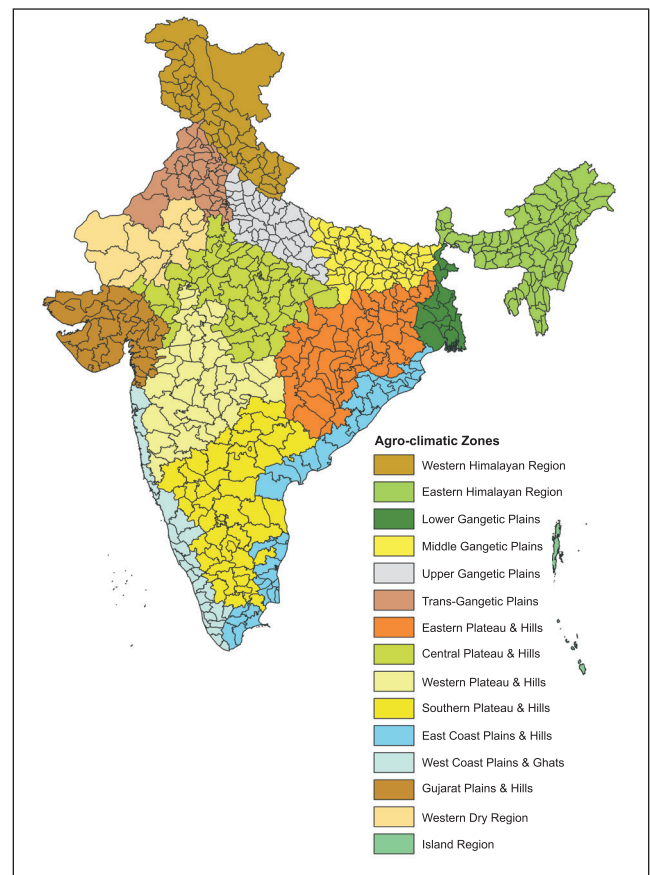


## Impact of Climate Change on Indian Agriculture: An Agro-Climatic Zone Level Estimation

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Climate change has emerged as the biggest challenge of the present era to the sustainable development. According to the Intergovernmental Panel on Climate Change (IPCC, 2018), greenhouse gas accumulation due to increased anthropogenic emissions has caused 1.0°C of global warming above pre-industrial levels which is likely to reach 1.5°C between 2030 and 2052, causing greater frequency of extremes events (droughts, floods, heat waves) and obstruction to the normal functioning of ecosystems.

Climate variations have significant impact on agriculture production and farm livelihoods especially in India, with diverse agro-climatic settings. Several studies in the past have attempted to analyse the variability/trend in meteorological variables and the consequent impact of climate change on crop yields in the country. A rising trend has been observed in both minimum and maximum temperatures over the past decades (Kothawale and Rupa Kumar, 2005; Kothawale et al., 2010; Birthal et al., 2014; Rao et al., 2014; Mondal et al., 2015). However, there are no clear long-term evidences for rainfall variations at the national level (Kumar et al., 2010; Jayaraman and Murari, 2014) but, regional analysis reveals a changing pattern of precipitation (Goswami et al., 2006, Jain and Kumar, 2012, Mallya et al., 2016). Moreover, under different climate scenarios several studies that examined the impact of change in rainfall and temperatures on crop yields indicate a decline in rice, wheat and maize in the country (Mall et al., 2006; Auffhammer et al., 2012, Gupta et al., 2014). For instance, Guiteras (2009) predicted reduction in major crop yields in India by 4.5 to 9 percent over the period 2010-2039 and by 25 percent in the long-run (2070-2099) without any long-run adaptations. In their study Kumar et al.



**Figure 1: Fifteen Agro-climatic zones of Planning Commission (map not to be scaled)**

(2014b) projected that climate change will reduce wheat yield in the range of 6 to 23 percent by 2050 and 15 to 25 percent by 2080 in India. Further, towards 2100, rice yield will be lower by 15 percent and wheat yield by 22 percent (Birthal et al., 2014).

**Table 1 : Spatial characteristic of Agro-climatic zones**

Agro-climatic Zone	Climate	Area <sup>s</sup> (Km <sup>2</sup> )	Gross Cropped Area <sup>p</sup> (ha) 2016-17	Food grains yield (Ton/ha) 2016-17	Annual Rainfall (mm) (1966-2011)	% Annual change Rainfall (1966-2011)	Annual MinT (°C) (1966-2011)	% Annual change MinT (1966-2011)	Annual MaxT (°C) (1966-2011)	% Annual change MaxT (1966-2011)	States <sup>@</sup>
Western Himalayan Region	Cold arid to humid	331392 (10.08)	3203114 (1.68)	2.178	1158.21	-0.3584***	14.18	0.2940***	26.27	0.0798***	Himachal Pradesh (12,16.80), Jammu & Kashmir <sup>w</sup> (22, 67.06), Uttarakhand (13,16.14)
Eastern Himalayan Region	Per humid to humid	274942 (8.36)	5972030 (3.14)	1.828	2463.50	-0.1972*	18.40	0.1552***	27.86	0.0591***	Arunachal Pradesh (16, 30.46), Assam (27, 28.53), Manipur (9, 8.12), Meghalaya (7, 8.16), Mizoram (8, 7.67), Nagaland (11, 6.03), Sikkim (4, 2.58), Tripura (4, 3.81), West Bengal (3, 4.64)
Lower Gangetic Plains	Moist sub-humid to dry sub-humid	69730 (2.12)	8501020 (4.47)	2.659	1485.36	-0.0909	21.21	0.1167***	31.55	0.0259***	West Bengal (15, 100)
Middle Gangetic Plains	Moist sub humid to dry sub humid	163793 (4.98)	14580454 (7.66)	1.590	1113.14	-0.1213	19.45	0.1277***	32.08	0.0460***	Uttar Pradesh (23, 42.51), Bihar (38, 57.49)
Upper Gangetic Plains	Dry sub-humid to semi-arid	141881 (4.32)	15287799 (8.04)	2.345	878.24	-0.4602***	18.87	0.1126***	32.28	0.0325***	Uttar Pradesh (41, 100)
Trans-Gangetic Plains	Extreme arid to dry sub-humid	147044 (4.47)	17865062 (9.39)	3.640	672.73	-0.0730	18.26	0.1240***	31.90	0.0380***	Chandigarh (1, 0.08), Delhi (9,1.01), Haryana (21, 30.07), Punjab (20, 34.25), Rajasthan (3, 34.60)
Eastern Plateau & Hills	Moist sub-humid to dry sub-humid	378178 (11.50)	10966699 (5.76)	1.560	1324.19	0.1026*	19.95	0.0729***	31.42	0.0140***	Chhattisgarh (18, 35.75), Jharkhand (24, 21.08), Madhya Pradesh (5, 8.58), Maharashtra (3, 6.28), Odisha (17, 26.66), West Bengal (1, 1.66)
Central Plateau & Hills	Semi-arid to dry sub-humid	334700 (10.18)	27594902 (14.50)	1.947	916.80	-0.2602***	19.13	0.1055***	32.00	0.0506***	Madhya Pradesh (31, 58.58), Rajasthan (18, 32.63), Uttar Pradesh (7, 8.79)
Western Plateau & Hills	Semi-arid	332979 (10.13)	25132237 (13.21)	0.745	929.05	0.0567	19.95	0.0614***	32.91	0.0357***	Madhya Pradesh (14, 23.94), Maharashtra (25, 76.06)
Southern Plateau & Hills	Semi-arid	407014 (12.38)	20472724 (10.76)	2.720	843.24	0.1237**	21.41	0.0747***	32.23	0.0479***	Andhra Pradesh (15, 47.96), Karnataka (23, 37.10), Tamil Nadu (13, 14.94)
East Coast Plains & Hills	Semi-arid to dry sub-humid	199900 (6.08)	8584138 (4.51)	2.076	1100.96	0.1334*	22.38	0.0750***	31.34	0.0454***	Andhra Pradesh (8, 39.93), Odisha (13, 27.45), Puducherry (4, 0.25), Tamil Nadu (17, 32.37)
West Coast Plains & Ghats	Dry sub-humid to per humid	118634 (3.61)	6860436 (3.61)	1.366	2417.93	0.0052	20.60	0.0545***	30.36	0.0376***	Goa (2, 3.12), Karnataka (7, 34.39), Kerala (14, 32.75), Maharashtra (6, 25.90), Tamil Nadu (2, 3.84)
Gujarat Plains & Hills	Arid to dry sub-humid	196846 (5.99)	12238077 (6.43)	2.036	861.77	0.5244***	19.95	0.0369***	32.17	0.0203***	Gujarat (26, 99.69), Dadra & Nagar Haveli (1, 0.25), Daman & Diu (2, 0.06)
Western Dry Region	Arid to extremely arid	182157 (5.54)	12969632 (6.82)	1.962	427.54	0.1105	18.77	0.1155***	33.08	0.0545***	Rajasthan (12, 100)

Source: Authors Estimation. Census of India (2011), Singh (2006), NICRA District Agricultural Contingency Plans, Indian Meteorological Department, Directorate of Economics and Statistics, Ministry of Agriculture and Farmers' Welfare.

Note: Total Geographical Area of India: 3287469 sq. km and number of districts: 640 (Census, 2011)

W : Includes illegal occupied J & K area by Pakistan and China.

\$ : Figures in the parentheses includes percentage share of ACZ in the total geographical area of the country.

p : Figures in the parentheses includes percentage share of ACZ in the total gross cropped area of the country.

@ : Figure in the parenthesis represents (Number of Districts, Total percentage area of state under ACZ)

\*, \*\* & \*\*\* indicates 10, 5, and 1 percent level of significance

Since agricultural systems are impacted at micro level due to climatic variations, therefore in order to facilitate effective adaptation or policy interventions, macro level spatial contexts as in aforesaid studies do not offer concrete lead lines due to uncertainties and information gaps. Hence, there is a dire need to get empirics related to the impact of climate change for major crops at agro-climatic zone level so that location specific R&D and dynamic, diversified and flexible interventions having local contexts (Singh et al., 2018, 2019) can be suggested. Thus, the present study aimed to examine the impact of climate change on major *kharif* and *rabi* crops, across agro-climatic zones (ACZs) delineated by the erstwhile Planning Commission of the Government of India (1989). For impact assessment major crop yields and socio-economic, infrastructural and technological factors were paired with weather parameters to construct a district-level panel for the period 1966-2011, covering 301 districts spread across 14 agro-climatic zones (excluding island region) in the country. The data on above variables were compiled from the database maintained by International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) under the Village Dynamics Studies in Asia (VDSA) project with 1966 base district boundaries. The data on rainfall and temperature (minimum and maximum) was obtained from the Indian Meteorological Department (IMD), Government of India and later aggregated into the entire crop growing period (sowing, germination and harvesting) for each ACZ.

Table 1, depicts the spatial characteristic of agro-climatic zones, where it was found that Southern Plateau & Hills (comprising parts of Andhra Pradesh, Karnataka and Tamil Nadu) with 12.38 percent and Eastern Plateau & Hills with 11.50 percent covered the largest geographical area among the ACZs. Of the total gross cropped area, 14.50, 13.21 and 10.76 percent was occupied by Central Plateau & Hills, Western Plateau & Hills and Southern Plateau & Hills respectively. In case of foodgrain productivity, Trans-Gangetic Plain (3.640 tons) followed by Southern Plateau & Hills (2.720 tons) and Lower Gangetic Plains (2.659 tons) recorded the highest average foodgrain yield per hectare. On the other hand, Western Plateau & Hills (covering parts of Madhya Pradesh and Maharashtra) had the lowest average foodgrain yield of 0.74 ton/ha.

Wide variations were observed in the distribution of rainfall across the zones. On an average, Eastern Himalayan Region (comprising north-eastern states and parts of West Bengal), followed by the West Coast Plains & Ghats received the highest amount of rainfall, whereas Western Dry Region and Trans-Gangetic

Plains received the lowest. During the period from 1966-2011, rainfall registered an annual decline in the Himalayan regions and Gangetic Plains. On the other hand, rainfall increased in Western and Southern Plateau & Hills and Coastal regions.

The annual mean minimum temperature was the lowest in Western Himalayan Region comprising high altitude states of Himachal Pradesh, Jammu & Kashmir and Uttarakhand. On the other hand, East Coast Plains & Hills, Southern Plateau & Hills and Lower Gangetic Plains recorded the highest annual mean minimum temperature among the ACZs. Western Dry Region and Western Plateau & Hills had the highest annual mean maximum temperature. The estimates showed an increase in both the annual mean maximum and minimum temperatures in all the ACZs. The increase in maximum temperature was significantly higher in Himalayan regions followed by Western Dry Region (parts of Rajasthan) and Central Plateau & Hills. On the other spectrum, the rate of increase in the minimum temperature was higher in both the Himalayan Regions followed by the Middle Gangetic Plains and Trans-Gangetic Plains indicating an accelerated warming in the zones during the period.

## 2. Methodology

The present study used the following model,

$$\log y_{dt} = c + \alpha_d + \delta t + \gamma \log X_{dt} + \beta \log W_{dt} + \varepsilon_{dt} \dots (1)$$

where  $y_{dt}$  represents crop yield,  $W_{dt}$  is a vector of climate variables (rainfall, maximum and minimum temperatures),  $X_{dt}$  denote socio-economic and other factors (irrigated area, road length, rural literates, tractors, fertilizer consumption and pump set) and  $\varepsilon_{dt}$  is the error term for the  $d^{th}$  district during the  $t^{th}$  time period respectively. The model includes district level fixed effects,  $\alpha_d$  which controls for unobserved district specific heterogeneity due to time-invariant factors that influence dependent variable. Moreover, a time trend has been incorporated as a proxy to absorb the technological effects and other farm level adaptations.

### Marginal Effect

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

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

Where,  $\frac{dy}{dc}$  is combined marginal effect of change

in climate variables on the crop yield,  $\beta$  denote 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 the agro-climatic zone.

## Projected Impact of Climate Change

The future projections for crop yields are based on 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 (2036-2065) and long-term (2066-2095) changes under RCP 4.5 scenario, relative to the base 1976–2005. In addition to the above the study assumed another near-to-mid-term period (2026-2055) as an average of the projections made for near-term (2016-2045) and mid-term (2036-2065) period.

**Table 2: Projected changes in Temperature under RCP 4.5 scenario**

Variable	2030s	2050s	2080s
Annual Minimum Temperature (°C)	1.36 ± 0.18 (13.2%)	2.14 ± 0.28 (13.1%)	2.63 ± 0.38 (14.4%)
Annual Maximum Temperature (°C)	1.26 ± 0.20 (15.9%)	1.81 ± 0.27 (14.9%)	2.29 ± 0.36 (15.7%)

Figure in the parenthesis indicate the associated uncertainty range

Source: Climate Change over India: An Interim report (2017). Centre for Climate Change Research, ESSO-IITM, Ministry of Earth Sciences, Govt. of India.

Further, a uniform variation of 5, 7, 10 and 12 percent in rainfall was assumed for the different periods. The projected change in crop yield was calculated using equation (3),

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

Where,  $\Delta Y$  denote change in crop yield,  $\Delta R$  in rainfall and  $\Delta T$  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. Marginal Impact and Forecasts

**Kharif Crops:** During the period from 1966-2011, a decline in rice yield was observed in nearly all the ACZs, with the highest reduction of 2.62 percent found in Eastern Himalayan Region (covering north-eastern states and parts of West Bengal). This was followed by Western Himalayan Region, Lower Gangetic Plains and Southern Plateau & Hills where rice yield reduced by 2.34, 1.17 and 0.72 percent. As shown in Table 3, maize yield declined in Central Plateau & Hills (1.33 percent), Western Dry Region (1.03 percent), Trans-Gangetic Plains (0.65 percent) and Upper Gangetic Plains (0.03). Regional variations are reflected from the fact that, while maize was negatively

impacted by climatic variations in the above regions, it was benefitted in Himalayan Regions, Lower Gangetic Plains and Middle Gangetic Plains. The maximum reduction in groundnut occurred in Southern Plateau & Hills (covering parts of Andhra Pradesh, Karnataka and Tamil Nadu) and West Coast Plains & Ghats, whereas in Central Plateau & Hills it showed an increase of 0.55 percent. Wide variations were observed in sorghum yield which showed a decline of 4.54 percent in Central Plateau & Hills (covering parts of Madhya Pradesh, Rajasthan and Uttar Pradesh) and increase of 4.68 percent in Western Plateau & Hills (parts of Madhya Pradesh and Maharashtra). Amongst the crops, sugarcane was the most impacted by the changing climatic conditions in all the growing regions. The yield loss for sugarcane was to the extent of 9.91, 8.02 and 3.66 percent in East Coast Plains & Hills, Middle Gangetic Plains and Western Plateau & Hills respectively. While Pearl millet yield showed an increase of 2.09 percent in Trans-Gangetic Plains, it registered a decline of 1.23 and 0.84 percent in Gujarat Plains & Hills and Western Dry Region. Finger millet increased by 1.10 percent in West Coast Plains & Ghats. Further, the effect of climatic variations has been found to be negative for cotton in Western Plateau & Hills and Trans-Gangetic Plains, where yield reduced by 1.74 and 0.59 percent.

The projected impact of climate change on crop yields showed that rice yield will decline by 5.49 and 6.79 percent in Eastern Himalayan Region by 2050s and 2080s. In near-term it is likely to reduce by 2.94 and 3.56 percent in Western and Eastern Himalayan Region. By 2040s rice yield is projected to decline by around 2 percent in Lower Gangetic Plain (parts of West Bengal). In case of both Eastern and Southern Plateau & Hills, rice yield will decline by around 1.3 and 1.7 percent by 2040s and 2050s respectively. On the other hand, rice yield in West Coast Plains & Ghats will be benefited from future climate variations. The maximum decline in maize was observed in Central Plateau & Hills and Western Dry Region where the crop yield is projected to decline by 2.24 and 1.68 percent by 2040s respectively. By 2080s maize is likely to increase by around 7 to 8 percent in Western Himalayan Region and Lower Gangetic Plains. Yield loss in case of groundnut is expected to be around 4 and 5 percent by 2040s and 2050s in Gujarat Plains & Hills. In near-term groundnut yield will reduce by 1.96 and 1.82 percent in Southern Plateau & Hills and West Coast Plains & Ghats whereas, it will increase by 0.95 percent in Central Plateau & Hills. In the mid and long term scenarios, sorghum is likely to increase by around 8 and 11 percent in Western Plateau & Hills and decrease by the same magnitude in Central Plateau & Hills respectively. The productivity of cotton will decline the most in Western Plateau & Hills followed by Trans-Gangetic Plains. For sugarcane, yield is projected to decline by 11 and



**Table 3: Marginal effects of climate change (1966-2011) and projected change on *kharif* crop yields**

(in percent)

Agro-climatic Zone	Crops	Marginal Effects	2030s	2040s	2050s	2080s
			$\Delta \text{ MinT}= 1.36$	$\Delta \text{ MinT}= 1.75$	$\Delta \text{ MinT}= 2.14$	$\Delta \text{ MinT}= 2.63$
			$\Delta \text{ MaxT}= 1.26$	$\Delta \text{ MaxT}= 1.50$	$\Delta \text{ MaxT}= 1.81$	$\Delta \text{ MaxT}= 2.29$
			$\Delta \text{ R}= (+/-) 5\%$	$\Delta \text{ R}= (+/-) 7\%$	$\Delta \text{ R}= (+/-) 10$	$\Delta \text{ R}= (+/-) 12\%$
Western Himalayan Region	Rice	-2.34	-2.94	-3.66	-4.41	-5.49
	Maize	3.29	4.17	4.94	5.97	7.57
Eastern Himalayan Region	Rice	-2.62	-3.56	-4.49	-5.49	-6.79
	Maize	1.33	1.83	2.42	2.97	3.61
Lower Gangetic Plains	Rice	-1.17	-1.60	-1.91	-2.34	-2.96
	Maize	2.83	3.99	5.11	6.29	7.74
Middle Gangetic Plains	Rice	-0.17	-0.26	-0.33	-0.41	-0.51
	Maize	0.19	0.45	0.60	0.79	0.96
	Sugarcane	-8.02	-11.15	-14.19	-17.43	-21.50
Upper Gangetic Plains	Rice	-0.07	-0.16	-0.20	-0.27	-0.33
	Sugarcane	-0.13	-0.77	-1.15	-1.57	-1.85
	Maize	-0.03	0.12	0.18	0.27	0.32
	Sorghum	-0.68	-0.88	-1.12	-1.36	-1.67
Trans-Gangetic Plains	Rice	-0.37	-0.40	-0.46	-0.54	-0.69
	Cotton	-0.59	-0.86	-1.22	-1.50	-1.78
	Pearl Millet	2.09	8.43	11.35	15.58	18.90
	Maize	-0.65	-0.90	-1.25	-1.53	-1.83
Eastern Plateau & Hills	Rice	-0.67	-1.08	-1.36	-1.71	-2.12
	Maize	0.28	0.30	0.26	0.30	0.43
Central Plateau & Hills	Sorghum	-4.54	-5.71	-7.29	-8.76	-10.80
	Maize	-1.33	-1.75	-2.24	-2.72	-3.35
	Groundnut	0.55	0.95	1.26	1.59	1.94
Western Plateau & Hills	Sorghum	4.68	6.15	7.00	8.56	11.01
	Cotton	-1.74	-2.24	-2.77	-3.36	-4.19
	Sugarcane	-3.66	-4.39	-5.17	-6.17	-7.84
Southern Plateau & Hills	Rice	-0.72	-1.06	-1.32	-1.65	-2.05
	Groundnut	-1.56	-1.96	-2.54	-3.06	-3.75
East Coast Plains & Hills	Rice	-0.37	-0.57	-0.74	-0.93	-1.13
	Groundnut	-0.49	-0.52	-0.64	-0.74	-0.93
	Sugarcane	-9.91	-12.94	-16.70	-20.26	-24.87
West Coast Plains & Ghats	Rice	0.01	0.07	0.10	0.14	0.16
	Groundnut	-1.51	-1.82	-2.30	-2.75	-3.39
	Finger Millet	1.10	1.38	1.78	2.14	2.63
Gujarat Plains & Hills	Pearl Millet	-1.23	-2.00	-3.36	-4.17	-4.70
	Cotton	0.02	-0.30	-0.81	-1.06	-1.08
	Groundnut	-1.26	-2.31	-3.96	-4.97	-5.58
Western Dry Region	Pearl Millet	-0.84	-0.82	-1.04	-1.17	-1.45
	Maize	-1.03	-1.32	-1.68	-2.03	-2.50

Source: Authors' estimation

Note: Direction of rainfall for the future projections was premised on trend analysis for the period, 2001-2011.

13 percent in Middle Gangetic Plains (covering Bihar and parts of Uttar Pradesh) and East Coast Plains & Hills by 2030s. Pearl millet is likely to increase by 15.58 percent by mid-term period in Trans-Gangetic

Plains. On the other hand, for the same period yield will reduce by 4.17 and 1.17 percent in Gujarat Plains & Hills and Western Dry Region.

**Rabi Crops:** The results reveal that over the period, wheat yield was negatively impacted by climatic variations in all the growing regions except West Coast Plains & Ghats and Gujarat Plains & Hills (Table 4). The maximum yield reduction occurred in Western Dry Region (2.73), followed by Eastern Himalayan Region (2.03). Moreover, Gangetic Plains also showed a decline in wheat with the highest reduction of 1.02 percent found in Trans-Gangetic

Plains followed Lower Gangetic Plain (0.96 percent). Barley on the other hand showed a decline of 0.76 and 0.26 percent in Western Himalayan Region and Trans-Gangetic Plains, whereas in Middle Gangetic Plains and Upper Gangetic Plains, it registered a marginal increase of 0.04 and 0.01 percent. In nearly all the growing regions, rapeseed & mustard was positively impacted reflecting high tolerance and resilience of crop to the changing climatic conditions. In East Coast

**Table 4 : Marginal effects of climate change (1966-2011) and projected change for rabi crop yields**

(in percent)

Agro-climatic Zone	Crops	Marginal Effects	2030s	2040s	2050s	2080s
			$\Delta \text{MinT}= 1.36$	$\Delta \text{MinT}= 1.75$	$\Delta \text{MinT}= 2.14$	$\Delta \text{MinT}= 2.63$
			$\Delta \text{MaxT}= 1.26$	$\Delta \text{MaxT}= 1.50$	$\Delta \text{MaxT}= 1.81$	$\Delta \text{MaxT}= 2.29$
			$\Delta R= (+/-) 5\%$	$\Delta R= (+/-) 7\%$	$\Delta R= (+/-) 10$	$\Delta R= (+/-) 12\%$
Western Himalayan Region	Wheat	-0.47	-0.66	-0.85	-1.05	-1.29
	Barley	-0.76	-0.91	-1.04	-1.25	-1.60
Eastern Himalayan Region	Wheat	-2.03	-2.61	-3.28	-3.98	-4.93
	Rapeseed & Mustard	-1.08	-1.44	-1.77	-2.16	-2.70
Lower Gangetic Plains	Wheat	-0.96	-1.04	-1.24	-1.45	-1.83
	Rapeseed & Mustard	-1.21	-1.67	-2.01	-2.46	-3.10
Middle Gangetic Plains	Wheat	-0.28	-0.37	-0.46	-0.56	-0.69
	Rapeseed & Mustard	1.04	1.26	1.58	1.90	2.36
	Barley	0.04	0.05	0.09	0.10	0.12
Upper Gangetic Plains	Wheat	-0.09	-0.11	-0.14	-0.17	-0.21
	Barley	0.01	0.03	0.04	0.06	0.08
	Rapeseed & Mustard	0.20	0.29	0.37	0.46	0.57
Trans-Gangetic Plains	Wheat	-1.02	-1.53	-2.07	-2.57	-3.11
	Barley	-0.26	-0.30	-0.34	-0.40	-0.52
	Rapeseed & Mustard	1.59	2.32	3.14	3.89	4.70
Eastern Plateau & Hills	Wheat	-0.26	-0.30	-0.41	-0.48	-0.58
	Linseed	-0.87	-1.23	-1.62	-2.00	-2.43
Central Plateau & Hills	Wheat	-0.94	-1.31	-1.69	-2.07	-2.54
	Rapeseed & Mustard	2.73	3.69	4.72	5.76	7.10
Western Plateau & Hills	Wheat	-0.88	-1.12	-1.34	-1.62	-2.05
	Rapeseed & Mustard	-1.86	-2.05	-2.10	-2.45	-3.29
Southern Plateau & Hills	Wheat	-1.27	-1.73	-2.14	-2.62	-3.27
	Linseed	-1.35	-1.72	-2.08	-2.51	-3.16
East Coast Plains & Hills	Wheat	-1.46	-2.01	-2.61	-3.19	-3.92
	Rapeseed & Mustard	3.45	4.71	6.05	7.41	9.10
West Coast Plains & Ghats	Wheat	0.33	0.48	0.62	0.77	0.95
	Rapeseed & Mustard	2.45	3.37	4.33	6.34	6.53
Gujarat Plains & Hills	Wheat	0.44	1.29	2.48	3.20	3.49
	Rapeseed & Mustard	0.31	0.86	1.66	2.13	2.32
Western Dry Region	Wheat	-2.73	-3.71	-4.77	-5.84	-7.17
	Rapeseed & Mustard	2.57	3.50	4.50	5.50	6.75

Source: Authors' estimation

Note: Direction of rainfall for the future projections was premised on trend analysis for the period, 2001-2011.

Plains & Hills, Central Plateau & Hills and Western Dry Region, rapeseed & mustard showed the maximum increase of 3.45, 2.73 and 2.57 percent respectively. On the other spectrum, yield reduced by 1.86 and 1.21 percent in Western Plateau & Hills (parts of Madhya Pradesh and Maharashtra) and Lower Gangetic Plains (parts of West Bengal). During the period, linseed declined by 1.35 and 0.87 percent in both the Eastern and Southern Plateau & Hills respectively.

Climate projections for *rabi* crops indicate that wheat will reduce by 5.84 and 7.17 percent by 2050s and 2080s in Western Dry Region. For the similar periods it will reduce by 3.98 and 4.93 percent in Eastern Himalayan Region and 2.57 and 3.11 percent in Trans-Gangetic Plains. In Gujarat Plains & Hills, wheat is likely to increase by 3.20 percent by 2050s. Rapeseed & mustard is projected to increase up to 9.10, 7.10 and 6.75, percent by 2080s in East Coast Plains & Hills, Central Plateau & Hills and Western Dry Region. On the other hand, by 2040s it is likely to reduce by around 2 percent in Lower Gangetic Plains and Western Plateau & Hills. By 2050s barley will reduce by 1.25 and 0.4 percent in Western Himalayan Region and Trans-Gangetic Plains.

#### 4. Conclusion

The present study has captured the large-scale heterogeneity in climate parameters and their impact on agriculture at regional level. An examination of spatial and temporal variability in temperatures revealed a rise in both the annual mean maximum and minimum temperature, but change in annual mean minimum temperature was more pronounced than the annual mean maximum temperature in all the agro-climatic zones. During the period from 1966-2011, rainfall recorded an annual decline in Himalayan Regions and Gangetic Plains while an increase in Coastal Regions, Plateau & Hills and Western Dry Region. Overall, the empirical results show that climate change adversely impacts both the *kharif* and *rabi* crop yields across ACZs. As evident from the foregoing analysis, the near-term impact of climate change on crop yields will not be severe. However, it is likely that the increasing incidence of extreme fluctuations in climate in the form of droughts, dry spell, floods and heat waves could result into discernible effect on agriculture production and productivity (Kumar et al., 2014a). Special attention needs to be diverted to Himalayan hills, Lower Gangetic Plains, Western Plateau and Coastal regions where climate change is likely to result in lower yields and high farm vulnerability. Concerted efforts are needed in development and dissemination of climate resilient varieties and practices, promotion

of integrated watershed management for greater water use efficiency and crop diversification. Moreover, there is a dire need to formulate region-specific interventions and plans and prioritization of adaptation strategies to deal with current and future climate change for evolving farmers-centric climate adaptation and mitigation policy. Mainstreaming climate change and adaptation in the rural developmental paradigm is imperative to improve the envisaged agriculture outputs and outcomes for enhanced farm livelihoods.

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