa and Hisar were analysed considering the changing climate of the area. Statistically significant declines in wind speed were detected across Hisar and Sirsa in both annual and seasonal time scales. These declines were correlated with declines in PET in both annual and seasonal (*kharif, rabi*, winter, pre-monsoon, monsoon, and post-monsoon) time periods. The current study will be useful in accurately predicting the key agricultural water requirements under changing climates in the desert Hisar and Sirsa region.

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Table 1 Monthly Potential Evapotranspiration (mm/day) in Hisar using Thornthwaite formula (1985-2019)

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| 1985 | 0.38 | 0.77 | 2.39 | 5.22 | 9.79 | 10.83 | 8.03 | 7.57 | 6.26 | 3.01 | 1.42 | 0.67 |
| 1986 | 0.38 | 0.67 | 1.96 | 4.81 | 6.88 | 9.66 | 7.26 | 7.03 | 5.67 | 3.58 | 1.76 | 0.43 |
| 1987 | 0.38 | 0.93 | 2.11 | 4.76 | 5.72 | 11.52 | 12.11 | 10.26 | 7.36 | 4.16 | 1.48 | 0.49 |
| 1988 | 0.48 | 0.86 | 1.82 | 5.81 | 11.33 | 11.19 | 8.22 | 6.83 | 6.00 | 3.33 | 1.44 | 0.57 |
| 1989 | 0.34 | 0.62 | 1.82 | 3.76 | 8.34 | 9.52 | 8.64 | 7.31 | 6.00 | 3.64 | 1.61 | 0.52 |
| 1990 | 0.58 | 0.82 | 1.62 | 4.67 | 9.30 | 10.80 | 7.52 | 7.34 | 5.95 | 3.09 | 1.54 | 0.60 |
| 1991 | 0.35 | 0.76 | 1.77 | 3.98 | 8.10 | 9.65 | 10.41 | 7.31 | 5.91 | 3.03 | 1.48 | 0.65 |
| 1992 | 0.59 | 0.66 | 1.71 | 4.05 | 7.21 | 9.90 | 7.09 | 6.55 | 5.00 | 3.15 | 1.49 | 0.77 |
| 1993 | 0.40 | 1.06 | 1.48 | 4.40 | 9.31 | 10.59 | 7.79 | 8.52 | 5.83 | 3.40 | 1.69 | 0.56 |
| 1994 | 0.50 | 0.67 | 2.18 | 4.15 | 9.35 | 11.00 | 8.01 | 6.58 | 5.33 | 3.23 | 1.52 | 0.72 |
| 1995 | 0.35 | 0.77 | 1.59 | 4.24 | 8.83 | 11.14 | 9.45 | 6.54 | 6.01 | 3.90 | 1.57 | 0.60 |
| 1996 | 0.41 | 0.82 | 2.04 | 4.70 | 8.18 | 8.31 | 8.37 | 6.48 | 5.65 | 3.40 | 1.37 | 0.45 |
| 1997 | 0.37 | 0.75 | 1.88 | 3.97 | 6.44 | 7.66 | 8.08 | 6.15 | 5.99 | 2.63 | 1.37 | 0.40 |
| 1998 | 0.28 | 0.72 | 1.45 | 5.14 | 9.62 | 10.18 | 8.67 | 8.48 | 6.50 | 3.82 | 1.60 | 0.53 |
| 1999 | 0.36 | 0.78 | 2.03 | 5.69 | 9.17 | 9.77 | 9.50 | 7.68 | 6.81 | 3.66 | 1.57 | 0.46 |
| 2000 | 0.33 | 0.47 | 1.66 | 5.75 | 10.42 | 9.86 | 7.84 | 7.83 | 6.00 | 3.86 | 1.50 | 0.51 |
| 2001 | 0.27 | 0.82 | 1.90 | 4.53 | 8.42 | 7.25 | 7.15 | 6.36 | 6.01 | 4.12 | 1.68 | 0.68 |
| 2002 | 0.29 | 0.55 | 1.88 | 5.92 | 12.01 | 11.59 | 11.95 | 9.25 | 5.50 | 3.72 | 1.39 | 0.60 |
| 2003 | 0.23 | 0.74 | 1.85 | 5.22 | 7.79 | 11.52 | 7.20 | 6.98 | 5.75 | 3.01 | 1.27 | 0.55 |
| 2004 | 0.33 | 0.73 | 2.41 | 6.33 | 8.25 | 8.50 | 10.46 | 6.82 | 6.05 | 3.07 | 1.46 | 0.58 |
| 2005 | 0.32 | 0.65 | 2.10 | 4.15 | 7.36 | 10.09 | 7.60 | 7.68 | 5.59 | 3.43 | 1.53 | 0.40 |
| 2006 | 0.37 | 1.42 | 1.73 | 5.37 | 9.30 | 8.58 | 8.44 | 7.39 | 5.76 | 3.82 | 1.61 | 0.50 |
| 2007 | 0.32 | 0.86 | 1.63 | 5.63 | 8.89 | 9.73 | 8.88 | 7.78 | 6.01 | 3.10 | 1.71 | 0.45 |
| 2008 | 0.28 | 0.48 | 2.70 | 4.73 | 7.62 | 8.05 | 8.50 | 6.74 | 5.45 | 4.20 | 1.62 | 0.71 |
| 2009 | 0.41 | 0.81 | 2.01 | 5.10 | 9.39 | 10.72 | 8.88 | 9.27 | 5.77 | 3.35 | 1.30 | 0.52 |
| 2010 | 0.25 | 0.88 | 4.12 | 7.87 | 11.15 | 10.85 | 8.50 | 7.31 | 5.34 | 3.87 | 1.48 | 0.35 |
| 2011 | 0.25 | 0.84 | 1.92 | 4.30 | 8.89 | 9.57 | 8.15 | 7.08 | 5.54 | 3.30 | 1.82 | 0.58 |
| 2012 | 0.33 | 0.50 | 1.82 | 4.58 | 8.17 | 11.69 | 9.99 | 6.98 | 5.82 | 3.11 | 1.34 | 0.50 |
| 2013 | 0.26 | 0.76 | 1.93 | 4.55 | 9.08 | 10.40 | 8.92 | 6.89 | 6.17 | 4.07 | 1.34 | 0.60 |
| 2014 | 0.33 | 0.63 | 1.67 | 4.28 | 7.58 | 10.73 | 9.57 | 8.22 | 6.25 | 4.02 | 1.52 | 0.42 |
| 2015 | 0.28 | 1.03 | 1.47 | 4.18 | 8.92 | 8.85 | 7.68 | 7.46 | 6.18 | 4.27 | 1.74 | 0.59 |
| 2016 | 0.41 | 0.71 | 2.34 | 5.84 | 10.34 | 11.36 | 8.25 | 7.27 | 6.73 | 4.31 | 1.58 | 0.71 |
| 2017 | 0.39 | 0.87 | 1.87 | 6.26 | 9.82 | 8.87 | 8.56 | 7.69 | 6.27 | 4.10 | 1.41 | 0.54 |
| 2018 | 0.37 | 0.87 | 2.30 | 5.76 | 9.37 | 11.12 | 8.42 | 8.08 | 5.78 | 3.50 | 1.60 | 0.44 |
| 2019 | 0.38 | 0.64 | 1.50 | 5.37 | 7.56 | 10.16 | 7.88 | 7.44 | 7.17 | 3.72 | 1.72 | 0.31 |
| Normal | 0.36 | 0.77 | 1.96 | 5.00 | 8.80 | 10.03 | 8.63 | 7.46 | 5.98 | 3.57 | 1.53 | 0.54 |

Table 2 Monthly Potential Evapotranspiration (mm/day) in Sirsa using Thornthwaite formula (1985-2019)

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| 1985 | 0.38 | 0.80 | 2.43 | 5.18 | 9.82 | 11.19 | 8.49 | 8.53 | 6.89 | 3.18 | 1.70 | 0.63 |
| 1986 | 0.42 | 0.70 | 1.87 | 4.96 | 7.89 | 10.43 | 7.77 | 7.90 | 6.22 | 4.23 | 1.74 | 0.41 |
| 1987 | 0.47 | 0.98 | 2.04 | 5.12 | 6.08 | 12.13 | 11.94 | 9.47 | 7.70 | 4.02 | 1.47 | 0.48 |
| 1988 | 0.39 | 0.82 | 2.27 | 5.18 | 11.65 | 12.41 | 10.13 | 8.12 | 5.77 | 3.71 | 1.57 | 0.57 |
| 1989 | 0.34 | 0.75 | 2.24 | 5.18 | 11.47 | 12.21 | 10.01 | 7.73 | 6.27 | 3.80 | 1.42 | 0.40 |
| 1990 | 0.44 | 0.66 | 1.79 | 4.91 | 10.47 | 11.97 | 8.79 | 7.58 | 5.73 | 3.44 | 1.52 | 0.64 |
| 1991 | 0.33 | 0.76 | 2.22 | 5.18 | 11.57 | 12.32 | 10.07 | 8.32 | 6.03 | 3.45 | 1.56 | 0.56 |
| 1992 | 0.42 | 0.68 | 2.32 | 5.18 | 11.40 | 12.13 | 9.95 | 7.18 | 5.46 | 3.28 | 1.35 | 0.70 |
| 1993 | 0.32 | 0.99 | 2.11 | 5.18 | 11.67 | 12.43 | 10.14 | 9.47 | 5.92 | 3.21 | 1.58 | 0.53 |
| 1994 | 0.49 | 0.68 | 2.40 | 4.12 | 9.62 | 12.02 | 8.07 | 7.38 | 5.69 | 3.13 | 1.53 | 0.63 |
| 1995 | 0.35 | 0.71 | 1.40 | 4.39 | 9.89 | 12.33 | 10.17 | 6.42 | 6.49 | 3.85 | 1.67 | 0.57 |
| 1996 | 0.34 | 0.68 | 2.19 | 5.08 | 8.66 | 9.14 | 9.15 | 7.00 | 5.75 | 3.18 | 1.36 | 0.51 |
| 1997 | 0.40 | 0.75 | 1.92 | 3.98 | 6.63 | 8.57 | 8.74 | 6.75 | 6.27 | 2.58 | 1.30 | 0.43 |
| 1998 | 0.32 | 0.92 | 1.48 | 5.52 | 10.23 | 13.80 | 9.24 | 8.24 | 5.99 | 3.17 | 1.50 | 0.47 |
| 1999 | 0.23 | 0.72 | 2.21 | 6.38 | 9.57 | 10.37 | 9.62 | 8.24 | 6.75 | 3.86 | 1.69 | 0.57 |
| 2000 | 0.36 | 0.69 | 2.22 | 6.08 | 10.22 | 7.93 | 6.55 | 6.19 | 4.68 | 3.05 | 1.29 | 0.48 |
| 2001 | 0.19 | 0.81 | 1.88 | 5.05 | 9.90 | 9.15 | 9.12 | 8.03 | 6.82 | 4.52 | 1.85 | 0.67 |
| 2002 | 0.31 | 0.64 | 2.16 | 5.18 | 11.83 | 12.61 | 10.25 | 9.85 | 6.01 | 4.41 | 1.59 | 0.64 |
| 2003 | 0.21 | 0.64 | 2.30 | 5.18 | 11.51 | 12.25 | 10.03 | 9.09 | 5.84 | 3.59 | 1.40 | 0.62 |
| 2004 | 0.23 | 0.91 | 2.93 | 6.86 | 10.19 | 12.76 | 8.20 | 7.66 | 5.98 | 3.08 | 1.84 | 0.64 |
| 2005 | 0.33 | 0.65 | 2.30 | 5.18 | 11.57 | 12.32 | 10.07 | 9.14 | 6.14 | 3.90 | 1.43 | 0.37 |
| 2006 | 0.37 | 1.55 | 2.24 | 5.18 | 12.02 | 12.82 | 10.38 | 8.65 | 6.18 | 4.33 | 1.62 | 0.47 |
| 2007 | 0.37 | 0.86 | 2.14 | 5.18 | 11.76 | 12.53 | 10.20 | 8.94 | 6.57 | 3.45 | 1.76 | 0.49 |
| 2008 | 0.30 | 0.49 | 2.78 | 5.18 | 8.99 | 8.66 | 10.02 | 7.47 | 6.18 | 4.84 | 1.72 | 0.77 |
| 2009 | 0.42 | 0.86 | 2.10 | 5.67 | 11.03 | 13.14 | 10.85 | 10.25 | 6.67 | 3.79 | 1.26 | 0.55 |
| 2010 | 0.24 | 0.80 | 3.14 | 8.78 | 12.74 | 12.97 | 9.49 | 8.44 | 6.07 | 4.29 | 1.58 | 0.38 |
| 2011 | 0.22 | 0.73 | 2.22 | 5.18 | 11.56 | 12.31 | 10.07 | 7.60 | 6.16 | 3.77 | 1.94 | 0.54 |
| 2012 | 0.30 | 0.54 | 2.09 | 5.22 | 10.29 | 13.76 | 11.69 | 8.27 | 6.67 | 3.43 | 1.45 | 0.53 |
| 2013 | 0.27 | 0.69 | 2.21 | 5.43 | 10.89 | 12.07 | 10.20 | 7.71 | 7.02 | 4.50 | 1.31 | 0.55 |
| 2014 | 0.36 | 0.64 | 1.77 | 4.93 | 8.48 | 12.03 | 9.98 | 8.86 | 6.00 | 3.91 | 1.31 | 0.36 |
| 2015 | 0.25 | 0.94 | 1.62 | 5.39 | 9.89 | 10.07 | 8.13 | 7.89 | 6.46 | 4.35 | 1.56 | 0.66 |
| 2016 | 0.33 | 0.72 | 2.37 | 6.75 | 11.66 | 13.26 | 10.05 | 7.93 | 7.05 | 4.39 | 1.41 | 0.76 |
| 2017 | 0.40 | 0.89 | 1.99 | 7.11 | 11.46 | 10.65 | 9.97 | 8.72 | 6.66 | 4.30 | 1.25 | 0.46 |
| 2018 | 0.35 | 0.86 | 2.54 | 6.32 | 9.92 | 9.57 | 8.58 | 8.29 | 6.48 | 4.01 | 1.76 | 0.53 |
| 2019 | 0.34 | 0.70 | 1.94 | 6.75 | 9.95 | 12.40 | 7.55 | 7.49 | 7.14 | 3.92 | 1.66 | 0.20 |
| Normal | 0.34 | 0.78 | 2.17 | 5.49 | 10.36 | 11.62 | 9.53 | 8.14 | 6.28 | 3.77 | 1.54 | 0.54 |

Table 3 Seasonal Potential Evapotranspiration (mm/day) at Hisar during period 1985-2019

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Year | Annual | *Kharif* | *Rabi* | Winter | Premonsoon | Monsoon | Postmonsoon |
| 1985 | 4.69 | 7.95 | 1.44 | 0.57 | 5.80 | 8.17 | 1.70 |
| 1986 | 4.17 | 6.88 | 1.46 | 0.52 | 4.55 | 7.40 | 1.92 |
| 1987 | 5.11 | 8.62 | 1.59 | 0.66 | 4.20 | 10.31 | 2.05 |
| 1988 | 4.82 | 8.23 | 1.42 | 0.67 | 6.32 | 8.06 | 1.78 |
| 1989 | 4.34 | 7.26 | 1.43 | 0.48 | 4.64 | 7.87 | 1.92 |
| 1990 | 4.49 | 7.60 | 1.38 | 0.70 | 5.20 | 7.90 | 1.75 |
| 1991 | 4.45 | 7.56 | 1.34 | 0.56 | 4.62 | 8.32 | 1.72 |
| 1992 | 4.02 | 6.63 | 1.40 | 0.62 | 4.32 | 7.14 | 1.81 |
| 1993 | 4.59 | 7.74 | 1.43 | 0.73 | 5.06 | 8.18 | 1.88 |
| 1994 | 4.44 | 7.40 | 1.47 | 0.59 | 5.23 | 7.73 | 1.82 |
| 1995 | 4.58 | 7.70 | 1.46 | 0.56 | 4.89 | 8.28 | 2.02 |
| 1996 | 4.18 | 6.95 | 1.42 | 0.61 | 4.97 | 7.20 | 1.74 |
| 1997 | 3.81 | 6.38 | 1.23 | 0.56 | 4.10 | 6.97 | 1.47 |
| 1998 | 4.75 | 8.10 | 1.40 | 0.50 | 5.40 | 8.46 | 1.98 |
| 1999 | 4.79 | 8.10 | 1.48 | 0.57 | 5.63 | 8.44 | 1.90 |
| 2000 | 4.67 | 7.95 | 1.39 | 0.40 | 5.94 | 7.88 | 1.96 |
| 2001 | 4.10 | 6.62 | 1.58 | 0.55 | 4.95 | 6.69 | 2.16 |
| 2002 | 5.39 | 9.37 | 1.40 | 0.42 | 6.60 | 9.57 | 1.90 |
| 2003 | 4.34 | 7.41 | 1.28 | 0.49 | 4.95 | 7.86 | 1.61 |
| 2004 | 4.58 | 7.74 | 1.43 | 0.53 | 5.66 | 7.96 | 1.70 |
| 2005 | 4.24 | 7.08 | 1.40 | 0.48 | 4.53 | 7.74 | 1.79 |
| 2006 | 4.52 | 7.47 | 1.58 | 0.90 | 5.47 | 7.54 | 1.98 |
| 2007 | 4.58 | 7.82 | 1.35 | 0.59 | 5.38 | 8.10 | 1.75 |
| 2008 | 4.26 | 6.85 | 1.66 | 0.38 | 5.02 | 7.19 | 2.18 |
| 2009 | 4.80 | 8.19 | 1.40 | 0.61 | 5.50 | 8.66 | 1.72 |
| 2010 | 5.16 | 8.50 | 1.83 | 0.57 | 7.71 | 8.00 | 1.90 |
| 2011 | 4.35 | 7.26 | 1.45 | 0.54 | 5.03 | 7.59 | 1.90 |
| 2012 | 4.57 | 7.87 | 1.27 | 0.41 | 4.86 | 8.62 | 1.65 |
| 2013 | 4.58 | 7.67 | 1.49 | 0.51 | 5.18 | 8.10 | 2.00 |
| 2014 | 4.60 | 7.77 | 1.43 | 0.48 | 4.51 | 8.69 | 1.99 |
| 2015 | 4.39 | 7.21 | 1.56 | 0.66 | 4.85 | 7.54 | 2.20 |
| 2016 | 4.99 | 8.30 | 1.68 | 0.56 | 6.17 | 8.40 | 2.20 |
| 2017 | 4.72 | 7.91 | 1.53 | 0.63 | 5.99 | 7.85 | 2.02 |
| 2018 | 4.80 | 8.09 | 1.51 | 0.62 | 5.81 | 8.35 | 1.85 |
| 2019 | 4.49 | 7.60 | 1.38 | 0.51 | 4.81 | 8.16 | 1.91 |
| Normal | 4.55 | 7.65 | 1.46 | 0.56 | 5.25 | 8.03 | 1.88 |

Table 4 Seasonal Potential Evapotranspiration (mm/day) in Sirsa during period 1985-2019

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Year | Annual | *Kharif* | *Rabi* | Winter | Premonsoon | Monsoon | Postmonsoon |
| 1985 | 4.93 | 8.35 | 1.52 | 0.59 | 5.81 | 8.77 | 1.83 |
| 1986 | 4.54 | 7.53 | 1.56 | 0.56 | 4.91 | 8.08 | 2.13 |
| 1987 | 5.16 | 8.74 | 1.58 | 0.72 | 4.42 | 10.31 | 1.99 |
| 1988 | 5.22 | 8.88 | 1.56 | 0.61 | 6.37 | 9.11 | 1.95 |
| 1989 | 5.15 | 8.81 | 1.49 | 0.54 | 6.30 | 9.06 | 1.87 |
| 1990 | 4.83 | 8.24 | 1.42 | 0.55 | 5.72 | 8.52 | 1.87 |
| 1991 | 5.20 | 8.92 | 1.48 | 0.55 | 6.32 | 9.19 | 1.86 |
| 1992 | 5.00 | 8.55 | 1.46 | 0.55 | 6.30 | 8.68 | 1.78 |
| 1993 | 5.30 | 9.14 | 1.46 | 0.65 | 6.32 | 9.49 | 1.77 |
| 1994 | 4.65 | 7.82 | 1.48 | 0.59 | 5.38 | 8.29 | 1.76 |
| 1995 | 4.85 | 8.28 | 1.42 | 0.53 | 5.23 | 8.85 | 2.03 |
| 1996 | 4.42 | 7.46 | 1.38 | 0.51 | 5.31 | 7.76 | 1.68 |
| 1997 | 4.02 | 6.82 | 1.23 | 0.57 | 4.18 | 7.58 | 1.44 |
| 1998 | 5.07 | 8.84 | 1.31 | 0.62 | 5.74 | 9.32 | 1.71 |
| 1999 | 5.02 | 8.49 | 1.55 | 0.48 | 6.06 | 8.74 | 2.04 |
| 2000 | 4.14 | 6.94 | 1.35 | 0.52 | 6.17 | 6.34 | 1.61 |
| 2001 | 4.83 | 8.01 | 1.65 | 0.50 | 5.61 | 8.28 | 2.34 |
| 2002 | 5.46 | 9.29 | 1.62 | 0.47 | 6.39 | 9.68 | 2.21 |
| 2003 | 5.22 | 8.98 | 1.46 | 0.43 | 6.33 | 9.30 | 1.87 |
| 2004 | 5.10 | 8.60 | 1.61 | 0.57 | 6.66 | 8.65 | 1.85 |
| 2005 | 5.28 | 9.07 | 1.50 | 0.49 | 6.35 | 9.42 | 1.90 |
| 2006 | 5.48 | 9.20 | 1.76 | 0.96 | 6.48 | 9.51 | 2.14 |
| 2007 | 5.35 | 9.20 | 1.51 | 0.62 | 6.36 | 9.56 | 1.90 |
| 2008 | 4.78 | 7.75 | 1.82 | 0.39 | 5.65 | 8.08 | 2.45 |
| 2009 | 5.55 | 9.60 | 1.50 | 0.64 | 6.27 | 10.23 | 1.87 |
| 2010 | 5.74 | 9.75 | 1.74 | 0.52 | 8.22 | 9.24 | 2.08 |
| 2011 | 5.19 | 8.81 | 1.57 | 0.47 | 6.32 | 9.03 | 2.09 |
| 2012 | 5.35 | 9.32 | 1.39 | 0.42 | 5.87 | 10.10 | 1.81 |
| 2013 | 5.23 | 8.88 | 1.59 | 0.48 | 6.17 | 9.25 | 2.12 |
| 2014 | 4.88 | 8.38 | 1.39 | 0.50 | 5.06 | 9.22 | 1.86 |
| 2015 | 4.77 | 7.97 | 1.56 | 0.59 | 5.63 | 8.14 | 2.19 |
| 2016 | 5.56 | 9.45 | 1.67 | 0.53 | 6.93 | 9.58 | 2.19 |
| 2017 | 5.32 | 9.09 | 1.55 | 0.64 | 6.85 | 9.00 | 2.00 |
| 2018 | 4.93 | 8.19 | 1.67 | 0.60 | 6.26 | 8.23 | 2.10 |
| 2019 | 5.00 | 8.55 | 1.46 | 0.52 | 6.21 | 8.64 | 1.93 |
| Normal | 5.05 | 8.57 | 1.52 | 0.56 | 6.00 | 8.89 | 1.95 |

Table 5 Descriptive Statistical for monthly Potential Evapotranspiration at Hisar and Sirsa

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Month | Hisar | | | | | | | Sirsa | | | | | | |
| Max | Min | Mean | SD | CV | Skewness | Kurtosis | Max | Min | Mean | SD | CV | Skewness | Kurtosis |
| Jan | 0.59 | 0.23 | 0.36 | 0.08 | 23.43 | 1.07 | 1.53 | 0.49 | 0.19 | 0.34 | 0.07 | 22.23 | -0.08 | -0.44 |
| Feb | 1.42 | 0.47 | 0.77 | 0.18 | 23.17 | 1.31 | 4.45 | 1.55 | 0.49 | 0.78 | 0.18 | 22.95 | 2.42 | 9.76 |
| Mar | 4.12 | 1.45 | 1.96 | 0.48 | 24.26 | 2.90 | 12.03 | 3.14 | 1.40 | 2.17 | 0.36 | 16.40 | 0.38 | 1.38 |
| Apr | 7.87 | 3.76 | 5.00 | 0.87 | 17.40 | 1.08 | 1.84 | 8.78 | 3.98 | 5.49 | 0.92 | 16.67 | 1.61 | 3.95 |
| May | 12.01 | 5.72 | 8.80 | 1.36 | 15.43 | 0.13 | 0.30 | 12.74 | 6.08 | 10.36 | 1.50 | 14.51 | -1.09 | 1.26 |
| Jun | 11.69 | 7.25 | 10.03 | 1.19 | 11.82 | -0.63 | -0.38 | 13.80 | 7.93 | 11.62 | 1.55 | 13.30 | -0.95 | -0.08 |
| Jul | 12.11 | 7.09 | 8.63 | 1.20 | 13.96 | 1.38 | 2.02 | 11.94 | 6.55 | 9.53 | 1.13 | 11.84 | -0.47 | 0.60 |
| Aug | 10.26 | 6.15 | 7.46 | 0.89 | 11.89 | 1.27 | 2.02 | 10.25 | 6.19 | 8.14 | 0.92 | 11.28 | 0.14 | 0.08 |
| Sep | 7.36 | 5.00 | 5.98 | 0.49 | 8.23 | 0.90 | 1.46 | 7.70 | 4.68 | 6.28 | 0.56 | 8.92 | -0.07 | 1.38 |
| Oct | 4.31 | 2.63 | 3.57 | 0.44 | 12.29 | -0.03 | -0.96 | 4.84 | 2.58 | 3.77 | 0.53 | 14.06 | -0.08 | -0.66 |
| Nov | 1.82 | 1.27 | 1.53 | 0.14 | 9.07 | 0.10 | -0.61 | 1.94 | 1.25 | 1.54 | 0.18 | 11.95 | 0.20 | -0.76 |
| Dec | 0.77 | 0.31 | 0.54 | 0.11 | 20.18 | 0.04 | -0.36 | 0.77 | 0.20 | 0.54 | 0.12 | 22.48 | -0.33 | 0.55 |

Table 6 Trend analysis of Monthly Potential Evapotranspiration at Hisar and Sirsa during period 1985-2019

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Month | Mann-Kendall trend | | Sen's slope estimate | |
| Test Z | | Q | |
| Hisar | Sirsa | Hisar | Sirsa |
| Jan | -2.158\* | -2.130\* | -0.003\* | -0.003\* |
| Feb | 0 | -0.397 | 0.00 | -0.0009 |
| Mar | 0.114 | 0 | 0.0007 | -0.0001 |
| Apr | 1.618 | 3.011\*\* | 0.024 | 0.020\*\* |
| May | 0.653 | 0.937 | 0.014 | 0.013 |
| Jun | -0.114 | 0.909 | -0.002 | 0.015 |
| Jul | 0.795 | 0.256 | 0.009 | 0.002 |
| Aug | 0.766 | 0.426 | 0.011 | 0.006 |
| Sep | 0.824 | 2.215\* | 0.005 | 0.020\* |
| Oct | 2.385\* | 2.159\* | 0.018\* | 0.020 |
| Nov | 0.596 | -0.369 | 0.002 | -0.001 |
| Dec | -1.278 | -0.653 | -0.003 | -0.001 |
| Annual | 1.022 | 1.789+ | 0.006 | 0.011+ |

Table 7 Trend analysis of Seasonal Potential Evapotranspiration at Hisar and Sirsa during period 1985-2019

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Season | Mann-Kendall trend | | Sen's slope estimate | |
| Test Z | | Q | |
| Hisar | Sirsa | Hisar | Sirsa |
| Annual | 1.022 | 1.789+ | 0.006 | 0.011 |
| *Kharif* | 0.738 | 1.676+ | 0.009 | 0.021 |
| *Rabi* | 1.079 | 1.335 | 0.002 | 0.003 |
| Winter | -1.136 | -1.562 | -0.002 | -0.002 |
| Pre-monsoon | 1.164 | 1.789+ | 0.016 | 0.019 |
| Monsoon | 0.539 | 0.596 | 0.006 | 0.008 |
| Post-monsoon | 1.647+ | 1.732+ | 0.004 | 0.005 |

Figure 1 Seasonal Potential Evapotranspiration (mm/day) in Hisar during period 1985-2019

Figure 2 Seasonal Potential Evapotranspiration (mm/day) in Sirsa during period 1985-2019

|  |  |
| --- | --- |
|  |  |
| Fig 3 Trend analysis (Mann-Kendall trend -Test Z) of Monthly Potential Evapotranspiration at Hisar during period 1985-2019 | Fig 4 Trend analysis (Mann-Kendall trend -Test Z) of Monthly Potential Evapotranspiration at Sirsa during period 1985-2019 |
|  |  |
| Fig 5 Trend analysis (Sen's slope estimate- Q) of Monthly Potential Evapotranspiration at Hisar during period 1985-2019 | Fig 6 Trend analysis (Sen's slope estimate- Q) of Monthly Potential Evapotranspiration at Sirsa during period 1985-2019 |