POLICY BRIEF 44

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 the pre-industrial levels which is likely to reach 1.5°C between 2030 and 2052, causing greater frequency of extreme weather events and obstruction to the normal functioning of ecosystems.

Climate change is likely to have significant impact on agriculture production and farm livelihoods in India, with diverse agro-climatic settings. Several studies in the past have analysed 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 et al., 2010; Mondal et al., 2015). 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 (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 (Guiteras, 2009; Birthal et al., 2014; Gupta et al., 2014).

Since agricultural systems are impacted at micro level due to climatic variations, macro level spatial contexts 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

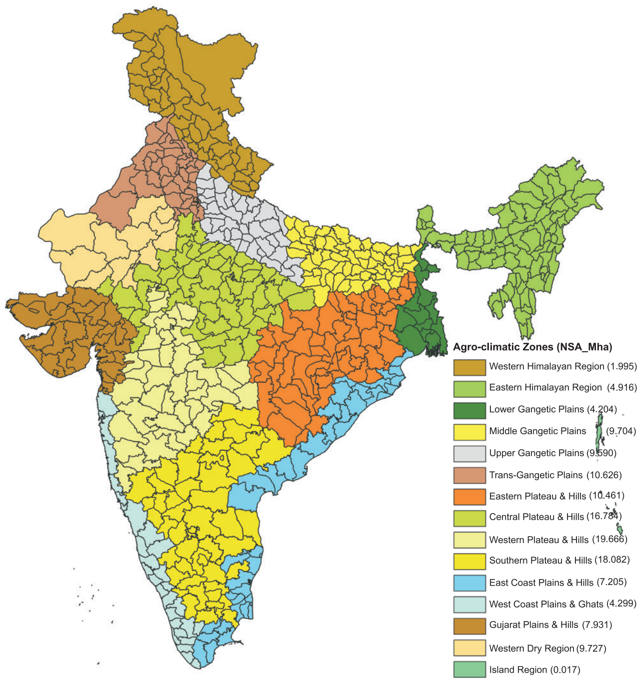

Figure 1: Fifteen Agro-climatic zones of Planning Commission (map not to be scaled)

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., 2014; 2019) can be suggested. Thus, the present study conducted as a part of National Innovations in Climate Resilient Agriculture (NICRA) examined 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.

Figure 1 depicts the spatial spread of the agro-climatic zones, wherein it was found that Western Plateau & Hills had the largest net sown area (NSA). This was followed by Southern Plateau & Hills and Central Plateau & Hills with a net sown area of approximately 18.08 and 16.78 million hectares respectively.

Wide variations were observed in the distribution of rainfall across the zones. During the period 1966-2011 Eastern Himalayan Region (comprising north-eastern states and parts of West Bengal), followed by the West Coast Plains & Ghats received the highest amount of annual rainfall, whereas Western Dry Region and Trans-Gangetic Plains received the lowest. Further, while rainfall registered an annual decline in the Himalayan regions and Gangetic Plains, it 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.

Methodology

The present study used the following model,

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

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 ε_{dt} is the error term for the d^{th} district during the t^{th} time period respectively. The model includes district level fixed effects, α_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).

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

Where, $\frac{dy}{dc}$ is combined marginal effect of change in climate variables on the crop yield, β 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 of 2040s (2026-2055) as an average of the projections made for near-term (2016-2045) and mid-term (2036-2065) period.

Table 1: Projected changes in temperature under RCP 4.5 scenario

Variable	Near-term (2030s)	Mid-term (2050s)	Long-term (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 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),

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

Where, ΔY denotes 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.

Table 2: Marginal effects of climate change (1966-2011) and projected change on *kharif* crop yields (%)

Agro-climatic Zone	Crops	Marginal Effects	2030s	2040s	2050s	2080s
			Δ MinT= 1.36	Δ MinT= 1.75	Δ MinT= 2.14	Δ MinT= 2.63
			Δ MaxT= 1.26	Δ MaxT= 1.50	Δ MaxT= 1.81	Δ MaxT= 2.29
			Δ R= (+/-) 5%	Δ R= (+/-) 7%	Δ R= (+/-) 10	Δ 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. ICRISAT-VDSA Database, India Meteorological Department (IMD) Government of India.
Note: Direction of rainfall for the future projections was premised on trend analysis for the period, 2001-2011.

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 2, 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 percent). 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). 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 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 3). 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 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.

Table 3 : Marginal effects of climate change (1966-2011) and projected change for *rabi* crop yields (%)

Agro-climatic Zone	Crops	Marginal Effects	2030s	2040s	2050s	2080s
			Δ MinT= 1.36	Δ MinT= 1.75	Δ MinT= 2.14	Δ MinT= 2.63
			Δ MaxT= 1.26	Δ MaxT= 1.50	Δ MaxT= 1.81	Δ MaxT= 2.29
			Δ R= (+/-) 5%	Δ R= (+/-) 7%	Δ R= (+/-) 10	Δ 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. ICRISAT-VDSA Database, India Meteorological Department (IMD) Government of India.
Note: Direction of rainfall for the future projections was premised on trend analysis for the period, 2001-2011.

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 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 *kharif* and *rabi* crop yields across ACZs. 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., 2014). 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 adaptation strategies to deal with climate change and evolve farmers-centric climate adaptation and mitigation policy.

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