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Assessment of Climate change impact on wheat yield in Western Dry Region: A District level analysis

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ABSTRACT

By using district-level data and robust OLS model, present study attempted to calculate and predict the climate change impact on wheat yield in western dry region. Study findings reveal that wheat yield declined by up 4% during 1966-2011 in Bhulwara, Ganganagar and Sirohi districts. Prediction results show that wheat yield would decline up to 21.06% in Ganganagar, 20.77% in Sirohi and 20.71% in Bundi districts in 2080s and lead food crisis in the region. To anticipate the crisis, there is need of a comprehensive combat plan to deal with it. Inherent and planed adaptation strategies i.e., cropping pattern change, use of modern biotechnology, adjustment of sowing dates and diversification in livelihood pattern to deal with climate change.

Keywords: OLS, Dry Region, Climate Change, Wheat Yield, Forecasting, Marginal Effect

1. INTRODUCTION

In India, the agriculture sector's output is critical in deciding socioeconomic outcomes for a wide population region and is defined as a high priority area for integrated development (GoI, 2013a; Singh and Nayak, 2020). At the macro-level, there are many significant indicators with respected to food security, wages, poverty and unemployment. Regional- level, agricultural success is a significant determinants for balanced growth, considering the widespread biophysical and agro-ecological characteristics of the economy, since many countries still play an important role in rural well-being. At grass-root level, the fact that a substantial number of small and marginal farmers remains, apart from the rising share of landless and causative workers working in this field, has more immediate consequences for food and income evaluation.

India is 1339. 30 million people and agriculture is the main occupation. In the 21st century, climate change poses severe challenges to produce and provide enough food for the flourishing population while preserving the atmosphere, which was already stressed (Singh, 2020a). wheat crops are very vulnerable to change I environmental because their agriculture production is directly affected by changes in temperature, precipitations and carbon dioxide levels as well as the indirect impact of changes in soil humidity and the spread and extent of infestation of pesticides and diseases (Mendelsohn, 2014; Singh, 2020b). Behind the European Union (EU) and China, India is the third largest wheat producer. Temperature increases in Indian wheat production from 1980 to 2008 were more extreme than changes in precipitation, with more than 90% of wheat irrigated in India (Singh and Mustard, 2012). Wheat is a winter (Rabi) which is planted from November to December is harvested in March to April and depends entirely on irrigation due to low precipitation in the Rabi cultivation season. There can sometimes be thundering storms connected with the Western disturbances. Increased precipitation in essential stages (crown root induction, vegetation and physiological maturing) increases yields over dry years (Kalra et al., 2008). In the western dry zone, wheat differences can also be caused by other factors including dates of seeding, soil humidity and the application of the fertiliser.

Being a sensitive crop to weather, regional vulnerability of wheat to climate change and variability are matter of concern and has been addressed under different scenarios. The predicted results suggest that global production would decrease by 2.3-10.5%, relative to the baseline for 1980-2010, respectively under 1.5- 2^{0}C temperature scenarios (Liu et al., 2019). Temperature increases will lead to many problems particularly as the growth time is reduced, amount of spikes is decreased, and heat stress influences water quality and is more vulnerable to decrease (Singh et al., 2013).

In previous studies, either the crop simulation model (Darwin et al., 1994), the Ricardian model (Cline, 1996) or the Panel model (Deschenes and Greenstone, 2007) had used country-level data or state-level data (Mendelsohn, 2006; Lobell and Field, 2007; Nelson et al, 2010; Singh and Sanatan, 2017), but none of studies, however, have attempted to estimate climate change impact on wheat productivity at district-level. The present study aims to measure and forecast the effect of climate change on wheat yield in Western Dry Region.

The paper is organized into five sections. Section 1 describes the importance of problem; Section 2 provides methods and materials encompassing data and analytical tools used; Section 3 presents results of study while Section 4 summarizes the discussion and the last Section presents the conclusion and policy implications.

2. METHODS AND MATERIALS

2.1. Study Area and Data Sources

The present study was undertaken in the Rajasthan state of western dry region of India, spread over an area of 342, 239 sq. km with 10 agro-climatic zones. The topography of the state is dominated by the Aravalli hills and 70% of desert in the western and north-western region, known as the Great Indian Thar Desert. The climate of the state vary from semi-arid to arid; with average annual temperature ranging between 0^0 and 50^{0}C. The state receives an annual average rainfall which varies from 480 millimetres to 750 millimetre and about 90% of which occurs during the South-west Monsoon period, which starts from June last until September. Nearly 70% of Rajasthan's population resides in rural areas (Census, 2011) and is predominately engaged in agriculture and livestock rearing for their livelihoods. Out of the total cropped area of 18.262 million hectare in the state, 70% is rainfed, which makes its agro-ecosystem highly susceptible to the climate induced perturbation. Generally, the state is marked by scarcity of water resources due to the relatively low and erratic precipitation pattern, a sizeable portion of which reverses back because of the arid conditions, leading to lower groundwater recharge (CGWB, 2017). Recurrence of drought is a major phenomenon in the state which severely affects food grain production and livestock, leasing to insecure livelihoods and migration.

The present study uses ICRISAT-VDSA database for crop yield, area under wheat irrigation, fertiliser consumption, road length, rural literacy, number of tractors and pump sets, while Indian Meteorological Department of India (IMD) database was used for the rainfall and temperatures data. Weightage index method was adopted to regenerate district boundaries of selected districts. Data was collected from 1966 to 2011.

2.2. Estimation Methods: Ordinary Least Square Model (OLS)

The present study uses Ordinary Least Square (OLS) model to capture climate change impact on wheat yield. The proposed model as follows.

$$Y_i = \alpha + B_1X_1 + B_2X_2 + B_3X_3 + B_4X_4 + B_5X_5 + B_6X_6 + B_7X_7 + B_8X_8 + B_9X_9 + U_i$$

Where, Y_i indicates wheat yield, X_1 is seasonal rainfall, X_2 is minimum temperature, X_3 is maximum temperature, X_4 is area under irrigation, X_5 is fertiliser consumption, X_6 is road length, $X_7$is rural literacy, $X_8$is number of tractors, $X_9$is no of pump sets, and U_i is error term.

In the model, study have included climatic parameters (i.e., annual rainfall, minimum temperature, maximum temperature) to assess climate change impact on wheat yield, while social (i.e., rural literacy) and technological variables (i.e., irrigation, fertiliser consumption, road length, tractors & pump sets) are included as an adaptation strategies farmers have opted to cope with climate change.

2.3. Marginal Effect

The marginal effects of the weather parameters were calculated at their mean values from the regression coefficients (which measure elasticity). Thus, the combined marginal effect of climate variables, viz., rainfall and minimum & maximum temperatures on crop yield was quantified using equation (2).

$$\frac{dy}{dc} = \left(\beta_{MT} * \left[\frac{\overline{Y}}{\overline{MT}}\right] + \beta_{MNT} * \left[\frac{\overline{Y}}{\overline{MNT}}\right] + \beta_R * \left[\frac{\overline{Y}}{\overline{R}}\right]\right) \ldots\ldots (2)$$

Where, $\frac{dy}{dc}$ is combined marginal effect of change in climate variables on the crop yield, βdenote coefficients which are determined from the model, $\overline{MT}$is mean maximum temperature, $\overline{MNT}$is mean minimum temperature, $\overline{R}$is mean rainfall, and $\overline{Y}$ is the mean crop yield during the period in an ACZ.

2.4. Projected impact of climate change

CORDEX South Asia multi-RCM reliability ensemble average estimate of projected changes in annual mean of daily minimum and maximum temperature over India for the 30 year future periods: near-term (2016-2045), mid-term (2036-65) and long-term (2066-2095) changes in future climate over India under RCP 4.5 scenario, relative to the base 1976-2005 to project the changes in crop yields was used.

Further, the projected change in crop yield was calculated using equation (3),

$$\Delta Y = \left(\frac{\partial Y}{\partial R}\right) * \Delta R + \left(\frac{\partial Y}{\partial T}\right) * \Delta T \ \ldots (3)$$

Where, ΔY denote change in crop yield, ΔR in rainfall and ΔT in temperature under different scenarios and $\left(\frac{\partial Y}{\partial R}\right)$ and $\left(\frac{\partial Y}{\partial T}\right)$ are their marginal effects.

3. RESULTS AND DISCUSSION

3.1. Spatial and temporal variability in rainfall and temperature

The minimum temperature is relatively increased higher in the Churu and Swaimadopur (0.02^{0}C/year) followed by in Ajmer and Alwar (0.01^{0}C/year) (Table 1). Further, maximum temperature is relatively increased higher in Barmer (0.018^{0}C/year) and Jodhpur (0.016^{0}C). The rainfall has declined in Ajmer (0.171^{0}C/year) followed by Alwar, Bhartpur, Bundi, Dausa, Karauli, Swaimadhopur and Tonk. Annual and Kharif season rainfall shows relative spatial and temporal variability in between districts. Similar trends also have reported in the rainy days. Desert districts such as Bikaner, Dausa, Swaimadopur have reported decline in rainy days, while other districts have reported increase in rainy days. Rainfall and rainy days trends during 1951-2017 shows that rainfall has been declined substantially, while rainy days has been increased.

Table 1: Trends in rainfall, temperature and rainy days

District	Latitude	Longitude	MinT (1951-2017)	MaxT (1951-2017)	Annual Rainfall (1951-2017)	Kharif Rainfall (1951-2017)	Rainy Days (1951-2017)
Ajmer	26° 27' N	74° 42' E	0.018*	0.012*	-0.171**	0.463^{NS}	0.089^{NS}
Alwar	27° 34' N	76° 38' E	0.018*	0.004^{NS}	-1.445*	-0.736**	0.116^{NS}
Bansawara	23° 30' N	74° 24' E	0.006*	0.007**	2.894^{NS}	1.594^{NS}	0.223**
Baran	25° 05' N	76° 33' E	0.017*	0.009*	0.422^{NS}	0.230^{NS}	0.041^{NS}
Barmer	25° 45' N	71° 25' E	0.008**	0.018*	2.397^{NS}	1.076^{NS}	0.151^{NS}
Bharatpur	27° 15' N	77° 30' E	0.013*	0.003^{NS}	-4.191**	-2.019**	0.019^{NS}
Bhilwara	25° 21' N	74° 40' E	0.012*	0.012*	0.755^{NS}	0.518^{NS}	0.257**
Bikaner	28° 01' N	73° 22' E	0.019*	0.013*	0.800^{NS}	0.518^{NS}	-0.073*
Bundi	25° 27' N	75° 41' E	0.016*	0.010*	-1.297***	-0.568*	0.184^{NS}
Chittorgarh	24° 54' N	74° 42' E	0.011*	0.011*	0.983^{NS}	0.729^{NS}	0.275**
Churu	28° 19' N	75° 01' E	0.022*	0.008**	1.112^{NS}	0.342^{NS}	0.026^{NS}
Dausa	26° 89' N	76° 33' E	0.020*	0.006***	-2.391***	-1.170*	-0.008*
Dhaulpur	26° 42' N	77° 53' E	0.014*	0.005^{NS}	-6.835*	-3.314*	0.087^{NS}
Dugarpur	23° 50' N	73° 50' E	0.005***	0.005***	2.426^{NS}	1.350^{NS}	0.246**
Ganganagar	23° 56' N	75° 41' E	0.018*	0.005^{NS}	0.532^{NS}	0.175^{NS}	0.122^{NS}
Hanumangarh	29° 35' N	74° 21' E	0.017*	0.003^{NS}	0.631^{NS}	0.214^{NS}	0.060^{NS}
Jaipur	26° 55' N	75° 52' E	0.023*	0.009**	-0.865^{NS}	-0.438^{NS}	0.060^{NS}
Jaisalmer	26° 55' N	70° 57' E	0.009*	0.0182*	0.315^{NS}	0.033^{NS}	0.044^{NS}
Jalore	25° 22' N	72° 58' E	0.007**	0.015*	1.297^{NS}	0.578^{NS}	0.337*
Jhalawar	27° 33' N	76° 33' E	0.013*	0.009*	2.542^{NS}	1.291^{NS}	0.242**
Jhunjhunu	28° 06' N	75° 20' E	0.022*	0.007**	0.795^{NS}	0.274^{NS}	0.055^{NS}
Jodhpur	26° 18' N	73° 04' E	0.014*	0.016*	0.610^{NS}	0.196^{NS}	0.056^{NS}
Karauli	26° 30' N	77° 04' E	0.014*	0.006***	-4.187**	-2.122**	0.056^{NS}
Kota	25° 10' N	75° 52' E	0.017*	0.010*	0.291^{NS}	0.159^{NS}	0.103^{NS}
Nagaur	27° 00' N	73° 40' E	0.020*	0.013*	0.354^{NS}	0.099^{NS}	0.071^{NS}
Pali	25° 46' N	73° 25' E	0.011*	0.014*	1.363^{NS}	0.689^{NS}	0.421*
Pratapgarh	24° 02' N	74° 4' E	0.007**	0.014*	0.894^{NS}	0.715^{NS}	0.267*
Rajsamand	25° 05' N	73° 88' E	0.009*	0.014*	1.666^{NS}	1.020^{NS}	0.263*
Swaimadopur	25° 58' N	76° 3' E	0.021*	0.007**	-2.694**	-1.374**	-0.149**
Sikar	27° 36' N	75° 15' E	0.024*	0.010*	0.160^{NS}	-0.004*	0.003^{NS}
Sirohi	24° 88' N	72° 85' E	0.005^{NS}	0.013*	0.028^{NS}	0.027^{NS}	0.439*
Tonk	26° 11' N	75° 50' E	0.022*	0.010*	-1.663**	-0.822**	0.181^{NS}
Udaipur	27° 42' N	75° 33' E	0.007**	0.010*	1.061^{NS}	-0.822**	0.410*
Rajasthan	27° 00' N	74° 00' E	0.015*	0.010*	-0.042***	0.004^{NS}	0.135^{NS}

Source: Author's Estimation, 2020. Note: significance level: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$, and NS is none significant.

3.2. Land use Pattern Change

Trends of area under forest reveal that forest area has been increased marginally in all districts, except in Jaisalmer district (i.e., 0.71% during 1988-2011), while area under not available for agriculture has declined in all districts, except in Churu, Durgapur and Tonk districts (Table 2). In these districts, area not available for cultivation has increased by 4.52, 25.25 and 10.09% during 1988-2011over 1966-87 level. Further, area under uncultivated land has been declined substantially in all the districts, expect in Jaisalmer and Jalore districts.

The net cropped area (NCA) has marginally increased in all the districts, except marginal decline in Sirohi district. Because of wheat has water intensive crop, area under irrigation shows the potential of expanding of irrigation practices. At macro level, Rajasthan state has reported about 21.15% of irrigated area, while at micro level; irrigated area is ranges from 3.10% in Barmer to 48.23% in Alwar district. This shows the vulnerability of the western dry region. Micro level results are providing regional dimensions of seasonal food security.

Table 2: District wise shift in land use pattern

District	Forest Area		Non-Agricultural Area		Uncultivated Land		Fellow Land		Net Cropped Area		Net Irrigated Area	
	1966-1987	1988-2011	1966-1987	1988-2011	1966-1987	1988-2011	1966-1987	1988-2011	1966-1987	1988-2011	1966-1987	1988-2011
Ajmer	4.28	6.17	17.55	16.69	27.32	23.86	6.45	5.40	44.37	47.87	10.30	9.59
Alwar	2.14	8.09	22.26	17.66	8.26	6.54	3.48	2.64	63.68	65.04	20.05	48.23
Bansawara	18.13	21.32	19.29	15.63	17.05	15.30	4.29	1.87	41.19	45.85	4.87	15.94
Baran	0.13	0.31	10.25	9.92	28.03	23.17	12.80	13.95	48.70	52.65	1.79	6.29
Barmer	0.54	1.00	7.17	7.12	34.20	27.99	11.06	9.13	47.04	54.77	0.63	3.10
Bharatpur	4.07	6.52	19.45	16.48	9.05	7.69	4.13	2.52	63.35	66.67	18.55	41.64
Bhilwara	4.16	6.66	22.01	20.53	40.85	32.56	3.97	4.56	29.02	35.65	12.38	13.81
Bikaner	1.01	2.78	5.04	9.70	61.89	39.26	5.59	7.55	26.46	40.66	0.68	5.32
Bundi	14.80	24.08	26.70	15.54	13.87	14.19	4.77	3.43	39.72	42.73	18.27	30.12
Chittorgarh	10.49	17.41	20.35	15.07	34.10	26.66	1.96	1.97	32.96	38.85	10.15	17.84
Churu	0.25	0.43	4.39	4.52	13.94	8.06	9.12	7.15	72.38	79.84	0.03	2.88
Dausa	4.25	6.70	13.19	11.99	19.80	15.43	7.84	5.66	54.81	60.11	20.29	31.54
Dhaulpur	4.07	6.52	19.45	16.48	9.05	7.69	4.13	2.52	63.35	66.67	18.55	41.64
Dugarpur	15.12	15.87	24.96	25.25	23.94	23.48	3.49	2.59	32.15	32.20	3.83	7.33
Ganganagar	1.02	3.43	5.52	6.27	17.17	8.59	8.42	8.95	67.40	72.63	29.75	41.72
Hanumangarh	1.02	3.43	5.52	6.27	17.17	8.59	8.42	8.95	67.40	72.63	29.75	41.72
Jaipur	4.25	6.70	13.19	11.99	19.80	15.43	7.84	5.66	54.81	60.11	20.29	31.54
Jaisalmer	0.75	0.71	24.07	12.38	68.61	74.76	1.26	1.73	4.95	10.51	0.01	1.38
Jalore	1.19	1.91	11.71	11.69	16.52	16.81	12.82	9.29	57.75	60.30	9.76	22.62
Jhalawar	13.15	18.97	14.42	9.93	23.33	19.69	1.66	1.76	47.70	49.34	7.06	25.13
Jhunjhunu	5.83	6.62	5.73	6.15	10.78	11.39	3.52	3.99	74.12	71.84	5.81	28.80
Jodhpur	0.13	0.31	10.25	9.92	28.03	23.17	12.80	13.95	48.70	52.65	1.79	6.29
Karauli	4.07	6.52	19.45	16.48	9.05	7.69	4.13	2.52	63.35	66.67	18.55	41.64
Kota	22.75	27.33	13.59	10.93	15.22	11.27	2.74	3.04	45.59	47.36	12.81	33.86
Nagaur	0.48	0.93	8.21	8.20	10.52	9.77	14.57	11.25	66.14	69.84	2.45	12.17
Pali	5.67	6.56	16.25	16.49	21.05	20.28	11.47	8.53	45.54	48.10	10.07	11.58
Pratapgarh	18.13	21.32	19.29	15.63	17.05	15.30	4.29	1.87	41.19	45.85	4.87	15.94
Rajsamand	10.49	17.41	20.35	15.07	34.10	26.66	1.96	1.97	32.96	38.85	10.15	17.84
Swaimadopur	19.22	24.33	17.86	14.82	13.46	10.70	3.12	3.63	46.31	46.44	11.43	23.88
Sikar	2.19	7.62	10.22	6.62	12.52	12.10	8.29	6.57	66.75	67.08	8.66	24.72
Sirohi	21.02	29.63	27.25	19.68	15.88	15.47	5.93	6.02	29.89	29.19	9.16	13.57
Tonk	2.91	3.60	9.89	10.09	20.76	16.70	5.19	6.23	61.19	63.36	10.70	22.27
Udaipur	17.62	22.08	36.85	32.95	25.36	25.20	1.96	1.60	18.17	18.12	6.12	6.09
Rajasthan	7.13	10.10	15.81	13.46	22.36	18.83	6.17	5.41	48.46	52.13	10.59	21.15

Source: Author's Estimation, 2020. Note: figures are in percentage

3.3. Extent of Marginalization

Fragmentation in the landholding has observed during 1970-2010. The calculated results show that number of marginal farmers has been increased substantially (Table 3). At macro level, in 1970 there were only 23.38% marginal farmers, which have been increased by 35.16% in 2010 (about 12%). At micro level, Banswara, Baran, Bhilwara and Sikar districts show two-fold increase in number of marginal farmers, while number of marginal farmers has marginally increased in Barmer and Jaisalmer districts. Jointly, land use pattern and increase in marginal farmers have shown a substantially pressure on less fertile land. With more than 50% of population is directly dependent on agriculture, while fragmentation and land use pattern change in favour of non-agricultural purposes, and continuously decline in per hectare productivity of wheat crop that there is a need of holistic approach in which agriculture would play vital role in rural economy.

Table 3: District- wise marginal farmers in Rajasthan

Districts	1970	1976	1980	1985	1990	1995	2000	2005	2010
Ajmer	41.38	42.48	42.79	44.03	47.10	44.29	47.37	48.24	49.24
Alwar	40.20	45.42	45.32	44.36	43.94	46.43	48.18	51.55	57.78
Banswara	36.87	42.59	43.19	46.89	47.67	50.72	56.96	61.78	65.77
Baran	21.99	28.14	29.76	27.74	28.54	28.79	33.46	32.45	34.48
Barmer	2.32	5.36	5.84	3.00	4.51	3.90	4.00	3.91	6.75
Bharatpur	38.41	46.54	45.28	47.31	47.03	50.86	52.10	54.61	55.83
Bhilwara	28.44	34.32	33.71	35.11	37.80	39.33	39.10	40.66	44.85
Bikaner	0.42	1.13	0.67	0.72	0.81	1.30	1.42	1.59	1.78
Bundi	24.52	31.31	31.48	30.79	34.37	30.88	35.63	39.92	45.46
Chittorgarh	25.14	33.37	28.55	30.71	32.21	34.14	37.68	39.60	44.73
Churu	0.92	1.51	1.05	0.99	1.08	1.53	2.06	3.24	5.58
Dausa	27.37	33.48	28.23	27.12	29.11	30.45	34.26	36.74	40.51
Dhaulpur	38.41	46.54	45.28	47.31	47.03	50.86	52.10	54.61	55.83
Dungarpur	37.29	49.89	51.78	53.72	56.86	56.57	58.77	61.37	65.54
Ganganagar	5.07	4.47	6.50	4.51	4.92	4.73	5.18	6.11	6.39
Hanumangarh	5.07	4.47	6.50	4.51	4.92	4.73	5.18	6.11	6.39
Jaipur	27.37	33.48	28.23	27.12	29.11	30.45	34.26	36.74	40.51
Jaisalmer	2.10	3.69	2.20	2.48	4.47	5.73	2.95	1.88	2.95
Jalore	6.24	7.43	8.35	6.73	8.40	8.45	8.89	9.33	9.89
Jhalawar	27.29	32.73	33.00	31.28	33.12	33.57	38.05	35.51	39.64
Jhunjhunu	14.83	17.44	16.48	16.52	20.46	19.76	23.74	28.85	36.67
Jodhpur	5.95	8.84	9.20	6.65	7.40	7.34	8.44	9.53	9.62
Karauli	38.41	46.54	45.28	47.31	47.03	50.86	52.10	54.61	55.83
Kota	21.99	28.14	29.76	27.74	28.54	28.79	33.46	32.45	34.48
Nagaur	6.54	8.10	10.24	8.54	9.53	10.28	10.88	10.09	12.09
Pali	25.68	27.24	24.94	27.34	27.65	27.55	28.04	29.02	29.65
Pratapgarh	42.54	51.11	47.57	48.39	49.76	50.65	51.53	55.04	58.58
Rajsamand	25.68	27.24	24.94	27.34	27.65	27.55	28.04	29.02	29.65
Sawai Madhopur	36.32	41.35	41.68	40.05	42.47	43.22	46.22	48.12	50.20
Sikar	16.98	20.40	22.73	18.80	19.72	20.52	23.84	25.84	34.37
Sirohi	33.58	34.60	42.00	34.05	34.92	35.44	34.92	36.99	37.37
Tonk	23.58	29.27	27.43	28.83	26.64	26.31	29.73	32.35	33.36
Udaipur	42.54	51.11	47.57	48.39	49.76	50.65	51.53	55.04	58.58
Rajasthan	23.38	27.87	27.50	27.16	28.32	28.99	30.91	32.51	35.16

Source: Authors estimation, 2020. Note: figures are in percentage

3.4. Impact of Climate change on Wheat Yield: Regression Results

The rainfall has a positive association with the yield of wheat in all the districts pertaining to Rajasthan, except in Jaipur, Jaisalmer and Sikar (Table 4). Minimum temperature association with wheat yield revealed that maximum temperature was negatively associated in all the districts, expect Ajmer, Alwar, Baran, Barmer, Bikaner, Jaipur and Kota districts, the maximum temperature was negatively associated in all the districts with wheat yield. Regression results show a positive relationship with the yield of wheat in all the study districts. Fertilizer consumption was positively associated with the yield of wheat in all districts, except in the Baran, Barmer, Bikaner, Churu, Dausa, Ganganagar, Hanumangarh, Jaipur, Jaisalmer, Jalore, Jodhpur and Pali districts. Road length and rural literacy rates were positively associated with the wheat yield in all the districts. The tractor was positively associated with the yield of wheat in all the districts, except Alwar, Bharatpur, Churu, Dausa, Dhaulpur, Dungarpur, Jaipur, Jhalawar, Jhunjhunu, Jodhpur, Karauli, Nagaur, Pali, Swai Madhopur, Sikar, Tonk, and Udaipur. The pump sets were positively associated in all the districts of Rajasthan. In totality, climatic factors are adversely affecting the wheat yield, while technological factors are moderating the adverse impacts of climate change in Rajasthan.

Table 4: District wise regression results

Districts	Ln Rainfall	Ln Min Temp	Ln Max Temp	Ln Irrigation	Ln Fertilizer	Ln Road length	Ln Ruliteracy	Ln Tractors	Ln Pumpset	Constant	Log likelihood	Prob > chi2	Observations	Wald chi2(31)
Ajmer	0.129*	0.048^{NS}	-0.174*	0.226*	0.215*	0.179*	0.064*	0.629*	0.186*	0.253*	10.14	0.000	45	120.96
Alwar	0.050*	0.900^{NS}	-0.010*	0.029*	0.253*	0.648*	0.419*	-0.005^{NS}	0.096*	0.387*	120.96	0.000	45	120.96
Banswara	0.152*	-0.304*	-0.676*	0.400*	0.058*	0.578*	0.628*	0.017*	0.016*	-0.826*	19.65	0.000	45	148.84
Baran	0.027*	0.256^{NS}	-0.880*	0.465*	-0.115^{NS}	0.768*	0.023*	0.007*	0.010*	0.044*	18.86	0.000	45	392.18
Barmer	0.062*	0.542^{NS}	-0.031*	0.108*	-0.001^{NS}	0.347*	0.089*	0.259*	0.129*	0.647*	2.46	0.000	45	79.14
Bharatpur	0.073^{NS}	-0.741*	-0.117*	0.104**	0.225*	0.642*	0.142*	-0.158^{NS}	0.061*	-0.617*	31.15	0.000	45	449.61
Bhilwara	0.055*	-0.399*	-0.944*	0.162*	0.058*	0.215*	0.185*	0.008*	0.027*	-0.829*	449.61	0.000	45	347.39
Bikaner	0.064*	0.263^{NS}	-0.590*	0.135*	-0.086^{NS}	0.147*	0.167*	0.105*	0.005*	0.088*	42.82	0.000	45	38.47
Bundi	0.036*	-0.123*	-0.697*	0.306**	0.129*	0.708*	0.244*	0.268*	0.134*	-0.737*	20.20	0.000	45	311.35
Chittorgarh	0.166^{NS}	-0.855*	-0.791*	0.007*	0.255*	0.444*	0.166*	0.041*	0.010*	-0.967*	15.53	0.000	45	224.25
Churu	0.040^{NS}	-0.052*	-0.362*	0.195**	-0.061^{NS}	0.533*	0.720*	-0.413^{NS}	0.144*	-0.440*	224.25	0.000	45	47.58
Dausa	0.089^{NS}	0.249^{NS}	-0.960*	0.040**	-0.041^{NS}	0.048*	0.537*	-0.019^{NS}	0.015*	0.248*	29.67	0.000	45	275.74
Dhaulpur	0.073^{NS}	-0.741*	-0.117*	0.104*	0.225*	0.642*	0.142*	-0.158^{NS}	0.061*	-0.617*	31.15	0.000	45	449.61
Dungarpur	0.027*	-0.166*	-0.110*	0.048*	0.131*	0.013*	0.556*	-0.041^{NS}	0.007*	-0.413*	17.34	0.000	45	90.56
Ganganagar	0.120^{NS}	-0.002*	-0.793*	0.160*	-0.058^{NS}	0.138*	0.289*	0.017*	0.031*	-0.960*	24.67	0.000	45	270.32
Hanumangarh	0.120*	-0.002*	-0.793*	0.160*	-0.058^{NS}	0.138*	0.289*	0.017*	0.031*	-0.960*	24.67	0.000	45	270.32
Jaipur	-0.089^{NS}	0.249^{NS}	-0.960*	0.040*	-0.041^{NS}	0.048*	0.537*	-0.019^{NS}	0.015*	0.248*	29.67	0.000	45	275.74
Jaisalmer	-0.271*	-0.989*	-0.118*	0.390*	-0.737^{NS}	0.845*	0.327*	0.027*	0.229*	-0.001*	10.76	0.000	45	19.09
Jalore	0.024^{NS}	-0.004*	-0.964*	0.169*	-0.071^{NS}	0.123*	0.177*	0.028*	0.041*	-0.222*	19.88	0.000	45	71.01
Jhalawar	0.206*	-0.119*	-0.814*	0.480^{NS}	0.059*	0.186*	0.021*	-0.051^{NS}	0.092*	-0.210*	18.29	0.000	45	405.89
Jhunjhunu	0.091*	-0.514*	-0.963*	0.259^{NS}	0.210*	0.236*	0.261*	-0.029^{NS}	0.028*	0.056*	18.44	0.000	45	217.76
Jodhpur	0.179^{NS}	-0.109*	-0.148*	0.381^{NS}	-0.113^{NS}	0.363*	0.835*	-0.068^{NS}	0.024*	-0.253*	14.00	0.000	45	173.91
Karauli	0.073*	-0.741*	-0.117*	0.104^{NS}	0.225*	0.642*	0.142*	-0.158^{NS}	0.061*	-0.617*	31.15	0.000	45	449.61
Kota	0.027^{NS}	0.256^{NS}	-0.880*	0.465*	-0.115^{NS}	0.768*	0.023*	0.007*	0.010*	0.044*	18.86	0.000	45	392.18
Naguar	0.019*	-0.612*	-0.216*	0.111*	0.255*	0.037*	0.144*	-0.001^{NS}	0.011*	-0.140*	15.96	0.000	45	160.98
Pali	0.149^{NS}	-0.782*	-0.840*	0.137*	-0.058^{NS}	0.479*	0.200*	-0.047^{NS}	0.037*	-0.868*	6.83	0.000	45	60.56
Pratapgarh	0.152*	-0.304*	-0.676*	0.400**	0.058*	0.578*	0.628*	0.017*	0.016*	-0.826*	19.65	0.000	45	148.84
Rajsamand	0.167*	-0.471*	-0.007*	0.242*	0.143*	0.896*	0.307*	0.002*	0.053*	-0.794*	17.42	0.000	45	107.55
Sawai Madhopur	0.078^{NS}	-0.419*	-0.713*	0.003*	0.202*	0.136*	0.181*	-0.069^{NS}	0.075*	-0.039*	15.41	0.000	45	222.26
Sikar	-0.019*	-0.612*	-0.216*	0.111*	0.255*	0.037*	0.144*	-0.001*	0.011*	-0.140*	15.96	0.000	45	160.98
Sirohi	0.167^{NS}	-0.471*	-0.007*	0.242*	0.143*	0.896*	0.307*	0.006*	0.053*	-0.794*	17.42	0.000	45	107.55
Tonk	0.006*	-0.185*	-0.225*	0.055*	0.048*	0.541*	0.923*	-0.033*	0.134*	-0.245*	17.77	0.000	45	327.67
Udaipur	0.036*	-0.656*	-0.903*	0.133^{NS}	0.006*	0.005*	0.247*	-0.020*	0.064*	-0.772*	39.14	0.000	45	369.27
Rajasthan	0.271*	-0.989*	-0.118*	0.390*	0.737*	0.845*	0.327*	0.027*	0.229*	-0.031*	10.76	0.000	45	19.09

Source: Author's Estimation, 2020. Note: significance level: * p <0.10, ** p <0.05, *** p< 0.01, and NS is none significant.

3.5. Marginal effect and forecasts

Overall, it was observed that wheat yield was adversely impacted by climate change in all the districts pertaining to Rajasthan (Table 5). The wheat yield declined by up to 4% during 1966-2011 in Bhilwara, Ganganagar and Sirohi districts. The calculated forecasting results show that the wheat yield would decline up to 21.06% in Ganganagar, 20.77% in Sirohi, and 20.71% in Bundi districts in the 2080s. In other words, the wheat yield has highly sensitive in Ganganagar, Sirohi and Bundi districts.

Table 5: District wise marginal effects and forecasting results

Districts	Marginal Effect (1966-2011)	2030s Δ MinT= 1.36 Δ MaxT= 1.26 Δ R= (+/-) 5%	2040s Δ MinT= 1.75 Δ MaxT= 1.50 Δ R= (+/-) 7%	2050s Δ MinT= 2.14 Δ MaxT= 1.81 Δ R= (+/-) 10	2080s Δ MinT= 2.63 Δ MaxT= 2.29 Δ R= (+/-) 12%
Ajmer	-2.94	-7.70	-9.55	-11.61	-14.46
Alwar	-1.23	-3.22	-4.00	-4.86	-6.05
Banswara	-1.24	-3.25	-4.03	-4.90	-6.10
Baran	-2.14	-5.61	-6.96	-8.45	-10.53

Barmer	-3.61	-9.46	-11.73	-14.26	-17.76
Bharatpur	-2.31	-6.05	-7.51	-9.12	-11.37
Bhilwara	-4.00	-10.48	-13.00	-15.80	-19.68
Bikaner	-2.14	-5.61	-6.96	-8.45	-10.53
Bundi	-4.21	-11.03	-13.68	-16.63	-20.71
Chittorgarh	-3.24	-8.49	-10.53	-12.80	-15.94
Churu	3.21	8.41	10.43	12.68	15.79
Dausa	-1.21	-3.17	-3.93	-4.78	-5.95
Dhaulpur	-2.35	-6.16	-7.64	-9.28	-11.56
Dungarpur	-2.32	-6.09	-7.55	-9.17	-11.43
Ganganagar	-4.28	-11.21	-13.91	-16.91	-21.06
Hanumangarh	-1.28	-3.35	-4.16	-5.06	-6.30
Jaipur	-1.59	-4.17	-5.17	-6.28	-7.82
Jaisalmer	-1.79	-4.69	-5.82	-7.07	-8.81
Jalore	-2.14	-5.61	-6.96	-8.45	-10.53
Jhalawar	-3.21	-8.41	-10.43	-12.68	-15.79
Jhunjhunu	-2.14	-5.61	-6.96	-8.45	-10.53
Jodhpur	-3.21	-8.42	-10.44	-12.69	-15.81
Karauli	-2.17	-5.69	-7.05	-8.57	-10.68
Kota	-3.24	-8.49	-10.53	-12.80	-15.94
Naguar	-2.14	-5.61	-6.96	-8.45	-10.53
Pali	-3.21	-8.41	-10.43	-12.68	-15.79
Pratapgarh	-1.21	-3.17	-3.93	-4.78	-5.95
Rajsamand	-3.26	-8.55	-10.60	-12.89	-16.05
Sawai Madhopur	-1.37	-3.59	-4.45	-5.41	-6.74
Sikar	-2.19	-5.74	-7.12	-8.65	-10.77
Sirohi	-4.22	-11.06	-13.72	-16.67	-20.77
Tonk	-3.70	-9.71	-12.04	-14.63	-18.23
Udaipur	-1.28	-3.35	-4.16	-5.06	-6.30
Rajasthan	-2.41	-6.31	-7.83	-9.52	-11.86

Source: Author's Estimation, 2020. Note: figures are in percentage

4. DISCUSSION

The global climate has changed relative to the pre-industrial period, and there are multiple lens of evidence that there changes have had impacts on organisms and ecosystems, as well as on human systems and well-being. Limiting global warming to 1.5^{0}C would limit risks of increases in heavy precipitation events on a global scale and in several regions compared to conditions at 2^{0}C global warming. The climate change impact in the western dry region was mostly related to increased water stress and decline in crop yield (i.e., wheat) (Kaur et al., 2018). Impact of climate change on agriculture will be one of the major deciding factor influencing the future food security in the region. Study results highlights that backward and resource poor districts are relatively highly vulnerable to climate change. As majority of farmers (> 80%) having less than one hectare land size will be most affected, as they entirely rely on climate-sensitive livelihoods (Singh, 2020a). In this situation, climate risk management strategies, capable of helping farm-households improve farm productivity and livelihood security are vital (Singh, 2020b).

5. CONCLUSION

A rise in both the minimum and maximum temperature, but change in annual maximum temperature was more pronounced that the minimum temperature in all the districts and Rajasthan as whole. Overall, the empirical results showed that climate change adversely impacts the wheat yield across the districts. Results also showed that high yielding districts, viz., Ganganagar and Hanumangarh are much sensitive to changing climate compared to low yielding districts, i.e., Jaisalmer, Barmer, Churu and Bikaner.

As evident from the foregoing analysis, the short-term impact of climate change on wheat yield will not severe. However, it is likely that increasing incidence of extreme fluctuations in climate in the form of drought, dry spells and heat waves could result into discernible effect on wheat productivity. In totality, climate change has brought livelihood and food crisis in Rajasthan. A robust battle strategy is required in order to foresee this crisis. Any of the methods for coping with climate change include and expected adaptation strategies, i.e., cropping pattern change, use of new biotechnologies, change in seeds and diversification if subsistence patterns. Further, low-cost water saving technology can allow Rajasthan's poorest districts to practice irrigated agriculture with very little water in water-proof districts and structural water reforms, introducing private and tradable groundwater and water resources, will bring out a substantial increase in the amount of water farmers get in their regions. Moreover, Rajasthan will not only support farmers' livelihoods but will also be future exporters of agro-products in India by allowing judicial use of natural resources and integrating modern technology. The same amount of fertilisers pumped into the ground that they had 20 years before was injected by farmers. However, the chemical characteristics of the soil has changes absolutely. This paper thus proposes a systematic approach to satisfy the demand and availability of chemical fertilisers.

Conflict of interest

The authors declare that there is no conflict of interest.

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