TREND ANALYSIS OF WEATHER PARAMETERS AND CLIMATIC WATER BALANCE AT NEW DELHI

1. Climate change, the present day’s serious global concern is primarily caused by the increase of green house gases like carbon dioxide, methane, and nitrous oxide in the atmosphere. Global warming, a consequence of climate change, refers to the observed increase in the average temperature of the air near earth’s surface in recent decades. IPCC (2007) has reported that global surface temperature has increased at a rate of 0.74 ± 0.18 °C during 1906 to 2005 and 0.6 ± 0.2 °C during 1901 to 2000. Besides air temperature, climate change also affects precipitation and hence ground water recharge, sea level and hence coastal ecosystem, frequency of extreme weather events like drought, flood and coastal storms, etc. Implications of climate change in the present and future scenario has been documented by many authors (Wigley and Raper, 1992; Chattopadhyay and Hulme, 1997; Sherif and Singh, 1999; Patz et al., 2005; Lehner et al., 2006; Kundzewicz et al., 2009). As climate change adversely affects the natural ecosystem of a region, Indian agriculture, on which 58% of the population depends for livelihood, is likely to be negatively impacted by it, jeopardizing the future food and water security. So, it necessitates knowing the trends in climatic variables to assess the extent of climate change for devising adaptation and mitigation measures for agricultural sustainability.

As climate change may alter the regime of climatic parameters such as rainfall and potential evapotranspiration of a place, the estimates of soil water balance and water balance indices (humidity index, aridity index, and moisture index) at a given location, will provide useful information on soil moisture storage, period of water deficit, and water surplus for agricultural planning (Verma et al., 2012). Knowledge of moisture deficit gives the idea for supplemental irrigation requirement, whereas moisture surplus for drainage provision and moisture storage for future use in agriculture. The soil water balance study can be successfully utilized for estimating probable length of growing season, irrigation needs, leaching of salts, variations in water table depth, drought risk assessment, soil water availability for sowing of crops, crop planning and judging the agricultural potential of the region (Verma et al., 2012). The climatic water balance of Thornthwaite and Mather (1955) has been commonly used for wide range of soil and vegetation conditions in India (Debnath, 1996; Sudhishri et al., 2007; Verma et al., 2012). So, keeping these in view, this study was undertaken to see the long term trend of the weather parameters vis-à-vis the climatic water balance of the New Delhi station.

This study is based on weather data collected at the agromet observatory of ICAR-Indian Agricultural Research Institute, New Delhi located at 28°38'23" N latitude and 77°09'27" E longitude at an elevation of 229 m above sea level. The climate of the area is semi-arid with warm summer and mild winter. The soil is sandy loam with field capacity of 0.25 m³/m³, permanent wilting point of 0.08 m³/m³ and maximum water holding capacity of 0.41 m³/m³ for a rooting depth of 1.0 m. Daily meteorological data of maximum and minimum temperature, morning and evening relative humidity, rainfall, bright sunshine hour and average wind speed were collected from the year 1995 to 2014 (20 years). From the daily weather data, monthly average, Kharif season (July, August, September and October) average, Rabi season (November, December, January, February and March) average and annual average were calculated and subjected to trend analysis. In the present study, 20 years data has been used to study the trend of weather parameters. However, normally 30 years data is considered for knowing the trend of weather parameters. So, the interpretations of the present work should be used with caution.

Climatic water balance for all the months of a year was calculated following the climatic water balance procedure of Thornthwaite and Mather (1955). In the climatic water balance method, the potential evapotranspiration (PET) was calculated by using FAO-56 Penman-Monteith equation (Allen et al., 1998). This method requires daily data of minimum and maximum temperature (°C), relative humidity (%), wind speed (km/day) and sunshine hours (hr) for computing potential/reference evapotranspiration (ET₀) as follows:

\[ ET₀ = \frac{0.408Δ(R_n - G) + γ \left( \frac{900}{T + 273} \right) U_2 (e_s - e_a)}{Δ + γ(1 + 0.34U_2)} \]  (1)

where, \( R_n \) is the net radiation at the crop surface (MJ/m²/day); \( G \) is the soil heat flux density (MJ/m²/day); \( T \) is the mean daily air temperature at 2 m height (°C); \( U_2 \) is the wind speed at 2 m height (m/s); \( e_a \) is the saturation vapor pressure (kPa); \( e_s \) is the actual vapor pressure (kPa); \( (e_s - e_a) \) is the saturation vapor pressure deficit (kPa); \( Δ \) is the slope of vapor pressure curve (kPa/°C); and \( γ \) is the psychrometric constant (kPa/°C).

Water deficit causes soil moisture stress, which adversely affects crop growth. In order to have optimum crop growth, suplemental irrigation needs to be given at
the appropriate time. Similarly, water surplus results in
waterlogging and hence aeration stress to plant and poor
crop growth. So, water surplus requires provision of
proper drainage for optimum growth of plants. In this
paper, water surplus and deficit was calculated on monthly
basis for crop planning.

The Mann-Kendall test statistic $S$ was calculated
using the formula:

$$S = \sum_{k=1}^{n} \sum_{j=k+1}^{n} \text{sgn}(x_j - x_k)$$

(2)

where, $x_i$ and $x_j$ are the annual values or parameters
in years $j$ and $k$, respectively and $\text{sgn}(x_j - x_k)$ is 1 if
$x_j - x_k > 0$; 0 if $x_j - x_k = 0$ and -1 if $x_j - x_k < 0$.

If $n$ is $\leq 9$, the absolute value of $S$ is compared
directly to the theoretical distribution of $S$ derived by
Mann and Kendall (Gilbert, 1987). At certain probability
level, $H_0$ is rejected in favour of $H_1$, if the absolute value
of $S$ equals or exceeds a specified value $S_{n\alpha/2}$, where $S_{n\alpha/2}$ is
the smallest $S$ which has the probability less than
$\alpha/2$ to appear in case of no trend. A positive or negative
value of $S$ indicates an upward or downward trend,
respectively.

For $n \geq 10$, the statistic $S$ is approximately normally
distributed with zero mean and variance $\text{Var}(S)$ as follows:

$$\text{Var}(S) = \frac{1}{18} \left[ n(n-1)(2n+5) \right]$$

(3)

The standardized test statistic $Z$ is

$$Z = \frac{S - 1}{\sqrt{\text{Var}(S)}}$$

if $S > 0$,

$$Z = \frac{S + 1}{\sqrt{\text{Var}(S)}}$$

if $S < 0$.

The presence of a statistically significant trend is
evaluated using the $Z$ value. A positive or negative value
of $Z$ indicates an upward or downward trend, respectively.
The statistic $Z$ has a normal distribution. To test for either
an upward or downward monotone trend (a two-tailed
test) at $\alpha$ level of significance, $H_0$ is rejected if the
absolute value of $Z$ is greater than $Z_{\alpha/2}$, where $Z_{\alpha/2}$ is
obtained from the standard normal cumulative distribution
tables.

To estimate true slope (change per unit year) within
the time series, Sen’s nonparametric method (Sen, 1968)
is used where the trend is assumed to be linear. The
magnitude of the trend is predicted by the Sen’s estimator.
The slope is calculated by the equation:

$$Q_i = \frac{x_j - x_k}{j-k}$$

for $i = 1, 2, \ldots, N$,

where, $x_j$ and $x_k$ are data values at times $j$ and $k$ ($j > k$),
respectively. The median of these estimates is Sen’s
estimator of slope. A positive or negative value of $Q_i$
indicates an increasing or decreasing trend, respectively.

The mean monthly maximum, minimum and mean
temperature ($°C$), morning, evening and mean relative
humidity (%), bright sunshine hours (h), monthly rainfall
(mm), Potential/Reference evapotranspiration (mm/day)
and average wind speed (km/hr) are presented in Table 1.
It was observed that May was the hottest month whereas
January was the coldest month during the study period.
Summer (April, May and June) season was drier
compared to Kharif (July, August, September and
October) and Rabi (November, December, January,
February and March) season as indicated by lower relative
humidity. Summer season also showed higher number of
bright sunshine hour and average wind speed. The higher
pan evaporation in April, May and June seems to be
related to the higher temperature, lower humidity, more
number of bright sunshine hour and higher average wind
speed in these months.

The mean annual maximum temperature ranged
between 29.38 to 31.59 °C with an average value of
30.86 ± 0.55 °C for the period 1995 to 2014 (Table 2). The
Mann-Kendall trend analysis showed that test $Z$ was
+0.292 and Sen’s slope estimator was +0.006, which
indicated that mean annual maximum temperature
increased at the rate of 0.006 °C per year for the period
under study. However, the rate of increase of mean annual
maximum temperature was not significant at 90%
confidence level. The mean Kharif maximum temperature
varied between 32.37 to 34.74 °C with a mean value of
33.54 ± 0.68 °C (Table 2). The trend analysis of mean
maximum Kharif temperature showed that it increased
($Z = +0.876$) at the rate of 0.027 °C per year for the period
of study. Similar to mean annual maximum temperature,
the increasing trend of mean Kharif maximum temperature
was not significant at 90 % confidence level. The mean Rabi
maximum temperature varied between 23.22 to 25.46 °C with a mean value of 24.34 ± 0.67 °C. The mean Rabi
maximum temperature decreased ($Z = -0.490$) non-significantly (90% confidence level) at the rate 0.022 °C per year as depicted by Sen’s slope
estimator (Table 2). The annual, Kharif and Rabi
maximum temperature showed least variation with CV of
1.80, 2.03 and 2.76 %, respectively (Table 2).
### TABLE 1

Mean monthly values of meteorological parameters during the period of study (1995-2014)

| Month | Mean monthly Tmax (°C) | Mean monthly Tmin (°C) | Mean monthly RH max (%) | Mean monthly RH min (%) | Mean monthly T (°C) | Mean monthly RH (%) | Mean monthly bright sunshine hours (h) | Total monthly rainfall (mm) | Mean monthly PET (mm/day) | Mean monthly Average wind speed (km/hr) |
|-------|------------------------|------------------------|-------------------------|------------------------|---------------------|--------------------|----------------------------------------|----------------------------|--------------------------|------------------------------------------|
| Jan   | 19.1                   | 6.1                    | 12.6                    | 91.2                   | 55.2                | 73.2               | 4.2                      | 17.1                        | 1.66                     | 3.2                         |
| Feb   | 23.2                   | 9.0                    | 16.1                    | 87.9                   | 46.3                | 67.1               | 6.0                      | 25.7                        | 2.57                     | 3.9                         |
| Mar   | 29.4                   | 13.7                   | 21.5                    | 80.7                   | 37.0                | 58.8               | 7.6                      | 15.4                        | 3.97                     | 3.9                         |
| Apr   | 36.4                   | 19.3                   | 27.9                    | 62.6                   | 30.6                | 46.6               | 8.3                      | 8.0                         | 5.57                     | 4.4                         |
| May   | 39.6                   | 24.4                   | 32.0                    | 58.7                   | 33.4                | 46.1               | 7.5                      | 38.0                        | 6.57                     | 5.7                         |
| Jun   | 38.6                   | 26.8                   | 32.7                    | 66.7                   | 44.3                | 55.5               | 6.2                      | 80.9                        | 6.35                     | 6.3                         |
| July  | 34.9                   | 26.8                   | 30.9                    | 81.9                   | 64.8                | 73.4               | 4.6                      | 198.7                       | 4.87                     | 4.6                         |
| Aug   | 33.5                   | 26.1                   | 29.8                    | 84.5                   | 68.6                | 76.5               | 4.8                      | 209.7                       | 4.39                     | 3.8                         |
| Sept  | 33.5                   | 24.0                   | 28.7                    | 83.7                   | 60.1                | 71.9               | 6.5                      | 113.7                       | 4.30                     | 3.7                         |
| Oct   | 32.3                   | 17.8                   | 24.8                    | 83.9                   | 41.4                | 62.7               | 6.9                      | 21.9                        | 3.32                     | 2.3                         |
| Nov   | 27.5                   | 11.3                   | 19.5                    | 86.1                   | 41.5                | 63.9               | 5.4                      | 13.7                        | 2.11                     | 2.0                         |
| Dec   | 22.1                   | 7.0                    | 14.5                    | 89.5                   | 47.9                | 68.7               | 4.1                      | 7.8                         | 1.60                     | 2.5                         |

(Tmax: Maximum temperature, Tmin: Minimum temperature, RHmax: Maximum relative humidity, RHmin: Minimum relative humidity, PET: Potential evapotranspiration)

### TABLE 2

Descriptive statistics and trend analysis of maximum and minimum temperature (°C)

| Statistics | Annual | Kharif | Rabi |
|------------|--------|--------|------|
|            | Maximum temp (°C) | Minimum temp (°C) | Mean temp (°C) | Maximum temp (°C) | Minimum temp (°C) | Mean temp (°C) | Maximum temp (°C) | Minimum temp (°C) | Mean temp (°C) |
| Minimum    | 29.38  | 17.11  | 23.24 | 32.37  | 22.74  | 27.88  | 23.22  | 7.96  | 16.06 |
| Maximum    | 31.59  | 18.48  | 25.04 | 34.74  | 24.89  | 29.70  | 25.46  | 10.61 | 17.56 |
| Mean       | 30.86  | 17.72  | 24.27 | 33.54  | 23.68  | 28.55  | 24.34  | 9.48  | 16.93 |
| SD         | 0.55   | 0.44   | 0.45  | 0.68   | 0.55   | 0.48   | 0.67   | 0.67  | 0.48  |
| CV         | 1.80   | 2.50   | 1.87  | 2.03   | 2.32   | 1.68   | 2.76   | 7.08  | 2.83  |
| N          | 20     | 20     | 20    | 20     | 20     | 20     | 19     | 19    | 19    |
| Z Test     | +0.292 | -0.811 | +0.357 | +0.876 | -1.655 | +0.422 | -0.490 | -0.280 | -0.070 |
| Sen’s slope | +0.006 | -0.014 | 0.003 | +0.027 | -0.032 | 0.006 | -0.022 | -0.019 | -0.008 |
| Trend      | Increase | Decrease | Increase | Increase | Decrease | Increase | Decrease | Decrease | Decrease |
| Significance | NS   | NS   | NS   | NS   | 0.1   | NS   | NS   | NS   | NS   |

However, the mean annual minimum temperature varied between 17.11 to 18.48 °C with a mean value of 17.72 ± 0.44 °C (Table 2). The trend analysis test showed that the mean annual minimum temperature decreased (Z = -0.811) at the rate of 0.014 °C per year for the period 1995 to 2014. However, the decreasing trend was not significant at 90% confidence level. The mean minimum temperature varied between 22.74 to 24.89 °C with a mean value of 23.68 ± 0.55 °C for Kharif and between 7.96 to 10.61 °C with a mean value of 9.48 ± 0.67 °C for...
Rabi season for the same period of study. The minimum temperature decreased both for Kharif (Z = -1.655) and Rabi (Z = -0.280) seasons at the rate of 0.032 and 0.019 °C per year, respectively, as indicated by Sen’s slope estimator. The decreasing trend of mean minimum temperature was significant at 90% confidence level for Kharif season only but not for Rabi season. The annual, Kharif and Rabi minimum temperature also showed little variation as indicated by CV value of less than 10% (Table 2). The annual mean temperature increased (Z = +0.357) at the rate 0.003 °C per year whereas Kharif mean temperature increased (Z = +0.006) at the rate 0.006 °C per year (Table 2). However, the Rabi mean temperature decreased (Z = -0.070) at the rate 0.008 °C per year. The trends of mean temperature were non-significant at 90% confidence level for all the three periods considered. Many workers have also reported increase in the annual mean temperature in other parts of India (Rupa Kumar et al., 2006; Patle et al., 2013; Choudhury et al., 2012).

The mean annual maximum relative humidity (RH) varied between 74.04 to 85.11% with a mean value of 79.79 ± 2.50% and mean annual minimum RH varied between 43.68 to 56.30% with a mean value of 47.57 ± 3.26% (Table 3). Both the mean annual maximum and minimum RH increased (Test Z value of +1.395 for maximum RH and +1.979 for minimum RH) during the period 1995 to 2014. The rate of increase was 0.165% per year for maximum RH and 0.206% per year for minimum RH. However, the increasing trend of RH was significant (95% confidence level) for maximum RH and non-significant for maximum RH.

The mean Kharif maximum RH varied between 77.00 to 91.54% with a mean value of 83.49 ± 3.45% and mean Kharif minimum RH varied between 53.31 to 68.37% with a mean value of 58.70 ± 4.37% during the period of study from 1995 to 2014 (Table 3). The Kharif maximum RH increased (Z = +1.525) at the rate of 0.201% per year and minimum RH increased (Z = +1.363) at the rate of 0.265% per year for the same period of study. However, the increasing trends of both maximum and minimum RH of Kharif season were not significant at 90% confidence level.

The mean Rabi maximum RH ranged between 80.60 to 93.45% with an average value of 86.92 ± 3.12% and mean Rabi minimum RH ranged between 34.58 to 56.37% with a mean value of 45.26 ± 5.41% for the study period (Table 3). The maximum RH increased (Z = +1.609) at the rate of 0.248% per year whereas minimum RH increased (Z = +1.679) at the rate of 0.381% per year. The increasing trend of Rabi minimum RH was significant whereas it was not significant (90% confidence level) with respect to Rabi maximum RH.

The mean RH increased for annual (Z = +1.720), Kharif (Z = +1.590) and Rabi (Z = +1.889) period and the rate of increase was 0.187%, 0.226% and 0.301% per year, respectively. The increasing trend was significant for annual and Rabi period but was not significant for Kharif at 90% confidence level. Similar results were reported by many researchers for India (Padmakumari et al., 2013; Patle et al., 2013). The maximum, minimum and mean RH of Annual, Kharif and Rabi period showed least variation except for the minimum RH of Rabi season with CV value of >10%.

The mean annual bright sunshine hours (BSS) varied between 5.24 to 7.78 with a mean value of 6.02 ± 0.64 (Table 4). The test Z value of -2.174 and Sen’s slope of -0.049 indicated that mean annual BSS decreased significantly (95% confidence level) at the rate of 0.049 hrs/year during the period of 1995 to 2014. The mean bight sunshine hour during Kharif varied between 4.31 to 7.69 with an average value of 5.70 ± 0.82 and during Rabi varied between 4.43 to 7.92 with an average value of 5.47 ± 0.81. Both Kharif (Z = -1.528) and Rabi (Z = -3.289) bright sunshine hour decreased at the rate of 0.058 and 0.084 hrs/year, respectively for the same period. The decrease of BSS was significant (99% confidence level) for Rabi season whereas it was non-significant during Kharif season. Padmakumari et al. (2013) and Patle et al. (2013) have also observed significant decrease of BSS in many parts of India. The decrease of bright sunshine hours in Delhi and elsewhere in India can be attributed to the increasing aerosol particles in the atmosphere caused by the anthropogenic activity (Padmakumari et al., 2013). Aerosols and other particulate matters absorb solar energy and reflect sunlight back into the space. The mean annual, Kharif and Rabi BSS showed appreciable variation with CV values of 10.56, 14.39 and 14.72%, respectively.

The mean annual average wind speed (AWS) varied between 2.71 to 5.37 km/hr with an average value of 3.87 ± 0.80 for the period of 1995 to 2014 (Table 4). The mean annual AWS increased (Z = +1.460) at the rate of 0.047 km/hr per year from 1995 to 2014 which was not significant at 90% confidence level. The mean AWS of Kharif varied between 1.74 to 5.41 km/hr and of Rabi between 1.56 to 4.29 km/hr with a mean value of 3.59 ± 1.15 km/hr and 3.08 ± 0.81 km/hr, respectively. Both Kharif (Z = +1.200) and Rabi (Z = +0.770) mean AWS increased at the rate 0.057 and 0.039 km/hr per year, respectively. Similar type of result has been reported by Patle et al. (2013) for Hissar, India. Similar to mean annual AWS, both Kharif and Rabi AWS trend were not
TABLE 3

Descriptive statistics and trend analysis of maximum and minimum relative humidity (%)

| Statistics | Annual | Kharif | Rabi |
|------------|--------|--------|------|
|            | Maximum RH (%) | Minimum RH (%) | Mean RH (%) | Maximum RH (%) | Minimum RH (%) | Mean RH (%) | Maximum RH (%) | Minimum RH (%) | Mean RH (%) |
| Minimum    | 74.04   | 43.68  | 59.05 | 77.00  | 53.31  | 65.37  | 80.60  | 34.58  | 57.72  |
| Maximum    | 85.11   | 56.30  | 69.24 | 91.54  | 68.37  | 79.96  | 93.45  | 56.37  | 74.90  |
| Mean       | 79.79   | 47.57  | 63.69 | 83.49  | 58.70  | 71.10  | 86.92  | 45.26  | 66.12  |
| SD         | 2.50    | 3.26   | 2.61  | 3.45   | 4.37   | 3.62   | 3.12   | 5.41   | 3.85   |
| CV         | 3.13    | 6.85   | 4.09  | 4.13   | 7.44   | 5.09   | 3.59   | 11.95  | 5.82   |
| N          | 20      | 20     | 20    | 20     | 20     | 20     | 20     | 19     | 19     |
| Z test     | +1.395  | +1.979 | +1.720| +1.525 | +1.363 | +1.590 | +1.609 | +1.679 | +1.889 |
| Sen’s slope| +0.165  | +0.206 | 0.187 | +0.201 | +0.265 | 0.226  | +0.248 | +0.381 | 0.301  |
| Trend      | Increase| Increase| Increase| Increase| Increase| Increase| Increase| Increase| Increase|
| Significance| NS    | 0.05   | 0.1   | NS    | NS    | NS    | NS    | 0.1    | 0.1    |

significant at 90% confidence level. The mean annual, Kharif and Rabi AWS showed appreciable variation with CV value of 20.78, 32.03 and 26.26%, respectively.

The mean annual Potential evapotranspiration (PET) varied between 3.49 to 4.39 mm/day with a mean value of 3.94 ± 0.24 mm/day for the study period 1995 to 2014 (Table 5). The annual PET increased (Z = +0.552) at the rate of 0.008 mm/day per year as shown by the Sen’s slope. The mean PET for Kharif varied between 3.67 to 4.81 mm/day with a mean value of 4.22 ± 0.34 mm/day and for Rabi between 2.10 to 2.68 mm/day with a mean value of 2.38 ± 0.17 mm/day. Contrary to mean annual PET, mean Kharif PET (Z = -0.357) decreased at the rate 0.005 mm/day per year. However, the mean Rabi PET did not show any trend during the same period of study. Both Annual and Kharif trends were non-significant at 90% confidence level. The mean annual, Kharif and Rabi PET showed least variation (CV ≤10%). The increasing trend

TABLE 4

Descriptive statistics and trend analysis of bright sunshine hour (hr) and average wind speed (km/hr)

| Statistics | Annual | Kharif | Rabi | Annual | Kharif | Rabi |
|------------|--------|--------|------|--------|--------|------|
|            | Bright sunshine hour (hr) | Average wind speed (km/hr) | |
| Minimum    | 5.24   | 4.31   | 4.43 | 2.71   | 1.74   | 1.56 |
| Maximum    | 7.78   | 7.69   | 7.92 | 5.37   | 5.41   | 4.29 |
| Mean       | 6.02   | 5.70   | 5.47 | 3.87   | 3.59   | 3.08 |
| SD         | 0.64   | 0.82   | 0.81 | 0.80   | 1.15   | 0.81 |
| CV         | 10.56  | 14.39  | 14.72| 20.78  | 32.03  | 26.26|
| N          | 20     | 20     | 19   | 20     | 20     | 19   |
| Z Test     | -2.174 | -1.528 | -3.289| +1.460 | +1.200 | +0.770|
| Sen’s slope| -0.049 | -0.058 | -0.084| +0.047 | +0.057 | +0.039|
| Trend      | Decrease| Decrease| Decrease| Increase| Increase| Increase|
| Significance| 0.05   | NS    | 0.01 | NS    | NS    | NS   |
of mean annual PET is contrary to the findings of many authors (Verma et al., 2008; Patle et al., 2013; Padmakumari et al., 2013) for different parts of India. The negative trend of mean annual PET in spite of decreased BSS (Table 4) may be attributed to the increased mean annual temperature and average wind speed (Tables 2 and 4) at the study location.

The total annual rainfall (P) varied between 554 to 1670 mm with a mean value of 815 ± 256 mm for the period 1995 to 2014 (Table 5). The total annual rainfall decreased (Z = -0.097) over the years at the rate of 2.238 mm per year, which was non-significant at 90% confidence level. The Kharif total rainfall varied between 270 to 1199 mm with a mean value of 544 ± 223 and Rabi total rainfall between 2 to 251 mm with a mean value of 89 ± 75 for the same period of study. The Kharif rainfall increased (Z = +0.422) at the rate 5.264 mm per year where as Rabi rainfall decreased (Z = -0.910) at the rate 1.400 mm per year during the study period. The rate of change of both Kharif and Rabi rainfall were non-significant for the period of study. The total annual, Kharif and Rabi rainfall did not show any definite trend throughout India (Rupa Kumar et al., 2006; Jain and Kumar, 2012; Choudhury et al., 2012; Laskar et al., 2014). The total rainfall in annual and Kharif period showed wide variation with CV value of 31 and 41%, respectively where as Rabi period showed little variation with CV of 8.42% during the period of study.

The monthly climatic water balance (Thorntwaite and Mather, 1955) of IARI, New Delhi is depicted in Fig. 1. Out of the 12 months, August month showed water surplus (121.3 mm) where as July month showed neither water surplus nor water deficit. However, the rest 10 months showed water deficit varying between 34.2 mm in the month of January to 165.6 mm in the month of May. The highest water deficit in the month of May is attributed to the highest PET (203.6 mm) and least precipitation (38 mm). The yearly total water deficit of the station was 800.4 mm and total water surplus was 121.3 mm.

The monthly P/PET varied between 0.05 in April to 1.54 in August. The mean P/PET was 1.05 for Kharif season and 0.25 for Rabi season. The higher P/PET (>1.0) in Kharif season suggests successful cropping during Kharif season. The July month P/PET (1.32) indicates sowing of Kharif crops in the first week of July. However the lower value of P/PET (<0.5) suggest that Rabi crops can be grown in the month of November either with residual soil moisture or pre-sowing irrigation followed by supplemental irrigation for optimum crop growth and development.

From the study of trend analysis of climatic parameters and climatic water balance it can be concluded that

(i) The mean annual and Kharif maximum temperature increased at the rate of 0.006 and 0.876 °C per year, respectively where as mean Rabi maximum temperature decreased at the rate 0.022 °C for the period 1995 to 2014. The annual, Kharif and Rabi minimum temperature decreased at the rate 0.014, 0.032 and 0.019 °C per year,
respectively for the study period. The annual and Kharif mean temperature increased at the rate 0.003 and 0.006 °C per year where as Rabi mean temperature decreased at the rate 0.008 °C per year for the study period.

(ii) The mean annual maximum, minimum and mean RH increased at the rate of 0.165, 0.206 and 0.187% per year, respectively for the period 1995 to 2014. Similarly, mean Kharif maximum, minimum and mean RH increased at the rate of 0.201, 0.265 and 0.226% per year whereas mean Rabi maximum, minimum and mean RH increased at the rate of 0.248, 0.381 and 0.301% per year for the study period.

(iii) The mean annual, Kharif and Rabi BSS decreased at the rate 0.049, 0.058 and 0.084 hrs per year, respectively for the period of study 1995 to 2014. The average wind speed increased at the rate 0.047, 0.057 and 0.039 km/hr for the period of study.

(iv) The mean annual PET increased at the rate of 0.008 mm/day per year whereas mean Kharif PET decreased at the rate of 0.005 mm/day per year. However, the mean Rabi PET did not show any trend during the study period.

(v) The total annual rainfall increased at the rate of 2.238 mm per year for the period considered. However, total Kharif rainfall increased at the rate 5.264 mm per year and Rabi rainfall decreased at the rate 1.400 mm per year for the study period.

(vi) The climatic water balance study of the station indicated that August month is water surplus, July month is neither water surplus nor deficit whereas the rest 10 months show water deficit. It also indicated that successful rainfed cropping during Kharif season is possible but, Rabi cropping requires supplemental irrigation.

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