Climatic variability and its impact on rice and wheat productivity in Punjab

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ABSTRACT

The annual and seasonal (*kharif* and *rabi* seasons) trends in temperature (maximum and minimum) and rainfall during 30 years (1986 to 2015) at five locations of Punjab (Bathinda, Faridkot, Ludhiana, SBS Nagar and Patiala) has been analysed. The study revealed that during the last three decades most of the stations experienced significant increase in maximum as well as minimum temperatures in both *kharif* and *rabi* seasons. In *kharif* season maximum temperature positively deviated by 0.12°C to 1.34°C whereas in wheat growing period the deviation results was from 0.13°C to 0.93°C at all the locations. The rainfall during *kharif* season has decreased by 23.2, 27.6, 55.4, 185.4 and 199.6 mm from normal at Bathinda, Faridkot, Ludhiana, SBS Nagar and Patiala districts, respectively in last three decades. Mann Kendall statistics showed increasing trend in maximum temperature and highlighted that the trend was highly significant in Faridkot, SBS Nagar and Patiala district. To know the impact of climate change quadratic form of regression was applied and the results revealed that the increase in minimum temperature during *kharif* and *rabi* season has negative effect on yield of rice and wheat crop in Punjab.

Keywords: Minimum and maximum temperature, rainfall, trends, Mann-Kendall statistics.

Understanding meteorological conditions is essential to any agricultural work, because it is very sensitive to global climate changes and therefore, needs to be evaluated. In numerous studies, it is projected that increasing temperature and decline in rainfall may indirectly reduce agricultural production. Punjab is one of the most fertile regions in India. There are many evidences of climate variability in Punjab. The rise in minimum temperature, increased variability in rainfall, decline in average precipitation and increase in relative humidity has serious implications on yields of different crops. The wheat yield declined from the peak of 4.7 tonnes ha^{-1} in 1999-00 to 4.1 tonnes ha^{-1} in year 2005-06 due to rise in temperature, especially during the critical periods of growth in the months of January to March (Sidhu *et al.* 2011). Keeping in view the importance of climate variability on productivity of paddy and wheat in Punjab, the present study is an attempt to analyse the change in climatic pattern and its impact on paddy and wheat productivity in Punjab state.

MATERIALS AND METHODS

To examine the changing pattern of important climatic variables mainly temperature (maximum and minimum) and rainfall of five different locations of Punjab viz., Bathinda, Fairdkot, Ludhiana, SBS Nagar and Patiala districts for 30 years (1986 to 2015) period were used.

The variability in temperature and rainfall over the three decades were assessed by Mann Kendall test (Mann, 1945; Kendall, 1975). To assess the changing trend of temperature and rainfall on yield of rice and wheat in Punjab, the time series data of maximum temperature, minimum temperature and rainfall was analyzed by fitting different regression models. The quadratic form of regression (without interaction term) was finally chosen after several exercises with linear and log form of equations. To reduce excessive variation in dependent variable that is yield (kg ha^{-1}) of rice and wheat in Punjab, the log form was used. The log value of crop yield was regressed with maximum temperature, minimum temperature, rainfall and square term of each, making a total of 6 explanatory variables.

Quadratic form of regression was applied as under:

$$\log y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_1 \beta + \beta_5 x_2 \beta + \beta_6 x_3 \beta + t + \in \ldots\ldots\ldots(I)$$

Where, log y= log value of rice and wheat productivity, x_1= maximum temperature; x_2= minimum temperature; x_3= rainfall; t= trend and $\in$= error term

In above model, the significance of trend in both the periods suggests the importance of time in explaining the yield of rice and wheat in Punjab. While dealing with time series data, the first step is to check whether the underlying time series is stationary or not. To check unit root in the data,

Table 1: Seasonal and annual variability of temperature (minimum and maximum) and rainfall from year 1986 to 2015, Punjab.

Location	Maximum temperature			Minimum temperature			Rainfall		
	Mean (°C)	d	S-value	Mean(°C)	d	S-value	Mean(mm)	d	S-value
***Kharif* season (June to September)**									
Bathinda	36.2	0.49	0.002 NS	25.3	0.44	0.036***	220.8	-23.16	-2.985 NS
Faridkot	35.3	0.33	0.035***	26.1	0.76	0.057***	318.5	-27.61	-1.885 NS
Ludhiana	34.6	0.12	0.008 NS	25.7	0.35	0.029***	626.3	-55.42	-0.400 NS
SBS Nagar	34.2	1.34	0.05***	24.0	0.04	0.001 NS	834.7	-185.38	-11.930**
Patiala	33.8	1.17	0.066***	24.3	1.73	0.109***	556.3	-199.64	-12.059**
***Rabi* season (November to March)**									
Bathinda	25.0	0.05	0.025 NS	11.2	0.13	0.004 NS	51.6	-6.47	-0.376 NS
Faridkot	25.8	0.70	0.048***	11.8	0.87	0.059 NS	69.4	-3.00	0.500 NS
Ludhiana	24.1	0.32	0.007 NS	11.4	0.36	0.031***	135.1	20.35	-0.743 NS
SBS Nagar	25.1	0.67	0.04 ***	10.9	0.11	0.020 NS	169.7	-25.00	-0.695 NS
Patiala	24.3	1.33	0.053***	10.7	0.93	0.089***	83.7	-23.37	-1.750 NS
Annual									
Bathinda	30.8	0.11	0.003 NS	16.9	0.29	0.029***	296.5	-40.52	-3.983 NS
Faridkot	30.2	0.66	0.044 ***	17.2	0.65	0.072***	410.5	-28.80	-2.280 NS
Ludhiana	29.7	0.37	0.008 NS	17.1	0.53	0.041***	898.5	-44.00	-0.595 NS
SBS Nagar	30.0	0.66	0.044 ***	16.2	0.29	0.014 NS	1057.2	-205.15	-11.200**
Patiala	29.4	1.43	0.074 ***	16.6	1.59	0.114***	672.4	-224.00	-14.375**

Notes: ***, ** and * denote significance at 1, 5 and 10 percent levels, respectively, d=deviations= Sen-slope

augmented Dickey- Fuller (ADF) test was used. The analysis of the unit root test proved that the data used for regression analysis were stationary at lag 1 from year 1986 to 2015.

RESULTS AND DISCUSSION

Climatic variability during kharif season

During the study period, Punjab has faced maximum temperature at peak level during the year 1987 (37°C), lowest has been received during year 1996 (33.7°C). During *kharif* season, the minimum temperature ranged between 24.0°C to 26.1°C with average value of 25.1°C (Table 1). Overall, the maximum temperature during rice growing period showed the deviation of 0.12°C to 1.34°C from the normal across the locations of Punjab. During June to September, the highest deviation from normal in minimum temperature has been observed in Patiala district (1.73°C) whereas SBS Nagar district exhibited the lowest deviation of 0.04 °C from normal (Table 1). SBS Nagar recorded highest average rainfall (834.7 mm) followed by Ludhiana (626.3mm) and Patiala (556.3 mm). In general, the rainfall during *kharif* season had decreased by 23.1, 27.6, 55.4, 185.4 and 199.6

mm from normal at Bathinda, Fairdkot, Ludhiana, SBS Nagar and Patiala districts, respectively in last three decades.

Climatic variability during rabi season

During *rabi* season (November to March), the average maximum temperature recorded at different locations in ascending order of magnitude are Ludhiana (24.1°C), Patiala (24.3°C), Faridkot (25.8°C), Bathinda (25.0°C) and SBS Nagar (25.1°C). The minimum temperature ranged between 10.9°C to 11.8°C with average value of 11.2°C at all the selected locations of Punjab (Table 1). During November till March, the deviation in minimum temperature ranged between 0.13°C to 0.93°C from the normal at different locations of Punjab. Rainfall ranged between 51.6 mm to 169.7 mm with an average value of 102 mm across the locations in Punjab. In general, the rainfall during winter season deviated negatively by 3 to 25 mm at different locations of Punjab.

Annual variability

The annual maximum and minimum temperatures in last three decades ranged between 29.4°C to 30.8°C and 16.2°C to 17.2°C with average values of 30.0°C and

Table 2: Estimates of regressing rice and wheat yield on temperature, rainfall and their quadratic terms in Punjab

Particulars	Coefficients	Standard error	p-value	t- value
Rice yield model				
Constant	0.6548[NS]	1.4239	0.6463	0.4598
$X_1(T_{max})$	-0.0506[NS]	0.0796	0.5260	-0.6360
$X_1^2(T_{max})^2$	0.0007[NS]	0.0011	0.5454	0.6061
$X_2(T_{min})$	0.2803***	0.0475	2.55468e-08	5.8993
$X_2^2(T_{min})^2$	-0.0051***	0.0009	7.72779e-08	-5.6690
$X_3(Rainfall)$	-1.96519e-05[NS]	3.90552e-05	0.6156	-0.5030
$X_3^2(Rainfall)^2$	6.4055e-10[NS]	2.32951e-08	0.9780	0.0275
Trend	0.0002*	0.0001	0.0582	1.9195
Wheat yield model				
Constant	4.4328[NS]	1.7376	0.0118	2.551
$X_1(T_{max})$	0.1495[NS]	0.1385	0.2821	1.080
$X_1^2(T_{max})^2$	-0.0038[NS]	0.0030	0.2109	-1.257
$X_2(T_{min})$	-0.5279***	0.1839	0.0047	-2.871
$X_2^2(T_{min})^2$	0.0308***	0.0104	0.0037	2.949
$X_3(Rainfall)$	-0.0009***	0.0002	6.22e-06	-4.695
$X_3^2(Rainfall)^2$	2.44477e-06***	6.9645e-07	0.0006	3.510
Trend	0.0007***	0.0001	4.72e-10	6.691

Notes: ***, ** and * denote significance at 1, 5 and 10 percent levels, respectively; NS=Non-Significant, Tmax=maximum temperature, Tmin=minimum temperature

16.8°C, respectively. Annual rainfall was more at SBS Nagar (1057 mm) followed by Ludhiana (898 mm), Patiala (672 mm), Faridkot (411 mm) and Bathinda (297 mm) in succession. Overall, annual rainfall had decreased by 28.8, 40.5, 44.0 205.2 and 224.0 mm from normal at Faridkot, Bathinda, Ludhiana, SBS Nagar and Patiala districts, respectively (Table 1).

Mann Kendall trend analysis

The Mann Kendall statistics showed that, there is increasing trend in maximum temperature in both *kharif* and *rabi* seasons at all the locations of Punjab, but the trend was highly significant in Faridkot, SBS Nagar and Patiala districts. Similar trend was observed in the annual variation of maximum temperature. Significant increasing trend in minimum temperature is observed in *kharif* season, at all the locations of Punjab except SBS Nagar, while in *rabi* season the minimum temperature had increasing trend at all the locations which was highly significant at Ludhiana and Patiala district.The gradual increase in the maximum and minimum temperature was also reported by Hundal and Kaur (2002). Kaur *et al.*(2006) reported that in Ludhiana (Punjab) the

maximum temperature has remained near normal over the past three decades. The annual and *kharif* season maximum temperature revealed a slight decreasing trend while in *rabi* season maximum temperature revealed a slight increasing trend.

The significant declining trend in annual and monsoon rainfall has been observed in SBS Nagar and Patiala district, but winter rainfall didn't show any significant change over the years at all the locations of Punjab. Hundal *et al.* (1997) revealed that an annual rainfall showed decreasing trend at Ballowal, Saunkhri and Bathinda while a little increasing trend at Ludhiana. The upward trend in maximum and minimum temperature and downward trend in rainfall as indicated by Mann-Kendall statistics, undergone significant changes during last three decades posing threats to yield of major crops grown in Punjab state.

Impact of climate variability on rice and wheat yield

To account for non-linear effects, we have included the minimum and maximum temperature, rainfall and squared term of each in the regression analysis. The model was

estimated as log-linear to reduce excessive variation in the dependent variable that is yield (kg ha^{-1}) of rice and wheat in Punjab state. The coefficients of this functional form are easily interpretable as proportionate changes. The data used for regression analysis were stationary at lag 1 from year 1986 to 2015 (Table 2).

The results revealed that the coefficient of minimum temperature is positive whereas the square term of minimum temperature is negative and also significant, which means that increase in minimum temperature from the long run average (1986-2015) initially affects the yield of rice positively, but subsequent increase in temperature affects yield of rice adversely. On the other hand, maximum temperature shows the non-significant effect on yield of rice crop. It clearly indicates that it is the minimum temperature and not maximum temperature that affects the yield of rice crop. The effect of rise in maximum temperature has been lessened or even minimized through assured irrigation in Punjab state, which has led to the over-use of groundwater resources.

In wheat growing period, the estimated coefficient for minimum temperature is negative though it is weak; but square of temperature is positive (Table 2). Some of the weaknesses of the estimated minimum temperature is also on account of too much of fluctuations in the minimum temperature in the month of March. The estimated coefficients suggest that increase in the minimum temperature from the long run average temperature of the concerned months has negative effect on the yield of wheat in Punjab. Furthermore, the coefficient of rainfall has found to be negatively significant in wheat growing period, meaning thereby that excess rainfall is having derogatory effects on the wheat yield. The above result to some extent is in line with the simulation based study (Singh *et al.*, 2008).

CONCLUSIONS

The minimum temperature during *kharif* season showed significant increasing (0.02°C per year) trend at different locations of Punjab except SBS Nagar, while in winter season minimum temperature had increasing trend. In rice growing period maximum temperature positively deviated by 0.12°C to 1.34°C whereas in wheat growing period the deviation results was from 0.13°C to 0.93°C at all the locations of Punjab. Following the above changes in temperature and rainfall and its effects on rice and wheat crop certain ameliorative measures are desired.

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