551.509.32 : 551.579 (540.23)

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 m^3/m^3, permanent wilting point of 0.08 m^3/m^3 and maximum water holding capacity of 0.41 m^3/m^3 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 (ET_0) as follows:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma\left(\frac{900}{T+273}\right)U_2\left(e_s - e_a\right)}{\Delta + \gamma(1 + 0.34U_2)} \quad (1)$$

where, Rn is the net radiation at the crop surface ($MJ/m^2/day$); G is the soil heat flux density ($MJ/m^2/day$); 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_s is the saturation vapor pressure (kPa); e_a 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:

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \text{sgn}\left(x_j - x_k\right) \quad (2)$$

where, x_j and x_k are the annual values or parameters in years *j* and *k*, *j* > *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 ≤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 $S_{\alpha/2}$, where $S_{\alpha/2}$ is the smallest *S* which has the probability less than α/2 to appear in case of no trend. A positive or negative value of *S* indicates an upward or downward trend, respectively.

For *n* ≥10, the statistic *S* is approximately normally distributed with zero mean and variance Var(s) as follows:

$$Var(S) = \frac{1}{18}\left[n(n-1)(2n+5)\right] \quad (3)$$

The standardized test statistic Z is $\frac{S-1}{\sqrt{VAR(S)}}$ if S>0, 0 if S=0 and $\frac{S+1}{\sqrt{VAR(S)}}$ 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 α level of significance, H_0 is rejected if the absolute value of *Z* is greater than $Z_{1-\alpha/2}$, where $Z_{1-\alpha/2}$ 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:

$$Q_i = \frac{x_j - x_k}{j-k} \text{ for } i = 1, 2, \ldots, N$$

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 T (°C)	Mean monthly RH max (%)	Mean monthly RH min (%)	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 minimum 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	19	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

TABLE 4

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

Statistics	Bright sunshine hour (hr)			Average wind speed (km/hr)		
	Annual	*Kharif*	*Rabi*	Annual	*Kharif*	*Rabi*
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

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 5

Descriptive statistics and trend analysis of potential evapotranspiration (mm/day) and rainfall (mm)

Statistics	Potential evapotranspiration (mm/day)			Rainfall (mm)		
	Annual	*Kharif*	*Rabi*	Annual	*Kharif*	*Rabi*
Minimum	3.49	3.67	2.10	554	270	2
Maximum	4.39	4.81	2.68	1670	1199	251
Mean	3.94	4.22	2.38	815	544	89
SD	0.24	0.34	0.17	256	223	75
CV	6.18	8.06	7.30	31	41	8
N	20	20	19	20	20	19
Z Test	+0.552	-0.357	0.00	-0.097	0.422	-0.910
Sen's slope	0.008	-0.005	0.00	-2.238	5.264	-1.400
Trend	Increase	Decrease	No trend	Decrease	Increase	Decrease
Significance	NS	NS	NA	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,

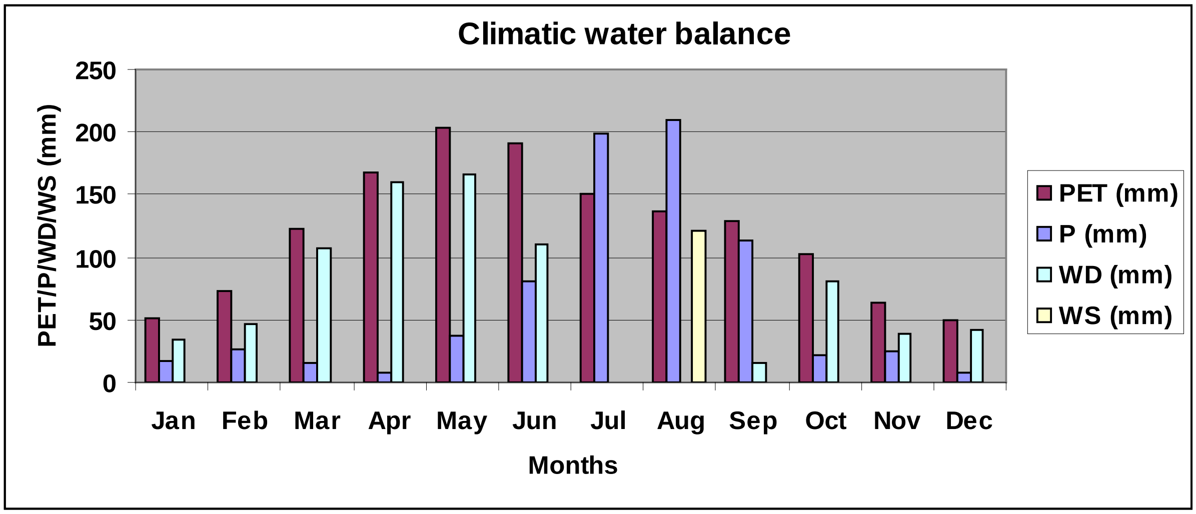

Fig. 1. Monthly climatic water balance for the period 1995 to 2014 at IARI, New Delhi (P-Precipitation, PET: Potential evapotranspiration, WS: Water surplus, WD: Water deficit)

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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