**Original Research Article**

**Impact of Climate Change on Potential Evapotranspiration in Bawal and Karnal Districts of Haryana, India: A Spatio-Temporal Analysis**

***ABSTRACT***

Crop water demands are determined in part by potential evapotranspiration (PET), which is essential to irrigation planning. Therefore, using the non-parametric Mann–Kendall (MK) test, trends in PET were found over Bawal and Karnal in Haryana (India) in the current study. Using weather data for 35 years from 1985 to 2019, PET values were first approximated using the Thornthwaite method for various time frames. At Bawal and Karnal, PET was observed to rise significantly over the yearly, *kharif, rabi*, pre-monsoon, monsoon, and post-monsoon time scales. Wind speed was shown to have a dynamic influence on the observed PET variations at the annual time scale and throughout all seven seasons in the Bawal and Karnal upon investigating the causal meteorological parameters accountable for the reported PET trends in these regions. The study's findings corroborate the theory that evapotranspiration rises over Bawal and Karnal.

**KEY WORDS:** E*vapotranspiration, trend, PET, meteorological parameters, Bawal and Karnal*

**Introduction**

 The availability of water has emerged as a key issue for planning and development, including flood prevention and food production. Due to the decrease in water supply in various regions of the world, the effects of climate change may be rather severe. According to Kothawale and Rupa Kumar (2002), during the past century, the mean annual temperature of all of India has increased at a rate of 0.05 °C decade−1, primarily as a result of an increase in the maximum temperature (0.07 °C decade−1) rather than a rise in the minimum temperature (0.02 °C decade−1). Most people agree that increased temperature can often cause an increase in evapotranspiration. The Food and Agriculture Organisation (FAO) adopted the concept of reference evapotranspiration (RET) in the FAO guidelines for crop water requirements based on studies by Doorenbos and Pruitt (1975, 1977), which are widely accepted for calculating evapotranspiration. The FAO recognised that evapotranspiration is one of the fundamental components of the hydrologic cycle.

 Evapotranspiration, or ET, is a crucial component of the hydrological and meteorological cycles and is recognised as a primary parameter representing climatic fluctuations (Luo *et al*., 2014, Yan *et al*., 2020, and Yin *et al*., 2020). The likelihood of heatwave occurrences and their persistence have increased recently, and as a result, many locations have experienced changes in ET, precipitation, and other climatic variables (Lyakaremye *et al*., 2021 and Ullah *et al*., 2022). Since, ET may be directly employed as an input variable in many hydrodynamic and water quality modelling systems, it is critical to comprehend its spatiotemporal features and contributing elements in the context of current climate change.

 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.

 A thorough comprehension of the spatiotemporal fluctuations in ET0 is necessary for more effective water resource planning and management. The "evaporation paradox" refers to this contentious behavior (Burn and Hesch, 2007), which defies intuitive assumption and has been observed to diminish in many places with rising temperatures (Liu, 2012). Numerous researchers have looked into the spatiotemporal variations in ET0 and the contributing climatic factors as a result of the “evaporation paradox”, which essentially offers a clear indication that the variations are the result of changes in multiple variables rather than any one variable.

 Several scholars have used data of varying durations at varying locations under varying types of climate to assess trends in evapotranspiration under warmer climates worldwide (Dinpashoh *et al*., 2011 and Jhajharia *et al*., 2012). Significant drops in pan evaporation (Epan) or potential evapotranspiration (PET) over different regions of the United States, over India, over several regions of the United States, over a few sites in the United States and the former Soviet Union, and over Australia were reported by Lawrimore and Peterson (2000), Golubev *et al*. (2001), and Roderick and Farquhar (2004), respectively. Similar declines in evapotranspiration were noted by a number of Chinese researchers (Zhang *et al*., 2007, Zhang *et al*., 2009 and Liu *et al*., 2010). Comparably, Epan was found 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) reported significant decreasing trends in evapotranspiration over different parts of northeast India for other studies from the Indian subcontinent.

 The PET trends may have a direct influence on the production of crops, and thus tracking trends in RET under climate change is vital for understanding the effect of altering RET on agriculture. One of the most well-known locations in the Thar Desert, Bikaner, has seen a number of changes in recent decades as a result of urbanisation and the widespread construction of irrigation canal networks of the Indira Gandhi Canal, which carries water from the Satluj and Vayas Rivers through the states of Punjab, Haryana, and Himachal Pradesh into the vast dry lands of the Thar Desert in the western part of Rajasthan. During the last 58 years, from 1951 to 2008, Bikaner has seen considerable increases in minimum, maximum, and mean temperatures at the annual time scale in the range of 0.1–0.4 °C decade−1 (Choudhary *et al*., 2009). The observed temperature rises in the Bawal and Karnal region during this time frame encouraged researchers to find out whether the arid climates of Bawal and Karnal would see any increases in evapotranspiration under global warming scenarios. The current study was conducted with the following goals because there is no information available regarding trends in PET over Bawal and Karnal: (1) calculate the potential evapotranspiration (mm/day) in Bawal and Karnal using the Thornthwaite formula; (2) calculate the evapotranspiration at Bawal and Karnal under arid climatic conditions; and (3) use the Mann–Kendall (MK) non-parametric test to look into trends in PET.

**Materials and methods**

**Study area and meteorological data**

 The objective of this study was to compute the spatiotemporal trend analysis of evapotranspiration at two distinct locations in Haryana, namely Bawal and Karnal, which are located in different agroclimatic zones. The study was conducted at the Department of Agricultural Meteorology, CCS HAU Hisar. The highest and lowest temperatures, or meteorological data, were gathered between 1985 and 2019 from the agro-met department of CSSRI Karnal in Hisar, IMD.

**Mann-Kendall techniques for analysing trends**

 Because the non-parametric MK method is less affected by the presence of outliers in the data and is better suited for non-normally distributed and censored data, it was employed in this study to identify trends in evapotranspiration and other climatic parameters (Mann, 1945; Kendall, 1975). Here, trends in PET are detected using the Mann-Kendall test, which is frequently used to evaluate the monotonic trend of the hydro-meteorological time series. This has been done with the hypothesis (H0) that the variable has no trend and the alternative hypothesis (HA) that the variable has a monotonic trend. Consequently, the MK statistic may be computed using the following formula: it is the total of the positive differences less the negative differences. The following statistic is used by the MK Test 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

 Additionally, at the 0.1, 0.05, and 0.001 significance levels, the statistical significance of the trend tendency of the mean temperature and rainfall was assessed using an anormalized test statistic.Geographic Information Systems (GIS) are utilised for interpolation in order to obtain data on the spatial distribution of PET for the entire state of Haryana. For this, CCSHAU Hisar's Arc GIS 10.4 software, which is accessible at the Department of Agriculture Meteorology, is used.

 The long-time sire’s daily temperature data was concealed into monthly mean temperature. Monthly mean temperature was used for computation of monthly PET by Thornthwaite method as given below:

Thornthwaite method for ET,

E = 1.6 (10T/I)a

Thornthwaite method (1948) further gave the following formula for computing 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

 To evaluate the ET, analysis of temperature data spanning more than 30 years was done. Results of a study on seasonal and annual ET patterns in the states of Bawal and Karnal, Haryana, were produced using daily temperature data spanning 35 years.

**Results and Discussion**

**Bawal**

 Bawal is located in the southern region of Haryana and is encircled by the Rajasthani desert. Despite having somewhat more rainfall than the other two stations in the western agroclimatic region (Hisar and Sirsa), the area's sandy soils also limit its potential for agriculture. According to Table 1, the potential evapotranspiration at Bawal station (Rewari) during the period of 1985–2019 was observed at its maximum in June 1990, or 14.24 mm/day, and at its minimum in January 1993, or 0.19 mm/day. The normal potential evapotranspiration also reached its maximum in June, or 10.79 mm/day, and its minimum in January, or 0.33 mm/day. For the Bawal site, a PET of 4.72 mm/day was noted as the yearly normal. The normal values for the winter, pre-monsoon, monsoon, and post-monsoon seasons were 0.55, 5.78, 8.06, and 1.97 mm/day, respectively, while for the *kharif and rabi* seasons were 7.90 and 1.53 mm/day.

 For the *kharif* season, the minimum and maximum numbers were 6.31 in 1997 and 9.79 in 1987, respectively; for the *rabi* season, the figures were 1.32 in 2012 and 1.80 in 2016. According to Table 2, PET values varied throughout the meteorological season from 0.31 to 0.94 in the winter, 4.22 to 8.30 in the pre-monsoon, 6.56 to 11.36 in the monsoon, and 1.59 to 2.66 mm/day in the 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. In the months of January and June, respectively, the lowest and maximum monthly potential evapotranspiration were determined to be 0.19 and 14.24 mm/day. The statistical parameters, or mean, standard deviation (SD), and coefficient of variation (CV), were found to vary from 0.33 to 10.79 mm, 0.08 to 1.67 mm, and 11.30 to 28.77%, respectively, based on tabulated figures. As Table 5 illustrates, the skewness and kurtosis ranged from -0.02 to 2.27 mm and -0.56 to 7.80 mm, respectively.

 In table 5, three months—December, January, and February—had greater variability (CV) than the other months. When comparing the Bawal station's long-term PET data (1985–2019) to other stations in the western agroclimatic zone, it can be concluded that this station experienced the least variation. October was the only month with a growing trend and a lower level of significance. There was also a non-significant positive/increasing trend in the yearly PET. As indicated in Table 4, the months of January, June, September, and December had a -ve trend, or falling trend, whereas the remaining months showed a +ve non-significant trend.Table 4. revealed that whereas the *kharif* season had a non-significant increasing trend, the *rabi* season had demonstrated a positive significant trend or increasing tendency.

 Table 3 indicates that during meteorological seasons, the pre-monsoon and post-monsoon had a non-significant positive trend, whereas the winter and monsoon seasons had a negative non-significant trend or decreasing. There was also a non-significant +ve trend in the annual readings. June saw a high ET of 10.79 mm/day at Bawal, which dropped to 5.99 mm/day in September. *Rabi* season saw a consistent drop in temperature (0.33 mm/day) through January as a result of the winter's low temperatures, followed by a rise in temperature around the summer solstices in February, March, and April.

 A minor trend at Bawal or PET had very little fluctuation over time, according to trend analysis. Only one month (at the 0.5 level of significance) was observed in the monthly PET trend; all other months, with the exception of January, June, September, and December, showed non-significant positive trends. On a seasonal basis, only the *rabi* season displayed positive significant trends. PET did not much change over the remainder of the season. From 1985 to 2005, Ingle *et al*. (2009) monitored the PET in Maharashtra. Using comparable patterns, the only months with a positive significant trend were March and October.

**Karnal**

 According to Table 2, the potential evapotranspiration of the Karnal station from 1985 to 2019 was recorded as having a maximum in June 2012 of 10.38 mm/day and a minimum in January 2003 of 0.26 mm/day. The normal monthly potential evapotranspiration was also recorded to have a maximum of 8.63 mm/day in June and a minimum of 0.43 mm/day in January. The yearly average for the Karnal area was found to be 4.14 mm/day for PET. The normal values were 6.78 and 1.49 mm/day in the *kharif* and *rabi* seasons, and 0.64, 4.91, 6.99, and 1.89 mm/day in the winter, pre-monsoon, monsoon, and post-monsoon seasons, respectively. For the *kharif* season, the lowest and maximum PET levels were 5.90 in 1997 and 7.42 in 1987, respectively; for the Rabi season, the values were 1.30 in 2012 and 1.70 in 2008.

 As indicated in Table 4, the PET fluctuated from 0.49 to 0.96 in the winter, 3.92 to 6.18 in the pre-monsoon, 6.30 to 8.41 in the monsoon, and 1.57 to 2.22 mm/day in the post-monsoon between 1985 and 2019. Variation is greatest prior to the monsoon season. The *kharif* and *rabi* seasons differed significantly, with the former having a five-times higher PET than the latter. Pre-monsoon and monsoon are the two meteorological seasons with the highest PET, respectively. The next two seasons' PET values were significantly lower because of the cold. In the months of January and June, respectively, the lowest and maximum monthly potential evapotranspiration were found to be 0.26 and 10.38 mm/day. The coefficient of variation (CV), standard deviation (SD), and mean varied from 7.06 to 19.62%, 0.08 to 0.98 mm, and 0.43 to 8.63 mm, respectively. Table 5 displays the range of values for skewness and kurtosis, which are -0.55 to 1.96 and -0.78 to 6.47, respectively. Variation (CV) was found to be larger in the cool months of the year compared to the hot months.

 The long-term PET data (1985–2019) displayed a -ve significant trend in the months of January and December, according to the trend analysis performed using the MK test. Additionally, June displayed a -ve non-significant trend, or a declining trend, whereas the other months displayed a +ve non-significant trend, or an increasing trend. There was a non-significant positive trend in the yearly PET as well. With the exception of a few months, Karnal's temporal trend of PET is thought to be relatively constant, as Table 6 indicates. The seasonal PET trend at Karnal revealed an increasing non-significance trend during the *kharif* and *rabi* seasons. According to Table 3, one meteorological season demonstrated a positive non-significant trend and another revealed a negative significant trend during the winter at the 0.05 level of significance. According to Sen's estimated slope, the wintertime PET was found to be declining at a rate of 0.002 mm each day.

 A typical station for the Eastern Agroclimatic Zone is Karnal. In the *rabi* season, October exhibited high ET (3.38 mm/day) which was consistently dropped till January (0.43 mm/day) and further increased to March due to the increase in temperature in the summer. In the *kharif* season, June showed high PET (8.63 mm/month) which was linearly declined to September (5.37 mm/day). Ren *et al*. (2012) computed the Hailer Meteorological Station, which is located in a cold, semi-arid, and sub-humid zone, and revealed similar results.

 Due to the drop in temperature throughout the winter, the monthly PET trend was found negatively significant in December and January. However, the subsequent months, with the exception of March and June, showed non-significant positive trends because of lag thermal gradients. According to seasonal trend analysis (MK Test), the PET trend showed a non-significant positive trend throughout the *kharif* season, similar to the *rabi* season. The winter season in the meteorological season exhibited a non-significant positive trend, but the pre-, monsoon, and post-monsoon seasons showed a negative significant trend (0.05 level of significance). There was a non-significant upward trend in annual PET. Overall, it is evident for the Karnal site that the winter season is changing, with diminishing trends at a rate of -0.002 mm/day. All other stations have also shown a reduction in PET over the winter, but Karnal was the first to note that the pattern was statistically significant.

**Conclusions**

 Considering to the significance of potential evapotranspiration (PET) in water balance studies, irrigation planning, reservoir planning, and operation, an attempt has been made to estimate PET using the Penman–Monteith (PM) method over Bawal and Karnal in this work. Following the estimation of PET using the PM technique, the trends in RET in Bawal and Karnal dry areas were examined in light of the region's changing climate. Over Bawal and Karnal, statistically significant declining trends in wind speed in annual and seasonal time scales were observed, associated with declining trends in PET in annual and seasonal (*kharif, rabi*, winter, pre-monsoon, monsoon, and post-monsoon) time scales. In the arid Bawal and Karnal region, the current study will be helpful in precisely determining the major agricultural water requirements under changing climates.

**Disclaimer (Artificial intelligence)**

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (Chat GPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Year  | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| 1985  | 0.29 | 0.75 | 2.97 | 6.38 | 10.75 | 11.79 | 7.88 | 7.36 | 6.14 | 3.17 | 1.48 | 0.56 |
| 1986  | 0.38 | 0.60 | 2.00 | 6.16 | 7.85 | 11.62 | 8.51 | 6.81 | 6.27 | 3.56 | 1.74 | 0.36 |
| 1987  | 0.32 | 0.99 | 2.06 | 6.45 | 6.86 | 12.66 | 14.00 | 10.24 | 8.54 | 4.69 | 1.48 | 0.37 |
| 1988  | 0.44 | 0.85 | 1.77 | 6.16 | 12.59 | 8.49 | 7.30 | 6.10 | 7.20 | 3.50 | 1.61 | 0.58 |
| 1989  | 0.30 | 0.69 | 2.10 | 4.43 | 9.19 | 11.44 | 8.33 | 7.23 | 5.69 | 3.64 | 1.50 | 0.37 |
| 1990  | 0.51 | 0.60 | 1.43 | 5.91 | 7.96 | 14.24 | 7.53 | 5.83 | 6.02 | 4.54 | 2.51 | 0.92 |
| 1991  | 0.33 | 0.66 | 1.78 | 4.56 | 8.81 | 10.82 | 10.86 | 7.31 | 6.30 | 3.25 | 1.63 | 0.62 |
| 1992  | 0.49 | 0.41 | 2.26 | 5.21 | 10.95 | 13.87 | 7.98 | 5.24 | 5.94 | 3.59 | 1.40 | 0.60 |
| 1993  | 0.19 | 1.08 | 1.73 | 4.05 | 10.57 | 11.18 | 6.46 | 8.15 | 5.88 | 3.75 | 1.76 | 0.49 |
| 1994  | 0.37 | 0.63 | 2.18 | 4.52 | 9.52 | 8.97 | 6.36 | 5.74 | 5.26 | 3.30 | 1.69 | 0.78 |
| 1995  | 0.40 | 0.82 | 1.79 | 4.70 | 9.37 | 11.46 | 8.67 | 5.31 | 5.10 | 3.95 | 1.65 | 0.60 |
| 1996  | 0.41 | 1.00 | 2.39 | 4.82 | 8.43 | 8.80 | 7.14 | 5.65 | 4.65 | 3.35 | 1.40 | 0.45 |
| 1997  | 0.41 | 0.81 | 1.98 | 4.06 | 6.61 | 7.92 | 7.99 | 5.85 | 5.43 | 2.91 | 1.45 | 0.41 |
| 1998  | 0.30 | 0.77 | 1.57 | 5.15 | 9.73 | 9.46 | 8.42 | 7.23 | 6.22 | 3.76 | 1.67 | 0.58 |
| 1999  | 0.38 | 0.84 | 2.27 | 5.93 | 9.05 | 9.49 | 8.40 | 7.10 | 6.17 | 3.59 | 1.59 | 0.47 |
| 2000  | 0.40 | 0.56 | 1.78 | 6.00 | 10.68 | 9.65 | 6.81 | 7.13 | 5.46 | 3.91 | 1.59 | 0.55 |
| 2001  | 0.29 | 0.76 | 1.89 | 5.30 | 8.36 | 8.38 | 7.72 | 7.46 | 6.73 | 4.15 | 1.75 | 0.70 |
| 2002  | 0.23 | 0.50 | 2.13 | 6.66 | 10.68 | 12.49 | 13.19 | 7.77 | 5.59 | 3.93 | 1.55 | 0.59 |
| 2003  | 0.21 | 0.73 | 2.09 | 6.44 | 9.20 | 11.95 | 7.21 | 6.48 | 5.88 | 3.24 | 1.40 | 0.52 |
| 2004  | 0.24 | 0.69 | 2.94 | 7.48 | 10.05 | 10.31 | 10.93 | 6.59 | 6.55 | 3.28 | 1.63 | 0.53 |
| 2005  | 0.30 | 0.70 | 2.66 | 4.92 | 8.24 | 11.20 | 7.43 | 7.67 | 6.03 | 3.56 | 1.61 | 0.38 |
| 2006  | 0.34 | 1.54 | 2.05 | 6.53 | 11.00 | 9.88 | 8.40 | 6.88 | 6.09 | 3.92 | 1.62 | 0.46 |
| 2007  | 0.30 | 0.90 | 1.87 | 6.71 | 9.71 | 11.18 | 8.59 | 7.24 | 6.06 | 3.46 | 1.91 | 0.43 |
| 2008  | 0.22 | 0.40 | 2.56 | 5.44 | 7.56 | 7.46 | 7.50 | 6.37 | 5.57 | 4.29 | 1.86 | 0.82 |
| 2009  | 0.40 | 0.82 | 2.32 | 6.02 | 10.60 | 13.28 | 8.96 | 8.10 | 6.27 | 3.66 | 1.49 | 0.55 |
| 2010  | 0.24 | 0.81 | 3.46 | 9.18 | 12.25 | 12.19 | 8.14 | 6.49 | 5.18 | 4.00 | 1.55 | 0.39 |
| 2011  | 0.26 | 0.80 | 2.21 | 4.91 | 9.96 | 9.99 | 7.84 | 6.73 | 5.35 | 3.55 | 1.90 | 0.51 |
| 2012  | 0.35 | 0.52 | 1.98 | 5.17 | 9.17 | 12.44 | 9.34 | 6.10 | 5.40 | 3.27 | 1.35 | 0.48 |
| 2013  | 0.26 | 0.71 | 2.15 | 5.06 | 9.46 | 9.81 | 7.70 | 6.00 | 5.85 | 3.71 | 1.20 | 0.61 |
| 2014  | 0.24 | 0.50 | 1.62 | 4.87 | 8.25 | 11.28 | 9.06 | 12.41 | 6.14 | 4.07 | 1.63 | 0.40 |
| 2015  | 0.29 | 1.01 | 1.90 | 5.13 | 9.91 | 9.52 | 7.80 | 7.29 | 6.67 | 4.36 | 1.87 | 0.52 |
| 2016  | 0.41 | 0.71 | 2.73 | 7.11 | 10.55 | 11.37 | 7.62 | 6.67 | 6.57 | 4.43 | 1.72 | 0.82 |
| 2017  | 0.40 | 0.91 | 2.31 | 7.37 | 9.89 | 9.41 | 8.06 | 7.09 | 6.13 | 4.22 | 1.53 | 0.60 |
| 2018  | 0.37 | 1.05 | 2.65 | 6.15 | 9.07 | 11.52 | 8.00 | 7.12 | 5.07 | 3.56 | 1.60 | 0.44 |
| 2019  | 0.37 | 0.66 | 1.73 | 5.11 | 8.36 | 12.16 | 8.86 | 7.11 | 6.38 | 3.97 | 1.97 | 0.31 |
| Normal  | 0.33 | 0.77 | 2.15 | 5.72 | 9.46 | 10.79 | 8.43 | 7.02 | 5.99 | 3.75 | 1.64 | 0.54 |

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

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| 1985 | 0.46 | 0.85 | 2.52 | 5.17 | 8.83 | 10.34 | 6.83 | 6.34 | 5.19 | 2.80 | 1.45 | 0.83 |
| 1986 | 0.50 | 0.76 | 2.02 | 4.76 | 6.17 | 8.15 | 6.88 | 6.33 | 4.92 | 3.25 | 1.86 | 0.60 |
| 1987 | 0.52 | 1.04 | 2.08 | 5.08 | 5.81 | 9.27 | 9.78 | 8.05 | 6.54 | 3.90 | 1.55 | 0.65 |
| 1988 | 0.59 | 0.91 | 1.87 | 5.65 | 9.45 | 8.72 | 6.87 | 6.10 | 5.62 | 3.36 | 1.62 | 0.75 |
| 1989 | 0.43 | 0.75 | 1.94 | 3.94 | 7.96 | 7.61 | 7.56 | 6.02 | 5.35 | 3.50 | 1.59 | 0.65 |
| 1990 | 0.65 | 0.85 | 1.60 | 4.53 | 7.85 | 10.14 | 6.69 | 6.35 | 5.54 | 3.15 | 1.76 | 0.72 |
| 1991 | 0.44 | 0.97 | 1.97 | 4.11 | 7.70 | 7.70 | 8.53 | 6.18 | 5.25 | 2.99 | 1.36 | 0.70 |
| 1992 | 0.58 | 0.65 | 1.94 | 4.39 | 6.88 | 8.72 | 6.76 | 5.99 | 5.06 | 3.13 | 1.60 | 0.80 |
| 1993 | 0.45 | 1.04 | 1.49 | 4.26 | 8.14 | 8.88 | 7.21 | 7.25 | 4.74 | 3.08 | 1.67 | 0.73 |
| 1994 | 0.57 | 0.76 | 2.24 | 4.70 | 7.80 | 9.41 | 6.76 | 6.46 | 5.03 | 3.00 | 1.55 | 0.80 |
| 1995 | 0.42 | 0.86 | 1.59 | 4.28 | 8.15 | 9.54 | 7.40 | 5.73 | 5.25 | 3.65 | 1.67 | 0.74 |
| 1996 | 0.48 | 0.85 | 2.22 | 4.60 | 7.59 | 7.87 | 7.41 | 5.95 | 5.05 | 3.18 | 1.48 | 0.56 |
| 1997 | 0.45 | 0.82 | 1.94 | 3.69 | 6.14 | 7.21 | 6.92 | 5.93 | 5.54 | 2.73 | 1.48 | 0.52 |
| 1998 | 0.40 | 0.88 | 1.45 | 4.77 | 8.73 | 8.82 | 7.31 | 6.21 | 5.52 | 3.47 | 1.81 | 0.62 |
| 1999 | 0.39 | 0.83 | 2.04 | 5.88 | 8.41 | 8.50 | 7.70 | 6.70 | 5.66 | 3.59 | 1.68 | 0.64 |
| 2000 | 0.44 | 0.56 | 1.68 | 5.45 | 8.84 | 7.53 | 6.88 | 6.76 | 5.69 | 3.85 | 1.84 | 0.65 |
| 2001 | 0.37 | 0.88 | 1.90 | 4.62 | 7.67 | 6.94 | 7.40 | 6.76 | 5.77 | 3.72 | 1.75 | 0.70 |
| 2002 | 0.41 | 0.72 | 2.07 | 5.40 | 9.06 | 8.92 | 9.47 | 6.73 | 4.56 | 3.23 | 1.63 | 0.73 |
| 2003 | 0.26 | 0.85 | 1.89 | 5.40 | 7.54 | 9.65 | 7.01 | 6.56 | 5.41 | 3.15 | 1.49 | 0.68 |
| 2004 | 0.41 | 0.85 | 2.61 | 6.09 | 7.88 | 7.41 | 8.18 | 6.22 | 5.64 | 3.05 | 1.66 | 0.72 |
| 2005 | 0.42 | 0.82 | 2.31 | 4.54 | 7.13 | 8.90 | 7.06 | 7.17 | 5.35 | 3.41 | 1.62 | 0.52 |
| 2006 | 0.44 | 1.49 | 1.86 | 5.21 | 8.45 | 8.64 | 7.63 | 7.04 | 5.54 | 3.63 | 1.72 | 0.64 |
| 2007 | 0.44 | 0.88 | 1.73 | 5.96 | 7.96 | 8.69 | 7.84 | 6.77 | 5.36 | 3.00 | 1.57 | 0.56 |
| 2008 | 0.38 | 0.60 | 2.56 | 4.69 | 6.59 | 6.81 | 7.27 | 6.11 | 5.03 | 4.05 | 1.75 | 0.87 |
| 2009 | 0.50 | 0.97 | 2.13 | 5.23 | 7.85 | 9.80 | 7.78 | 7.01 | 5.31 | 3.28 | 1.45 | 0.57 |
| 2010 | 0.29 | 0.88 | 2.77 | 6.90 | 8.88 | 8.98 | 7.22 | 6.43 | 4.82 | 3.59 | 1.68 | 0.52 |
| 2011 | 0.31 | 0.92 | 2.10 | 4.29 | 7.76 | 7.36 | 7.11 | 6.30 | 5.38 | 3.45 | 1.94 | 0.67 |
| 2012 | 0.38 | 0.63 | 1.84 | 4.60 | 7.94 | 10.38 | 7.87 | 6.06 | 5.24 | 2.90 | 1.47 | 0.59 |
| 2013 | 0.29 | 0.79 | 2.00 | 4.61 | 8.17 | 8.04 | 7.40 | 6.23 | 5.53 | 3.85 | 1.43 | 0.66 |
| 2014 | 0.40 | 0.66 | 1.67 | 4.10 | 6.96 | 10.20 | 7.77 | 7.08 | 5.31 | 3.43 | 1.60 | 0.50 |
| 2015 | 0.34 | 0.99 | 1.78 | 4.28 | 7.93 | 8.03 | 6.87 | 6.29 | 5.50 | 3.58 | 1.79 | 0.63 |
| 2016 | 0.42 | 0.80 | 2.10 | 5.73 | 8.15 | 9.35 | 7.38 | 6.41 | 5.86 | 3.80 | 1.70 | 0.70 |
| 2017 | 0.48 | 0.91 | 1.87 | 5.78 | 8.16 | 8.04 | 7.42 | 6.70 | 5.28 | 3.69 | 1.30 | 0.66 |
| 2018 | 0.40 | 0.92 | 2.36 | 5.09 | 7.63 | 8.31 | 7.16 | 6.49 | 5.06 | 3.25 | 1.69 | 0.53 |
| 2019 | 0.44 | 0.76 | 1.46 | 5.07 | 7.38 | 9.31 | 7.16 | 6.75 | 6.03 | 3.52 | 1.86 | 0.39 |
| Normal | 0.43 | 0.85 | 1.99 | 4.94 | 7.82 | 8.63 | 7.44 | 6.50 | 5.37 | 3.38 | 1.63 | 0.65 |

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

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Year | Annual | *Kharif* | *Rabi* | Winter | Premonsoon | Monsoon | Postmonsoon |
| 1985 | 4.96 | 8.38 | 1.54 | 0.52 | 6.70 | 8.29 | 1.74 |
| 1986 | 4.65 | 7.87 | 1.44 | 0.49 | 5.34 | 8.30 | 1.88 |
| 1987 | 5.72 | 9.79 | 1.65 | 0.66 | 5.12 | 11.36 | 2.18 |
| 1988 | 4.72 | 7.97 | 1.46 | 0.65 | 6.84 | 7.27 | 1.90 |
| 1989 | 4.57 | 7.72 | 1.43 | 0.50 | 5.24 | 8.17 | 1.83 |
| 1990 | 4.83 | 7.91 | 1.75 | 0.56 | 5.10 | 8.40 | 2.66 |
| 1991 | 4.74 | 8.11 | 1.38 | 0.49 | 5.05 | 8.82 | 1.83 |
| 1992 | 4.83 | 8.20 | 1.46 | 0.45 | 6.14 | 8.26 | 1.87 |
| 1993 | 4.61 | 7.71 | 1.50 | 0.64 | 5.45 | 7.92 | 2.00 |
| 1994 | 4.11 | 6.73 | 1.49 | 0.50 | 5.40 | 6.58 | 1.93 |
| 1995 | 4.49 | 7.44 | 1.53 | 0.61 | 5.29 | 7.64 | 2.07 |
| 1996 | 4.04 | 6.58 | 1.50 | 0.71 | 5.21 | 6.56 | 1.73 |
| 1997 | 3.82 | 6.31 | 1.33 | 0.61 | 4.22 | 6.79 | 1.59 |
| 1998 | 4.57 | 7.70 | 1.44 | 0.53 | 5.48 | 7.83 | 2.00 |
| 1999 | 4.61 | 7.69 | 1.52 | 0.61 | 5.75 | 7.79 | 1.88 |
| 2000 | 4.54 | 7.62 | 1.46 | 0.48 | 6.15 | 7.26 | 2.01 |
| 2001 | 4.46 | 7.32 | 1.59 | 0.52 | 5.18 | 7.57 | 2.20 |
| 2002 | 5.44 | 9.40 | 1.49 | 0.36 | 6.49 | 9.76 | 2.02 |
| 2003 | 4.61 | 7.86 | 1.37 | 0.47 | 5.91 | 7.88 | 1.72 |
| 2004 | 5.10 | 8.65 | 1.55 | 0.46 | 6.82 | 8.59 | 1.81 |
| 2005 | 4.56 | 7.58 | 1.54 | 0.50 | 5.27 | 8.08 | 1.85 |
| 2006 | 4.89 | 8.13 | 1.66 | 0.94 | 6.52 | 7.81 | 2.00 |
| 2007 | 4.86 | 8.25 | 1.48 | 0.60 | 6.10 | 8.27 | 1.93 |
| 2008 | 4.17 | 6.65 | 1.69 | 0.31 | 5.19 | 6.73 | 2.32 |
| 2009 | 5.21 | 8.87 | 1.54 | 0.61 | 6.31 | 9.15 | 1.90 |
| 2010 | 5.32 | 8.90 | 1.74 | 0.53 | 8.30 | 8.00 | 1.98 |
| 2011 | 4.50 | 7.46 | 1.54 | 0.53 | 5.69 | 7.48 | 1.98 |
| 2012 | 4.63 | 7.93 | 1.32 | 0.43 | 5.44 | 8.32 | 1.70 |
| 2013 | 4.38 | 7.31 | 1.44 | 0.48 | 5.56 | 7.34 | 1.84 |
| 2014 | 5.04 | 8.67 | 1.41 | 0.37 | 4.91 | 9.73 | 2.03 |
| 2015 | 4.69 | 7.72 | 1.66 | 0.65 | 5.65 | 7.82 | 2.25 |
| 2016 | 5.06 | 8.32 | 1.80 | 0.56 | 6.80 | 8.06 | 2.32 |
| 2017 | 4.83 | 7.99 | 1.66 | 0.65 | 6.52 | 7.67 | 2.12 |
| 2018 | 4.72 | 7.82 | 1.61 | 0.71 | 5.96 | 7.93 | 1.87 |
| 2019 | 4.75 | 8.00 | 1.50 | 0.52 | 5.07 | 8.63 | 2.08 |
| Normal | 4.72 | 7.90 | 1.53 | 0.55 | 5.78 | 8.06 | 1.97 |

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

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Year  | Annual | *Kharif* | *Rabi* | Winter | Pre-monsoon | Monsoon | Postmonsoon |
| 1985  | 4.30 | 7.12 | 1.48 | 0.65 | 5.51 | 7.17 | 1.69 |
| 1986  | 3.85 | 6.20 | 1.50 | 0.63 | 4.32 | 6.57 | 1.90 |
| 1987  | 4.52 | 7.42 | 1.62 | 0.78 | 4.32 | 8.41 | 2.04 |
| 1988  | 4.29 | 7.07 | 1.52 | 0.75 | 5.66 | 6.83 | 1.91 |
| 1989  | 3.94 | 6.41 | 1.48 | 0.59 | 4.61 | 6.64 | 1.91 |
| 1990  | 4.15 | 6.85 | 1.46 | 0.75 | 4.66 | 7.18 | 1.88 |
| 1991  | 3.99 | 6.58 | 1.41 | 0.71 | 4.59 | 6.91 | 1.68 |
| 1992  | 3.87 | 6.30 | 1.45 | 0.61 | 4.41 | 6.63 | 1.84 |
| 1993  | 4.08 | 6.75 | 1.41 | 0.74 | 4.63 | 7.02 | 1.83 |
| 1994  | 4.09 | 6.69 | 1.49 | 0.66 | 4.91 | 6.92 | 1.78 |
| 1995  | 4.11 | 6.73 | 1.49 | 0.64 | 4.67 | 6.98 | 2.02 |
| 1996  | 3.94 | 6.41 | 1.46 | 0.67 | 4.80 | 6.57 | 1.74 |
| 1997  | 3.61 | 5.90 | 1.32 | 0.63 | 3.92 | 6.40 | 1.57 |
| 1998  | 4.17 | 6.89 | 1.44 | 0.64 | 4.99 | 6.97 | 1.97 |
| 1999  | 4.34 | 7.14 | 1.53 | 0.61 | 5.45 | 7.14 | 1.97 |
| 2000  | 4.18 | 6.86 | 1.50 | 0.50 | 5.32 | 6.71 | 2.11 |
| 2001  | 4.04 | 6.53 | 1.56 | 0.62 | 4.73 | 6.72 | 2.06 |
| 2002  | 4.41 | 7.36 | 1.46 | 0.56 | 5.51 | 7.42 | 1.86 |
| 2003  | 4.16 | 6.93 | 1.39 | 0.55 | 4.94 | 7.16 | 1.77 |
| 2004  | 4.23 | 6.90 | 1.55 | 0.63 | 5.53 | 6.86 | 1.81 |
| 2005  | 4.10 | 6.69 | 1.51 | 0.62 | 4.66 | 7.12 | 1.85 |
| 2006  | 4.36 | 7.09 | 1.63 | 0.96 | 5.17 | 7.21 | 2.00 |
| 2007  | 4.23 | 7.10 | 1.36 | 0.66 | 5.22 | 7.16 | 1.71 |
| 2008  | 3.89 | 6.08 | 1.70 | 0.49 | 4.61 | 6.30 | 2.22 |
| 2009  | 4.32 | 7.16 | 1.48 | 0.73 | 5.07 | 7.47 | 1.77 |
| 2010  | 4.41 | 7.20 | 1.62 | 0.59 | 6.18 | 6.86 | 1.93 |
| 2011  | 3.97 | 6.37 | 1.56 | 0.61 | 4.72 | 6.54 | 2.02 |
| 2012  | 4.16 | 7.02 | 1.30 | 0.50 | 4.80 | 7.39 | 1.65 |
| 2013  | 4.08 | 6.66 | 1.50 | 0.54 | 4.93 | 6.80 | 1.98 |
| 2014  | 4.14 | 6.91 | 1.38 | 0.53 | 4.25 | 7.59 | 1.84 |
| 2015  | 4.00 | 6.48 | 1.52 | 0.66 | 4.66 | 6.67 | 2.00 |
| 2016  | 4.37 | 7.15 | 1.59 | 0.61 | 5.33 | 7.25 | 2.07 |
| 2017  | 4.19 | 6.90 | 1.48 | 0.69 | 5.27 | 6.86 | 1.88 |
| 2018  | 4.07 | 6.62 | 1.52 | 0.66 | 5.02 | 6.75 | 1.82 |
| 2019  | 4.18 | 6.95 | 1.41 | 0.60 | 4.64 | 7.31 | 1.92 |
| Normal  | 4.14 | 6.78 | 1.49 | 0.64 | 4.91 | 6.99 | 1.89 |

Table 5 Descriptive Statistical for monthly Potential Evapotranspiration at Bawal and Karnal

|  |  |  |
| --- | --- | --- |
| Month | Bawal | Karnal |
| Max | Min | Mean | SD | CV | Skewness | Kurtosis | Max | Min | Mean | SD | CV | Skewness | Kurtosis |
| Jan  | 0.51 | 0.19 | 0.33 | 0.08 | 24.06 | 0.20 | -0.56 | 0.65 | 0.26 | 0.43 | 0.08 | 19.62 | 0.39 | 0.65 |
| Feb  | 1.54 | 0.40 | 0.77 | 0.22 | 28.77 | 1.17 | 3.35 | 1.49 | 0.56 | 0.85 | 0.16 | 19.05 | 1.59 | 6.47 |
| Mar  | 3.46 | 1.43 | 2.15 | 0.44 | 20.38 | 0.99 | 1.17 | 2.77 | 1.45 | 1.99 | 0.32 | 16.24 | 0.49 | 0.09 |
| Apr  | 9.18 | 4.05 | 5.72 | 1.09 | 19.14 | 0.92 | 1.45 | 6.90 | 3.69 | 4.94 | 0.70 | 14.27 | 0.64 | 0.30 |
| May  | 12.59 | 6.61 | 9.46 | 1.35 | 14.31 | 0.08 | 0.10 | 9.45 | 5.81 | 7.82 | 0.83 | 10.56 | -0.55 | 0.43 |
| Jun  | 14.24 | 7.46 | 10.79 | 1.67 | 15.46 | -0.02 | -0.55 | 10.38 | 6.81 | 8.63 | 0.98 | 11.38 | 0.01 | -0.78 |
| Jul  | 14.00 | 6.36 | 8.43 | 1.62 | 19.20 | 2.07 | 4.91 | 9.78 | 6.69 | 7.44 | 0.69 | 9.27 | 1.96 | 4.45 |
| Aug  | 12.41 | 5.24 | 7.02 | 1.33 | 18.93 | 2.27 | 7.80 | 8.05 | 5.73 | 6.50 | 0.47 | 7.20 | 1.12 | 2.11 |
| Sep  | 8.54 | 4.65 | 5.99 | 0.70 | 11.68 | 1.25 | 4.17 | 6.54 | 4.56 | 5.37 | 0.38 | 7.06 | 0.57 | 1.78 |
| Oct  | 4.69 | 2.91 | 3.75 | 0.42 | 11.30 | 0.35 | -0.39 | 4.05 | 2.73 | 3.38 | 0.33 | 9.87 | 0.01 | -0.76 |
| Nov  | 2.51 | 1.20 | 1.64 | 0.23 | 13.86 | 1.59 | 5.43 | 1.94 | 1.30 | 1.63 | 0.15 | 9.27 | -0.09 | -0.46 |
| Dec  | 0.92 | 0.31 | 0.54 | 0.14 | 26.57 | 0.87 | 0.63 | 0.87 | 0.39 | 0.65 | 0.10 | 15.90 | -0.21 | 0.14 |

|  |  |
| --- | --- |
|  |  |
| Fig 1 Trend analysis (Mann-Kendall trend -Test Z) of Monthly Potential Evapotranspiration at Bawal during period 1985-2019 | Fig 2 Trend analysis (Mann-Kendall trend -Test Z) of Monthly Potential Evapotranspiration at Karnal during period 1985-2019 |
|  |  |
| Fig 3 Trend analysis (Sen's slope estimate- Q) of Monthly Potential Evapotranspiration at Bawal during period 1985-2019 | Fig 4 Trend analysis (Sen's slope estimate- Q) of Monthly Potential Evapotranspiration at Karnal during period 1985-2019 |

Table 6 Trend analysis of Monthly Potential Evapotranspiration at Bawal and Karnal during period 1985-2019

|  |  |  |
| --- | --- | --- |
| Month  | Mann-Kendall trend | Sen's slope estimate |
| Test Z | Q |
| Bawal | Karnal | Bawal | Karnal |
| Jan  | -1.051 | -3.181\*\* | -0.001 | -0.004\*\* |
| Feb  | 0.198 | 0.00 | 0.0008 | 0.00 |
| Mar  | 1.249 | -0.085 | 0.008 | -0.0004 |
| Apr  | 1.221 | 1.193 | 0.019 | 0.014 |
| May  | 0.227 | 0.114 | 0.009 | 0.0005 |
| Jun  | -0.227 | -0.085 | -0.006 | -0.003 |
| Jul  | 0.568 | 1.107 | 0.010 | 0.009 |
| Aug  | 0.483 | 1.306 | 0.009 | 0.0102 |
| Sep  | -0.426 | 0.539 | -0.004 | 0.003 |
| Oct  | 1.789+ | 1.618 | 0.015 | 0.011 |
| Nov  | 0.596 | 0.682 | 0.003 | 0.002 |
| Dec  | -0.483 | -2.584\*\* | -0.001 | -0.004\*\* |
| Annual  | 0.426 | 0.937 | 0.003 | 0.002 |

Fig 5 Trend analysis of Seasonal Potential Evapotranspiration at Bawal and Karnal during period 1985-2019

Table 7 Trend analysis of Seasonal Potential Evapotranspiration at Bawal and Karnal during period 1985-2019

|  |  |  |
| --- | --- | --- |
| Season  | Mann-Kendall trend | Sen's slope estimate |
| Test Z | Q |
| Bawal | Karnal | Bawal | Karnal |
| Annual  | 0.426043 | 0.937 | 0.002873 | 0.003 |
| *Kharif*  | 0.19882 | 0.823 | 0.001682 | 0.004 |
| *Rabi*  | 1.732575+ | 0.624 | 0.003334 | 0.001 |
| Winter  | -0.14201 | -2.272\* | -0.00022 | -0.002\* |
| Pre-monsoon  | 1.079309 | 1.335 | 0.013511 | 0.009 |
| Monsoon  | -0.05681 | 0.824 | -0.00126 | 0.006 |
| Post-monsoon  | 1.476949 | 0.766 | 0.004866 | 0.002 |