Climate, Climate Change, and Agriculture

06
CHAPTER

Mere desh ki dharti sona ugle ugle heerey moti
(My country's soil where crops grow like gold, diamonds, and pearls)

Manoj Kumar, Upkaar

Kaa barakhaa, jab krishi sukhaanee
(What's the use of that untimely rain after the crop has dried up)

Tulsidas, Ram Charit Maanas

Using district-level data on temperature, rainfall and crop production, this chapter documents a long-term trend of rising temperatures, declining average precipitation, and increase in extreme precipitation events. A key finding—and one with significant implications as climate change looms—is that the impact of temperature and rainfall is felt only in the extreme; that is, when temperatures are much higher, rainfall significantly lower, and the number of "dry days" greater, than normal. A second key finding is that these impacts are significantly more adverse in unirrigated areas (and hence rainfed crops) compared to irrigated areas (and hence cereals). Applying these estimates to projected long-term weather patterns implies that climate change could reduce annual agricultural incomes in the range of 15 percent to 18 percent on average, and up to 20 percent to 25 percent for unirrigated areas. Minimizing susceptibility to climate change requires drastically extending irrigation via efficient drip and sprinkler technologies (realizing "more crop for every drop"), and replacing untargeted subsidies in power and fertilizer by direct income support. More broadly, the cereal-centricity of policy needs to be reviewed.

INTRODUCTION

6.1 The bounty of Indian agriculture romanticized in that famous Manoj Kumar song—which also underlies the Prime Minister's goal of doubling farmers' incomes—increasingly runs up against the contemporary realities of Indian agriculture, and the harsher prospects of its vulnerability to long-term climate change.

6.2 The last few seasons have witnessed a problem of plenty: farm revenues declining for a number of crops despite increasing production and market prices falling below the Minimum Support Price (MSP). But in the medium to long term, the ghost of Malthus looms over Indian agriculture. Productivity will have to be increased, and price and income volatility reduced, against the backdrop of increasing resource constraints.

Shortages of water and land, deterioration in soil quality, and of course climate change-induced temperature increases and rainfall variability, are all going to impact agriculture. It is therefore opportune to analyze the effects of climate on Indian agriculture.

Why Agriculture Matters: An Irony

6.3 First, and foremost, agriculture matters in India for deep reasons, not least because the farmer holds a special place in Indian hearts and minds. The first salvo of satyagraha was fired by Mahatma Gandhi on behalf of farmers, the indigo farmers exploited by colonial rule. Not unlike in early, Jeffersonian America (Hofstadter, 1955), history and literature have contributed to the farmer acquiring mythic status in Indian lore: innocent, unsullied, hard-working, in harmony with nature; and yet poor, vulnerable, and the victim, first of the imperial masters and then of indigenous landlords and middlemen. Bollywood (and Kollywood and Tollywood) has also played a key role in creating and reinforcing the mythology of the Indian farmer (for example, in movies such as *Mother India, Do Beegha Zameen, Upkaar*, *Lagaan*, and more recently *Peepli Live*).

6.4 Agriculture also matters for economic reasons because it still accounts for a substantial part of GDP (16 percent) and employment (49 percent)[1]. Poor agricultural performance can lead to inflation, farmer distress and unrest, and larger political and social disaffection—all of which can hold back the economy.

6.5 The Nobel Prize winner, Sir Arthur Lewis (among others), argued that economic development is always and everywhere about getting people out of agriculture and of agriculture becoming over time a less important part of the economy (not in absolute terms but as a share of GDP and employment). The reason why agriculture cannot be the dominant, permanent source of livelihood is its productivity *level*, and hence the living standards it sustains, can never approach—and have historically never approached—those in manufacturing and services. That, of course, means that industrialization and urbanization must provide those higher productivity alternatives to agriculture. But this must happen along with, and in the context of, rapid productivity growth in agriculture, to produce greater food supplies for the people, provide rising farm incomes, and permit the accumulation of human capital.

6.6 At the same time, Dr. Ambedkar warned about the dangers of romanticizing rural India. He famously derided the village as "a sink of localism, a den of ignorance, narrow mindedness and communalism," thereby expressing a deeper truth—an Indian social complement to the Lewisian economic insight—that in the long run people need to move and be moved out of agriculture for non-economic reasons.

6.7 So the irony is that the concern about farmers and agriculture today is to ensure that tomorrow there are fewer farmers and farms but more productive ones. In other words, all good and successful economic and social development is about facilitating this transition in the context of a prosperous agriculture and of rising productivity in agriculture because that will also facilitate good urbanization and rising productivity in other sectors of the economy.

Long run agricultural performance

6.8 The focus on agriculture is warranted by its long run economic performance. Chand (2012) and Gulati (2009), among others have analysed the temporal and spatial performance of agriculture. Real agricultural growth since 1960 has averaged about 2.8 percent in India. The period before

[1] The International Labour Organization (ILO) estimates the agriculture share of employment at 44.3 percent.

the Green Revolution saw growth of less than 2 percent; the following period until 2004 yielded growth of 3 percent; in the period after the global agricultural commodity surge, growth increased to 3.6 percent (Figure 1). China's annual agricultural growth over the long run has exceeded that of India by a substantial 1.5 percentage points on average.

6.9 The volatility of agricultural growth in India has declined substantially over time: from a standard deviation of 6.3 percent between 1960 and 2004 to 2.9 percent since 2004. In particular, production of cereals has become more robust to drought.

6.10 But levels of volatility continue to be high and substantially higher than in China where the ups and downs have been virtually eliminated (Figure 2, circled area). An important contributing factor is that agriculture in India even today continues to be vulnerable to the vagaries of weather because close to 52 percent (73.2 million hectares area of 141.4 million hectares net sown area) of it is still un-irrigated and rainfed.[2]

6.11 Against this background, this chapter pursues three objectives - first, to document the changes in climactic patterns in temperature and rainfall over the past six decades.[3] Second, to estimate the effects of fluctuations in weather on agricultural productivity. And finally, to use these short-run estimates in conjunction with predicted changes in climate over the long-run to arrive at estimates of the impact of global warming on Indian agriculture. A number of distinguished Indian agricultural economists have analysed various aspects of agriculture [Chand (2007, 2010, 2012 2015), Gulati (1999, 2005, 2007, 2008, 2009, 2017), Ramaswami (2001, 2002, 2013), Swaminathan (2005, 2008, 2010)] but there have not been recent estimates of the impact of weather on agriculture at such a disaggregated level.

Motivation

6.12 But why re-invent the wheel, when there already is a burgeoning and serious body of research and analysis at the international level of the impact of climate on economic activity Deschênes, and Greenstone (2007 and 2011); Dell, Jones and Olken (2012 and 2014); IMF (2017); and Burke, Hsiang, and Miguel (2015)?

6.13 The answer is threefold. There is the standard worry that cross-country analysis might not apply to large, individual countries such as India, which is agrarian and is home to a great diversity of climate zones. A second, related point is that an India-specific analysis would be more granular, done at a spatially more disaggregated level than coarser cross-country analysis (although there are cross-country analysis that use such disaggregated data).

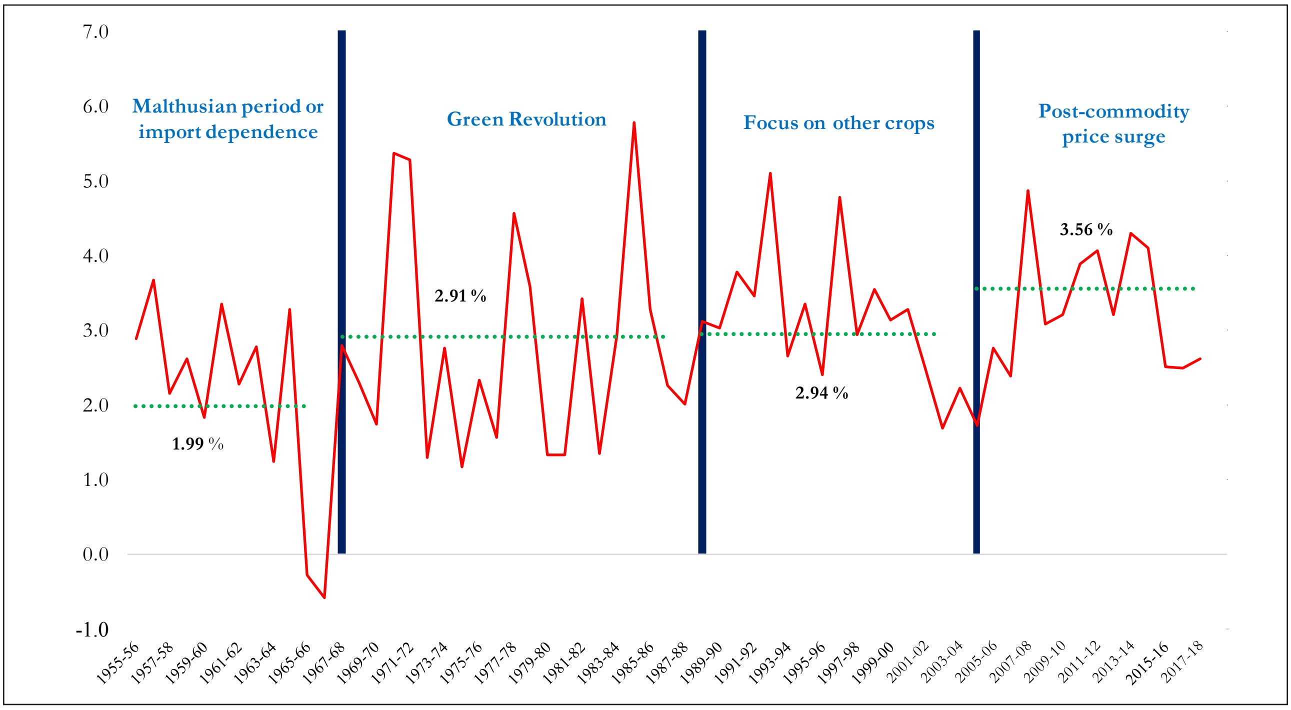
6.14 A final and important reason—with implications for research findings and hence policy input—has to do with data quality. Nearly all the available cross-country analysis use cross-country databases on temperature, weather, and extreme events. For example, Dell, Jones and Olken (2012, 2014) and IMF (2017) use a dataset created by the University of Delaware for temperature and precipitation. These databases rely on Indian data but with far fewer actual measurement points ("stations") than available with the Indian Meteorological Department (IMD). The Delaware

[2] Annual Report, 2016-17, Ministry of Agriculture & Farmers Welfare.

[3] Throughout this chapter, "weather" is used to refer to annual realizations of temperature and precipitation, whereas "climate" refers to long-term patterns in these variables.

Figure 1. Real Agricultural GVA Growth in India, 1960-2016

(in percent, 5 year moving average)

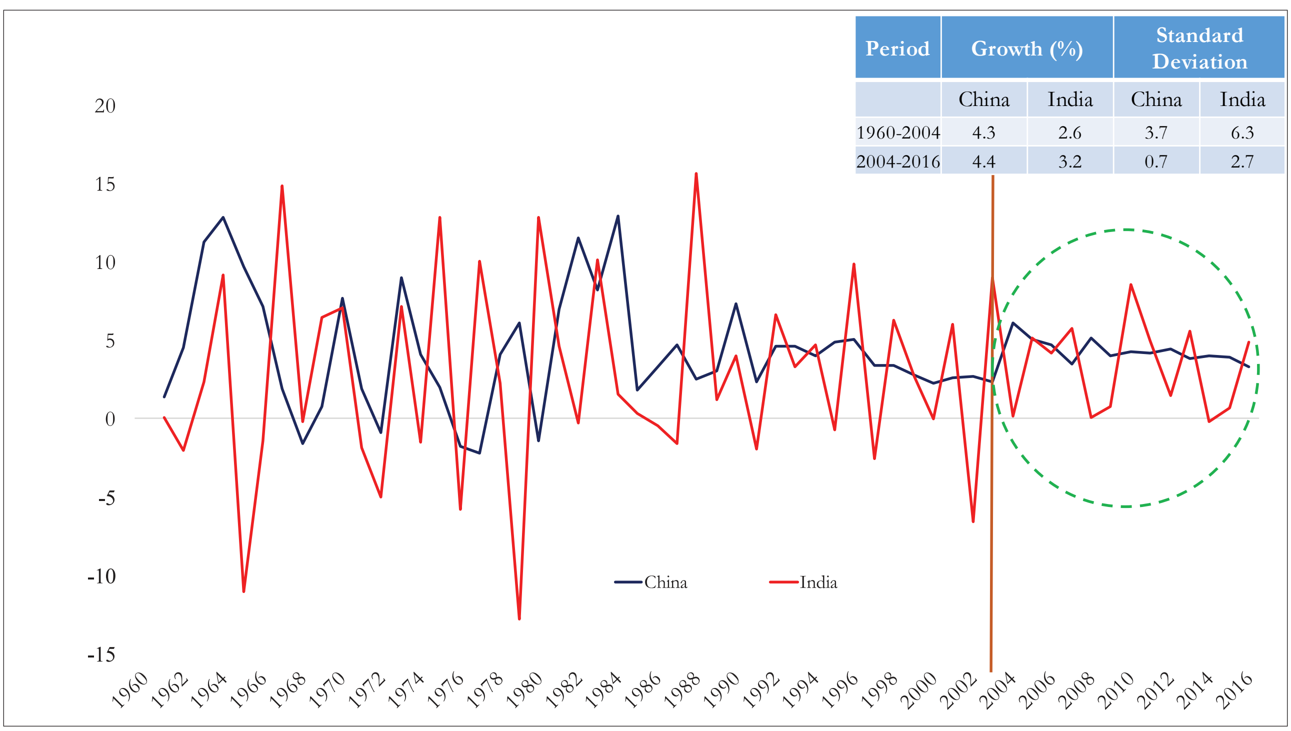


Source: Survey calculations.

Note: Numbers represent average agricultural growth rates for each period in percent.

Figure 2. Real Agricultural GDP Growth, China and India, 1960-2016

(in percent)



Period	Growth (%)		Standard Deviation	
	China	India	China	India
1960-2004	4.3	2.6	3.7	6.3
2004-2016	4.4	3.2	0.7	2.7

Source: Survey calculations.

Figure 3. Temperature and Rainfall : Comparison of Indian & International Data

Figure 3a. Average Annual Temperature

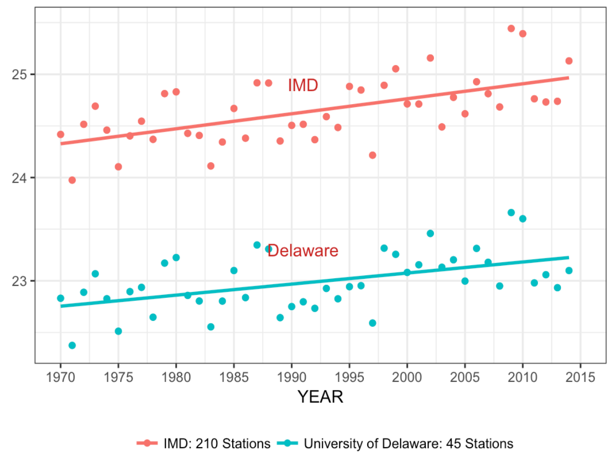
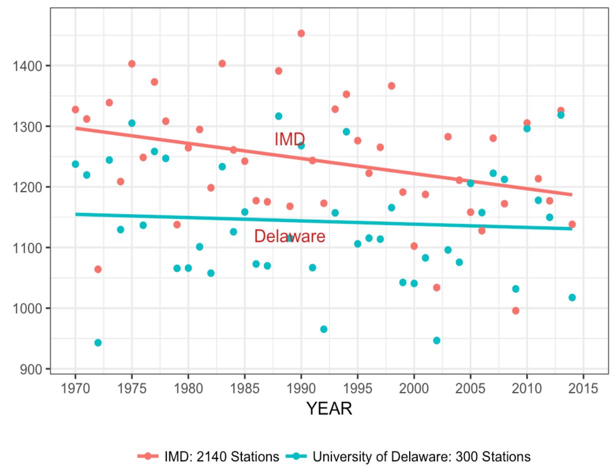


Figure 3b. Average Annual Rainfall



Source: Survey calculations from IMD and University of Delaware data. For temperature, the annual average is estimated for each grid point, and then averaged across all grid points to obtain the all-India average. For rainfall, the total rainfall for each grid point is averaged across all grid points to obtain the all-India average.

temperature data base is gridded (to make it spatially representative) but based on 45 weather stations in India whereas the IMD data is gridded from 210 weather stations. Similarly, the Delaware database for precipitation relies on Indian rainfall data provided by 300 stations compared to an actual sample of 2140 stations (See Annex for a comparison of Indian and cross-country databases).

6.15 The divergences between the cross-country databases are illustrated in Figures 3a and 3b below for the average annual temperature and average annual rainfall data, respectively.[4]

6.16 In these figures, there are substantial differences in both levels and trends between the two datasets. For example, IMD data (in red) record much higher average[5] levels of temperatures than the Delaware dataset (by over 1 degree Celsius on average, in climate terms, the difference between disaster and nirvana). Similarly, the IMD data shows higher levels of precipitation of about 100 millimetres on average (again a potential difference between deluge and drought) with a sharply declining trend since the 1970s unlike the Delaware data. These differences suggest that any analysis of long run climate impacts could be very different across these datasets.

6.17 Thus, armed with high quality, high resolution, temperature and precipitation data, this chapter proceeds to analyze patterns in temperature and precipitation in India, and the impact they have on agricultural productivity.

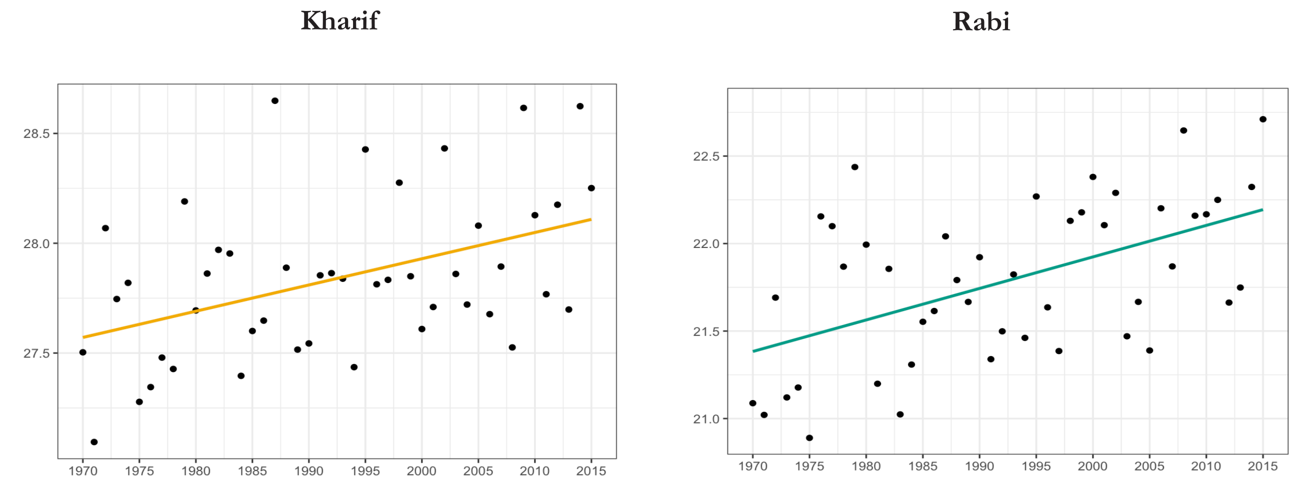
TEMPORAL AND SPATIAL PATTERNS OF TEMPERATURE AND PRECIPITATION

6.18 Figure 4 plots average temperature by cropping seasons. The broad pattern of rising temperatures post 1970s is common to both seasons. The average increase in temperature between the most recent decade and the 1970s is

[4] Averages calculated over all grid points of Delaware and IMD datasets, which lie within the boundaries of India.

[5] So, the differences between the two databases could arise for two reasons: daily (IMD) versus monthly (Delaware) and 210/2140 (IMD) versus 45/300 (Delaware) collections points for temperature/rainfall. IMD datasets are more detailed and disaggregated.

Figure 4. Average Temperature by Cropping Season: Kharif and Rabi
(degrees Celsius)



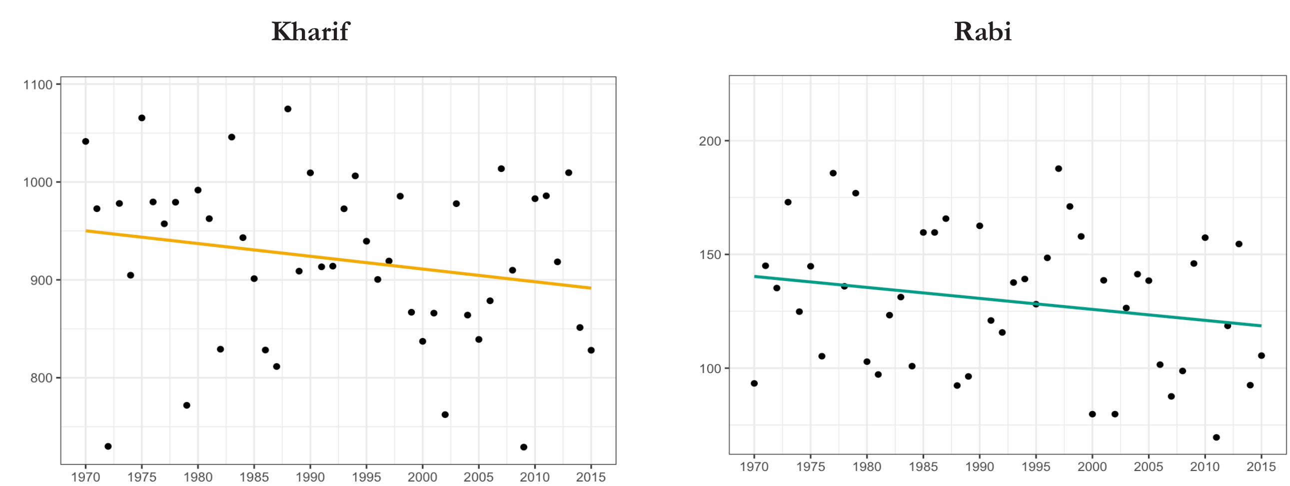
Source: Survey calculations from IMD data.

about 0.45 degrees and 0.63 degrees in the kharif and rabi seasons, respectively. These trends are consistent with those reported in Rajeevan (2013).

6.19 Figure 5 plots the rainfall patterns in the two seasons. Between the 1970s and the last decade, kharif rainfall has declined on average by 26 millimeters and rabi rainfall by 33 millimeters. Annual average rainfall for this period has on average declined by about 86 millimeters.

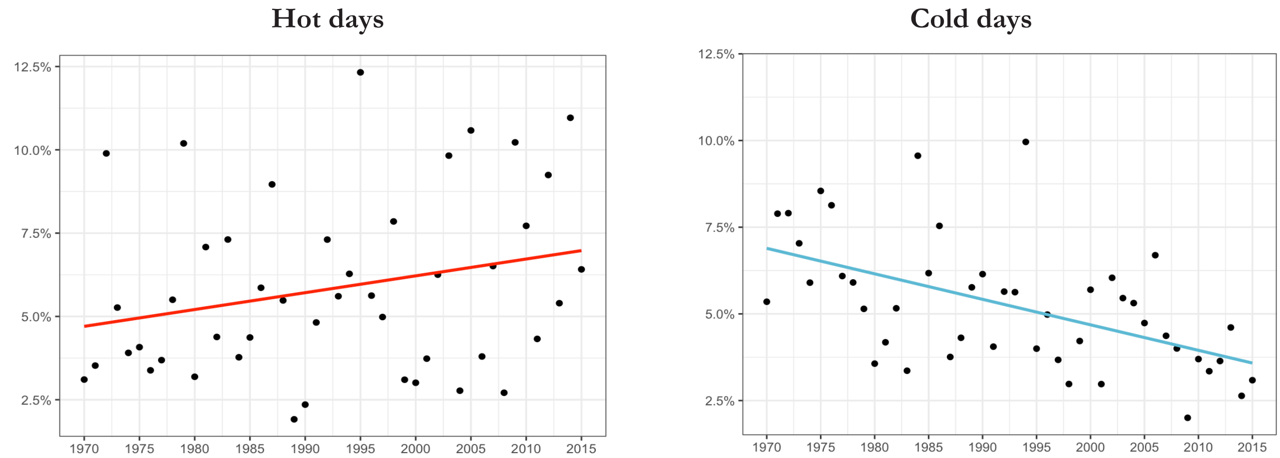
6.20 What about the number of days with extremely high and low temperatures? Figure 6 plots the proportion of days during the monsoon season in each year when the temperature was extremely high (defined as greater than the 95th percentile of the grid-point specific temperature distribution) and extremely low (less than the 5th percentile of the grid point specific temperature distribution). These figures are suggestive of a rise in the number of days with extremely high temperatures, and a corresponding decline in the number of days with low temperatures.

Figure 5. Average Precipitation by Cropping Season: Kharif and Rabi
(Millimetres)



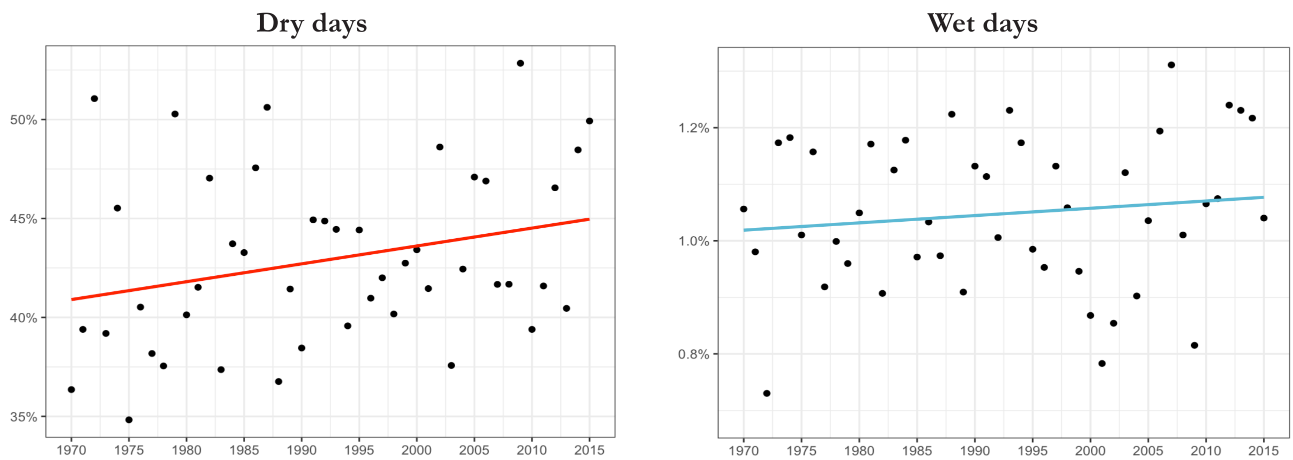
Source: Survey calculations from IMD data.

Figure 6. Very Hot and Cold Days during the Monsoon
(percentage of total days)



Source: Survey calculations from IMD data.

Figure 7. Dry and Wet Days during the Monsoon
(percentage of total days)

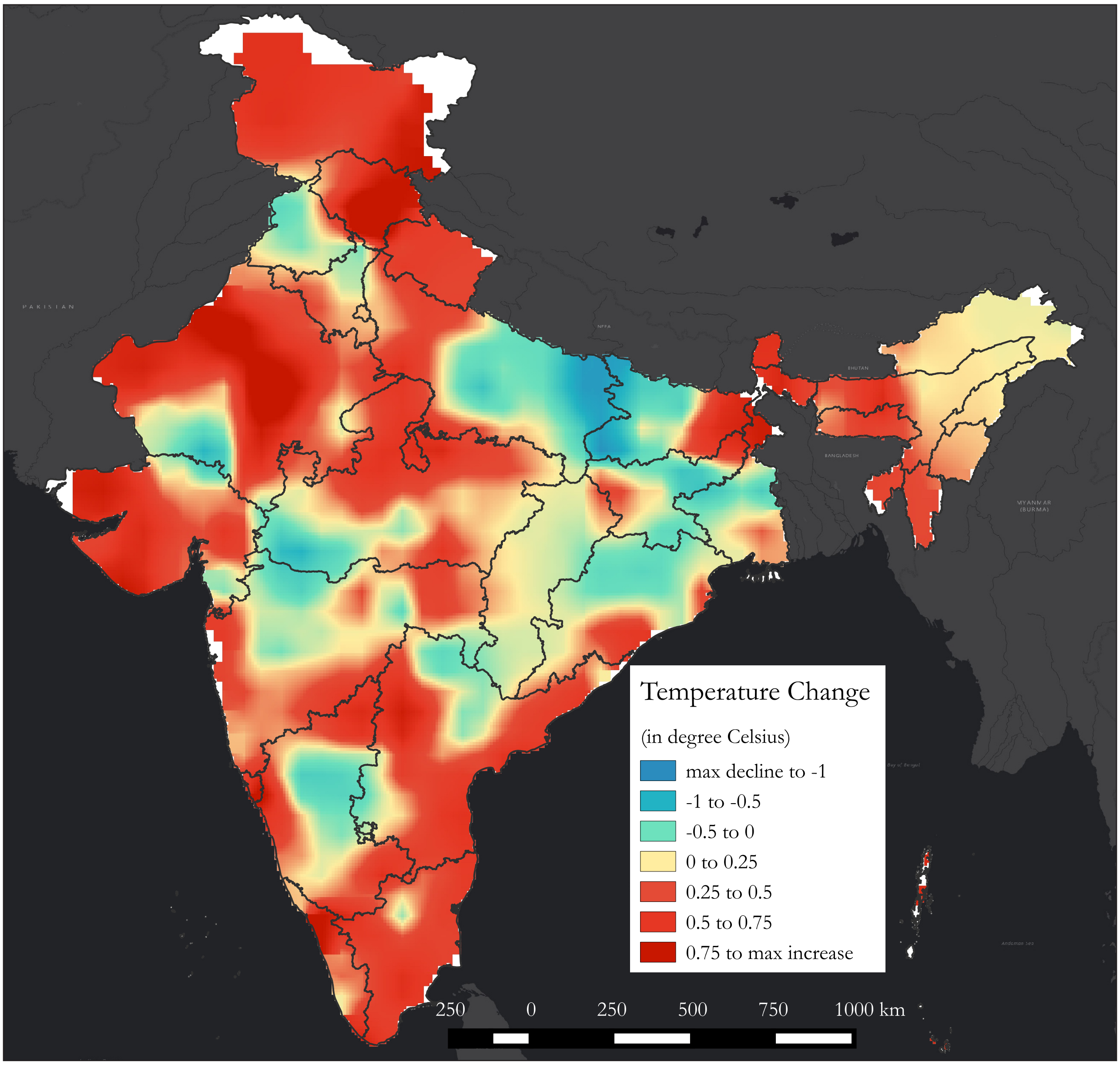


Source: Survey calculations from IMD data.

6.21 Turning attention to rainfall extremities, Figure 7 shows that the proportion of dry days (rainfall less than 0.1 mm per day), as well as wet days (rainfall greater than 80 mm per day) has increased steadily over time. Thus, the imprint of climate change is clearly manifest in the increasing frequency of extreme weather outcomes.

6.22 The spatial dimensions of changes in weather are displayed in Figure 8a (for temperature) and Figure 8b (for rainfall). They show, respectively, the difference in temperature and rainfall between the last decade (2005-2015) and the period 1950-1980. Figure 8a illustrates the pattern of average warming with a large part of the map covered in red. Temperature increases have been particularly felt in the North-East, Kerala, Tamil Nadu, Kerala, Rajasthan and Gujarat. Parts of India, for example, Punjab, Odisha and Uttar Pradesh have been the least affected. In contrast, Figure 8b indicates that extreme deficiencies are more concentrated in Uttar Pradesh, North-East, and Kerala, Chattisgarh and Jharkhand. There

Figure 8a. Spatial Changes in Temperature
(change in average temperature between the last decade and 1950-1980 period)



Source: Survey calculations from IMD data.[6] Red (blue) denotes rising (falling) temperature.

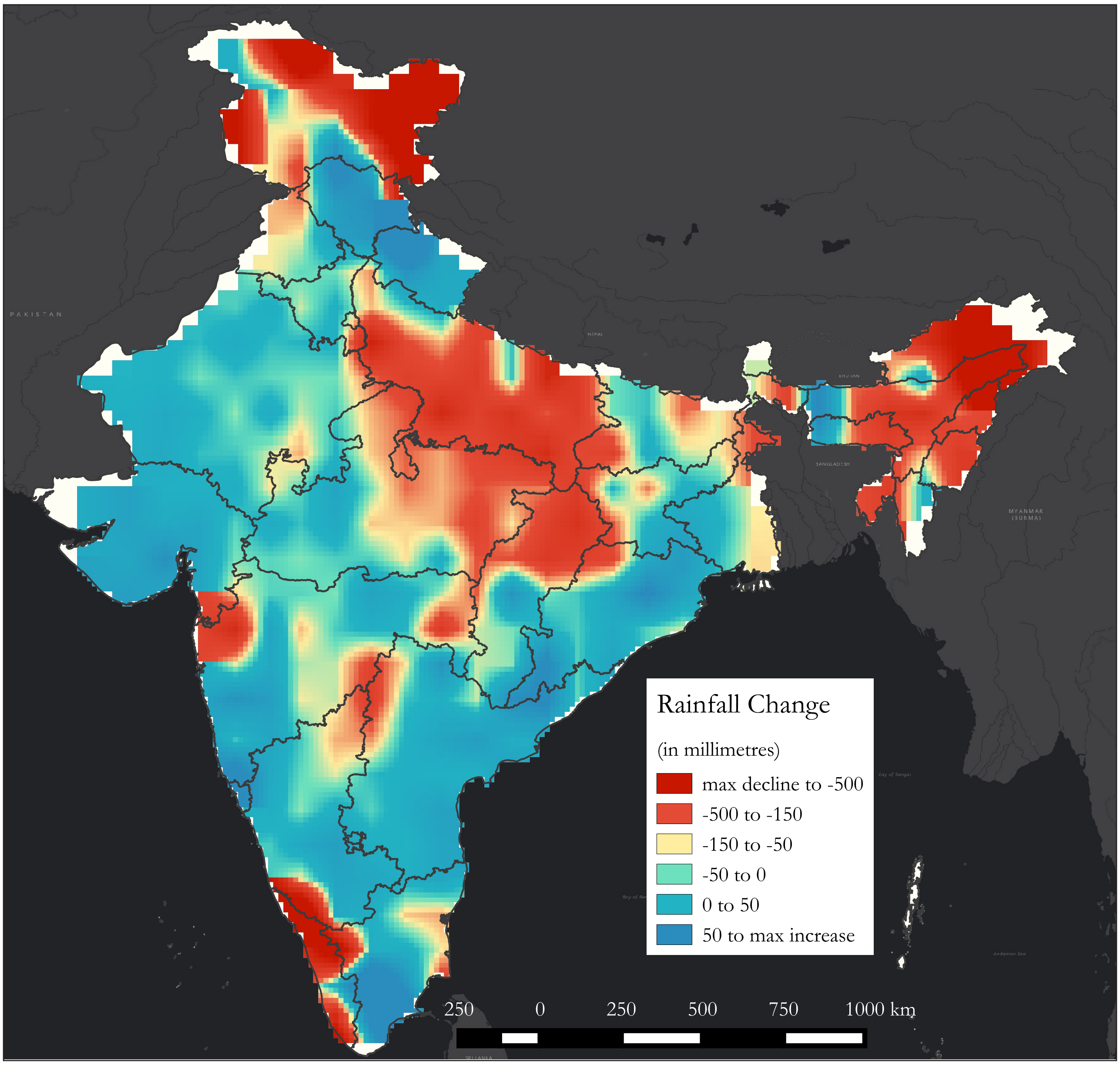
has actually been an increase in precipitation in Gujarat and Odisha and also Andhra Pradesh. What is interesting is that spatially temperature increases and rainfall declines seem to be weakly correlated.

IMPACT OF WEATHER ON AGRICULTURAL PRODUCTIVITY

6.23 Estimating the impact of temperature and climate on agriculture has become an increasing focus of economic research. Many of the

6 Grid point weather data (1 degree grid for rainfall and 0.5 degree grid for temperature) was converted to raster and further disaggregated (using bilinear smoothening). Areas in white represent missing grids.

Figure 8b. Spatial Changes in Rainfall
(change in average rainfall between the last decade and 1950-1980 period)



Source: Survey calculations from IMD data. Red (blue) denotes decreasing (increasing) rainfall.

concerns relate to developing countries because climate impacts seem to be either present only or disproportionately, in hotter and less rich parts of the world (IMF, 2017; Dell, Jones and Olken, 2012).

6.24 This chapter uses disaggregated data at the district level—on temperature, weather, and crop production, yields, and prices —to answer a number of important questions.[7] The analysis is conducted for the cropping seasons of kharif

[7] The impacts of CO^2 emissions and water transpiration have not been factored because of data limitations.

and rabi separately. A few main findings, supported by charts and tables, are highlighted here while the details of the methodology used and the regression analysis are discussed in the Annex.

Stark heterogeneity: Extreme versus Moderate shocks; Irrigated versus Unirrigated Areas

6.25 The present analysis yields two key findings. The first—and one with significant implications in the context of looming climate changes—is that the impact of temperature and rainfall is highly non-linear and felt almost only when temperature increases and rainfall shortfalls are extreme. The second is that these extreme shocks have highly divergent effects between unirrigated and irrigated areas (and consequently between crops that are dependent on rainfall), almost twice as high in the former compared with the latter.

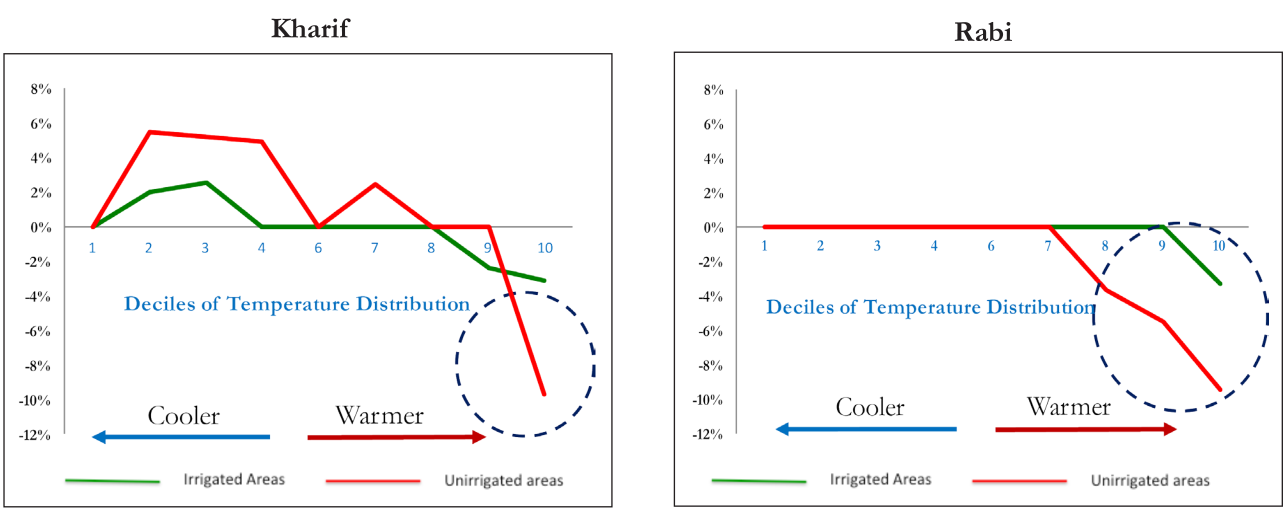
6.26 These findings are first illustrated graphically. In Figures 9 and 10, the x-axis depicts deciles of temperature and rainfall, with the 5th decile being the middle category (normal temperature and rainfall) against which all comparisons are made. So, consider the left panel of Figure 9: if temperature was in the 10th decile of the temperature distribution (i.e. the hottest possible), kharif yields in unirrigated areas (the red line) would be 10 percent lower than if temperature was normal, i.e. in the 5th decile.

6.27 Similarly, the left panel of Figure 10 shows that if rainfall were in the 1st decile (cases of drought and drought-like conditions), kharif yields would be 18 percent lower in unirrigated areas than if rainfall was normal (i.e in the 5th decile).

6.28 The first key finding that only high temperature shocks matter is reflected in the fact that the red line in the temperature graphs in Figure 9 (both panels) is very close to the x-axis for nearly the entire part of the distribution except toward the right corner. That is, under any condition of less-than-extreme heat, the impact is close to zero, and it is as if temperature is normal. Similarly, the fact that only extreme rainfall shortages matter is reflected in the fact that the red line in the rainfall graphs in Figure 10 is close to the x-axis except towards the left extreme.

6.29 A large literature focuses on the impact of a one-unit increase in temperature and a one unit decrease in rainfall on agricultural yields (e.g Dell, Jones and Olken 2012). The analysis in this chapter suggests that in the Indian context, such marginal changes in weather have little or no

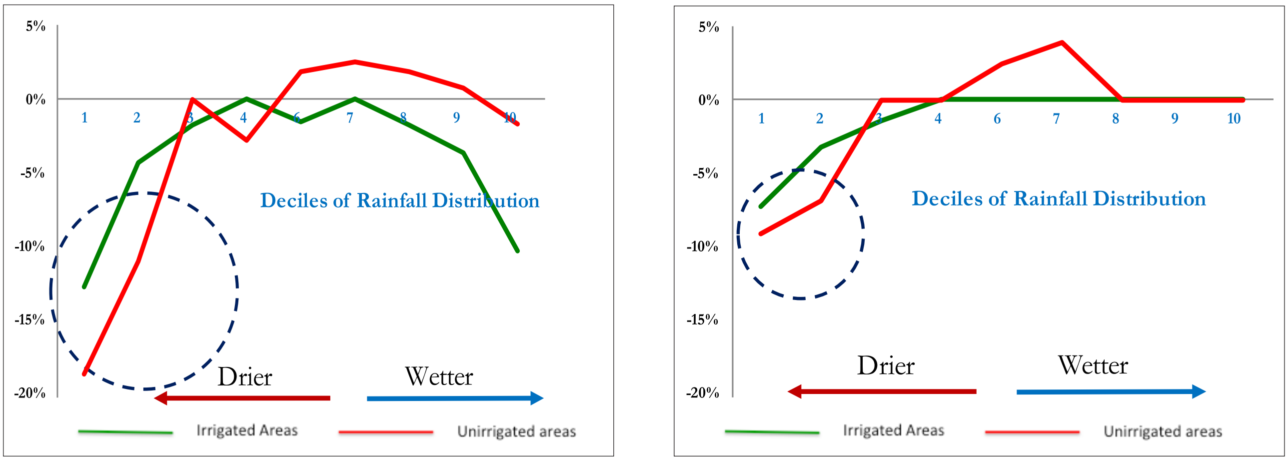
Figure 9. Effects of Temperature on Yields



Source: Survey calculations from IMD and ICRISAT data.

Figure 10 : Effects of Rainfall on Yields

Kharif **Rabi**



Source: Survey calculations from IMD and ICRISAT data.

impact, and that the adverse effects of weather are concentrated in the extremes. These findings have important implications for the impact of climate change on agriculture (discussed later in this chapter), since most climate change models predict an increase in extreme weather events.

6.30 The second key finding that these shocks have a much greater effect on unirrigated areas compared to irrigated areas is reflected in the fact that in all panels of Figures 9 and 10, the green line (showing the impact on irrigated areas) tend to be closer to the x-axis (of zero impact) than the corresponding red lines.[8]

6.31 Table 1 provides a detailed quantitative break-up of the effects of temperature and rainfall shocks between irrigated and unirrigated areas in the kharif and rabi seasons. Using the insights gained from figures 9 and 10, the quantitative impact of extreme shocks on yields and revenues is estimated. Extreme temperature shocks, when a district is significantly hotter than usual (in the top 20 percentiles of the district-specific temperature distribution), results in a 4 percent decline in agricultural yields during the kharif season and a 4.7 percent decline in rabi yields.[9] Similarly, extreme rainfall shocks - when it rains significantly less than usual (bottom 20 percentiles of the district-specific rainfall distribution). The result is a 12.8 percent decline in kharif yields, and a smaller, but not insignificant decline of 6.7 percent in rabi yields.

Table 1. Impact of Weather Shocks on Agricultural Yields

(percentage decline in response to temperature increase and rainfall decrease)

	Extreme Temperature Shocks	Extreme Rainfall Shocks
Average Kharif	4.0%	12.8%
Kharif, Irrigated	2.7%	6.2%
Kharif, Unirrigated	7.0%	14.7%
Average Rabi	4.7%	6.7%
Rabi, Irrigated	3.0%	4.1%
Rabi, Unirrigated	7.6%	8.6%

Source: Survey calculations.

[8] The one exception seems to be when there is an extreme excess of rainfall which seems to have a larger negative effect in irrigated areas than unirrigated areas (see the red and green lines in the right extreme of Figure 10, left panel).

[9] Based on ICRISAT data, the kharif crops considered in the analysis here are: Rice, Maize, Sorghum, Pulses, Cotton, Groundnut, Pearl Millet, Finger Millet and Soya. The rabi crops are: Wheat, Barley, Chickpea, Linseed, and Rape and Mustard Seed.

6.32 Unirrigated areas – defined as districts where less than 50 percent of cropped area is irrigated -- bear the brunt of the vagaries of weather. For example, an extreme temperature shock in unirrigated areas reduces yields by 7 percent for kharif and 7.6 percent for rabi. Similarly, the effects of extreme rainfall shocks are 14.7 percent and 8.6 percent (for kharif and rabi, respectively) in unirrigated areas, much larger than the effects these shocks have in irrigated districts.

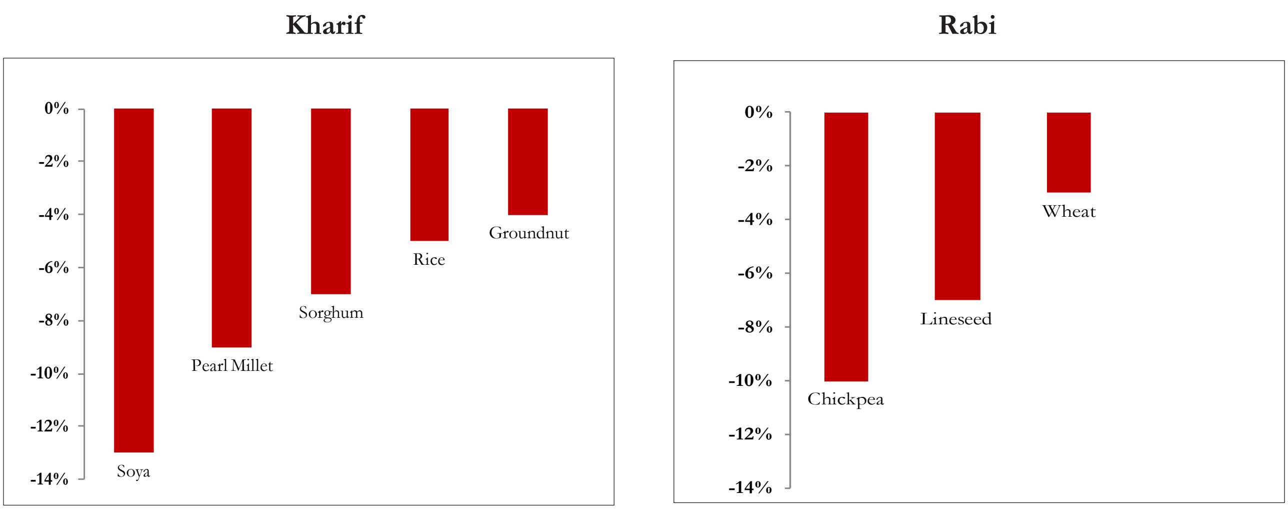
6.33 Finally, the literature suggests that several factors over and above the *level* of rainfall matter for agricultural yields. In particular, it matters *when* it rains. The data put together for this chapter makes it possible to explicitly test for these alternative channels. The results indicate that even after controlling for the level of rainfall, the number of dry days (defined as days during the monsoon with rainfall less than 0.1 millimetres) exerts a significant negative influence on productivity: holding the amount of rainfall constant, each additional dry day during the monsoon reduces yields by 0.2 percent on average and by 0.3 percent in unirrigated areas.

Crop impacts

6.34 A next finding relates to the varied susceptibility of different crops to temperature and precipitation. Figures 12 and 13 plot the effects of extreme temperature and rainfall shocks on the yields of individual crops[10]. The clear pattern that emerges is that crops grown in rainfed areas—pulses in both kharif and rabi—are vulnerable to weather shocks while the cereals—both rice and wheat—are relatively more immune.

6.35 Have the impacts changed over time? To answer this question, the analysis was redone by decade. In the last decade for which data is available (2004-2014), the impact of rainfall shocks in yields remains unchanged, but the effect of temperature shock increases threefold (relative to the first decade). However, since there is no secular trend in this impact, it cannot be ascertained whether the findings for the last decade are a one–off, or the start of a new long

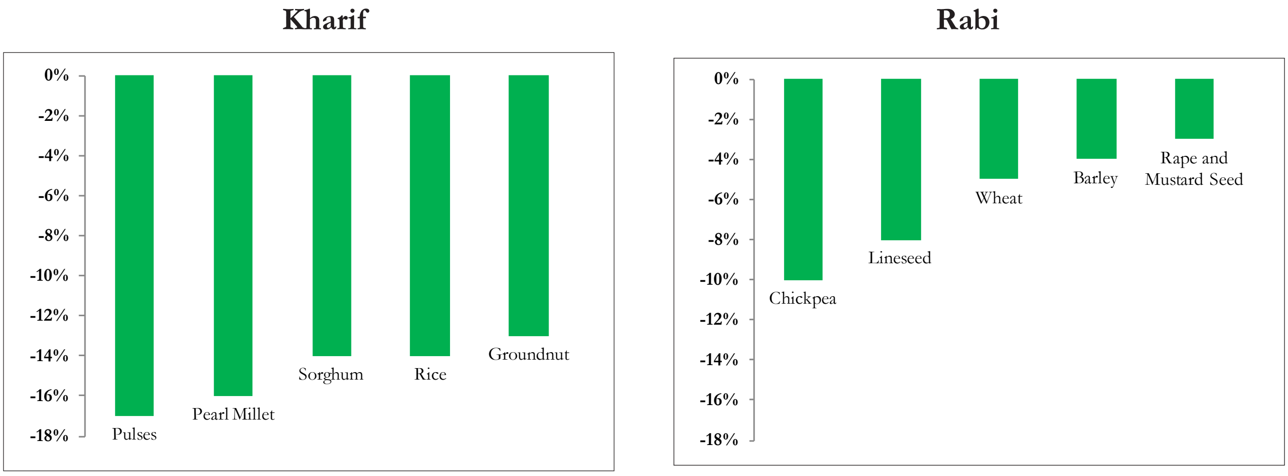
Figure 11. Effects of Extreme Temperature Increase on Crop Yields
(percentage decline)



Source: Survey calculations from IMD and ICRISAT data.

[10] These figures plot the coefficients on extreme temperature and extreme rainfall on individual crop level regressions. See Annex for a detailed description of the regression.

Figure 12. Effects of Extreme Rainfall Decrease on Crop Yields
(percentage decline)



Source: Survey calculations from IMD and ICRISAT data.

run trend with dramatically adverse consequences for Indian agriculture.[11]

IMPACT ON FARM REVENUE[12]

6.36 What do these numbers imply in terms of losses to farmers in the short and long run? Table 2 shows the impact of extreme shocks on famer incomes, measured by value of production.[13] Extreme temperature shocks reduce farmer incomes by 4.3 percent and 4.1 percent during kharif and rabi respectively, whereas extreme rainfall shocks reduce incomes by 13.7 percent and 5.5 percent. Once again, these average effects mask significant heterogeneity, with the largest adverse effects of weather shocks being felt in unirrigated areas. Ex-ante it is not clear which direction farm revenues should move in – on the one hand, these shocks reduce yields, but on the other, the lower supply should increase local prices. The results here clearly indicate that the "supply shock" dominates – reductions in yields lead to reduced revenues.

Table 2. Impact of Weather Shocks on Farm Revenue

	Extreme Temperature Shocks	Extreme Rainfall Shocks
Average Kharif	4.3%	13.7%
Kharif, , Irrigated	7.0%	7.0%
Kharif, Unirrigated	5.1%	14.3%
Average Rabi	4.1%	5.5%
Rabi, Irrigated	3.2%	4.0%
Rabi, Unirrigated	5.9%	6.6%

Source: Survey calculations from IMD & ICRISAT data.

6.37 Another way to present the result (not shown in Table 1) is as follows: In a year where temperatures are 1 degree Celsius higher farmer incomes would fall by 6.2 percent during the kharif season and 6 percent during rabi in unirrigated districts. Similarly, in a year when rainfall levels were 100 millimetres less than average, farmer incomes would fall by 15 percent during kharif and by 7 percent during the rabi season.

[11] The impact of extreme temperature shocks is also high in the first decade of our sample.
[12] Value of production is measured as the product of yields per hectare and prices. ICRISAT data do not have data on farm profits (revenues minus costs).
[13] When temperature is in the top 20 percentiles of the district-specific temperature distribution.

6.38 How do these estimates compare with those in the literature? Existing studies for India typically analyse the impact of weather shocks on the productivity of individual crops. For example, Swaminathan et. al. (2010) show that a 1 degree Celsius increase in temperature reduces wheat production by 4 to 5 percent, similar to the effects found here. Turning attention to international studies, Kurukulasuriya & Mendelsohn, (2008) find similar effects for 11 African countries – a one degree increase in temperature reduces revenues by 6 percent on average. A study by the IMF, (2017) finds that for emerging market economies a 1 degree Celsius increase in temperature would reduce agricultural growth by 1.7 percent, and a 100 millimetres reduction in rain would reduce growth by 0.35 percent. Since these are results on growth, they are not strictly comparable with the calculations in this chapter.

6.39 What do the numbers from Table 2 imply for the impact of climate change on agriculture performance in the long run? Climate change models, such as the ones developed by the Inter-governmental Panel on Climate Change (IPCC), predict that temperatures in India are likely to rise by 3-4 degree Celsius by the end of the 21st century (Pathak, Aggarwal and Singh, 2012). These predictions combined with our regression estimates imply that in the absence of any adaptation by farmers and any changes in policy (such as irrigation), farm incomes will be lower by around 12 percent on an average in the coming years. Unirrigated areas will be the most severely affected, with potential losses amounting to 18 percent of annual revenue.

6.40 Climate change models do not have unambiguous predictions on precipitation patterns, Rajeevan (2013). But if the observed decline in precipitation over the last three decades (of over 86 millimetres) is applied to the estimates, it is found that in unirrigated areas, farm incomes will decline by 12 percent for kharif crops, and 5.4 percent for rabi crops.

6.41 Finally, models of climate change also predict an increase in the variability of rainfall in the long-run, with a simultaneous increase in both the number of dry-days as well as days of very high rainfall. If the observed increase in the number of dry days over the past 4 decades are applied to the short-run estimates, this channel alone would imply a decrease in farm incomes by 1.2 percent.

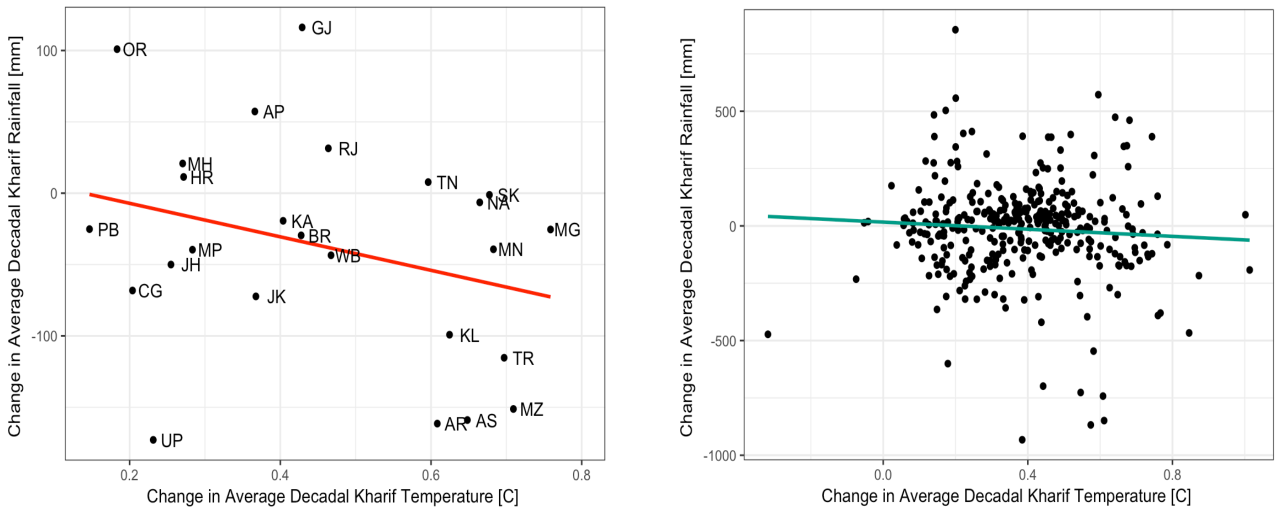
6.42 Overall the analysis here suggests at least three main channels through which climate change would impact farm incomes – an increase in average temperatures, a decline in average rainfall and an increase in the number of dry-days. Of course, all three are likely to be correlated, and therefore the total impact of climate change will not be the simple sum of these individual effects.

6.43 To examine this potential correlation, Figure 13 plots differences in average temperature against differences in average rainfall for kharif, with the differences measured as the level in the most recent ten years (2005-2015) relative to first decade of the dataset (1950-80). The relationship is weakly negative both at state and weather station levels; at the state level the correlation is -0.30. What this suggests is that at least historically weather shocks have not offset each other, they may be mildly re-inforcing. If this holds true going forward, the three effects that are identified in this chapter could be mildly additive.

6.44 Taking these correlations into account, farmer income losses from climate change could be between 15 percent and 18 percent on average, rising to anywhere between 20 percent and 25 percent in unirrigated areas. These are stark findings, given the already low levels of incomes in agriculture in India. Even more worryingly, it is possible the estimates arrived at in this chapter might be lower than the true effects of climate change, given the potentially non-linear impact of future increases in temperature. The results in this chapter stand in contrast with similar studies both

Figure 13. Difference in Average Temperatures and Rainfall for kharif

Figure 13a. Major States **Figure 13b. Grid Points**



Source: Survey calculations from IMD data.

Note: Excludes two potential outliers, Himacahal Pradesh and Uttarakhand.

globally and in India. For example, Deschenes and Greenstone (2007), find mild and even positive effects of climate change on agricultural profits in the United States. Kumar et al (2013) find that rice yields in unirrigated areas will only marginally be affected in the long run. Their estimates are based on climate change models that predict an increase in the average amount of rainfall.

6.45 At the same time, it is possible that these estimates overstate the true impact of climate change. The estimates in this chapter are derived using short-run variations in weather, and farmers may not be able to adapt to such fluctuations in the short-run. In the long-run, however, they may be able to change technologies or alter the crops they grow in response to sustained increases in temperature and changes in precipitation. Further it is possible that irrigation networks might expand, mitigating to some extent the adverse impacts of climate change.

CONCLUSIONS AND POLICY IMPLICATIONS[14]

6.46 Based on newly compiled weather data and a methodology that has not been applied to Indian data so far, this chapter estimated the impact of temperature and precipitation on agriculture. The main findings are as follows:

- A key finding—and one with significant implications as climate change looms—is that the impact of temperature and rainfall is felt only in the extreme; that is, when temperatures are much higher, rainfall significantly lower, and the number of "dry days" greater, than normal.
- A second key finding is that these impacts are significantly more adverse in unirrigated areas (and hence rainfed crops such as pulses) compared to irrigated areas (and hence crops such as cereals).
- Applying IPCC-predicted temperatures and projecting India's recent trends in precipitation, and assuming no policy responses, give rise to estimates for farm income losses of 15 percent to 18 percent

[14] In addition to the points noted below, there is a need to improve long term weather and crop forecasting and making them accessible to farmers and other relevant actors. For a recent example see TERI (2017).

on average, rising to 20 percent-25 percent for unirrigated areas. At current levels of farm income, that translates into more than Rs. 3,600 per year for the median farm household.

6.47 The policy implications are stark. India needs to spread irrigation – and do so against a backdrop of rising water scarcity and depleting groundwater resources. Figure 14 shows the increase in irrigation across time and space in India. In the 1960s, less than 20 percent of agriculture was irrigated; today this number is in the mid-40s. The Indo-Gangetic plain, and parts of Gujarat and Madhya Pradesh are well irrigated. But parts of Karnataka, Maharashtra, Madhya Pradesh, Rajasthan, Chattisgarh and Jharkhand are still extremely vulnerable to climate change on account of not being well irrigated.

6.48 The challenge is that the spread of irrigation will have to occur against a backdrop of extreme groundwater depletion, especially in North India. Figure 15a (Aeschbach, 2012) shows that India pumps more than twice as much groundwater as China or United States (Shah, 2008). Indeed global depletion is most alarming in North India (indicated by the "skyscrapers" in Figure 15a). Further analysis of groundwater stations reveals a 13 percent decline in the water table over the past 30 years, illustrated in Figure 15b.

6.49 Fully irrigating Indian agriculture, that too against the backdrop of water scarcity and limited efficiency in existing irrigation schemes, will be a defining challenge for the future. Technologies of drip irrigation, sprinklers, and water management—captured in the "more crop for every drop" campaign—may well hold the key to future Indian agriculture (Shah Committee Report, 2016; Gulati, 2005) and hence should be accorded greater priority in resource allocation. And, of course, the power subsidy needs to be replaced by

Figure 14. Spread of Irrigation over the Years

Figure 14a. Irrigated Proportion (1966)

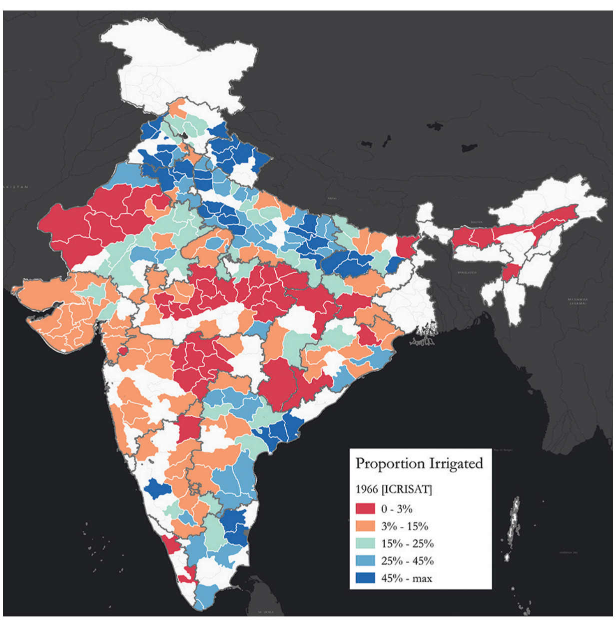
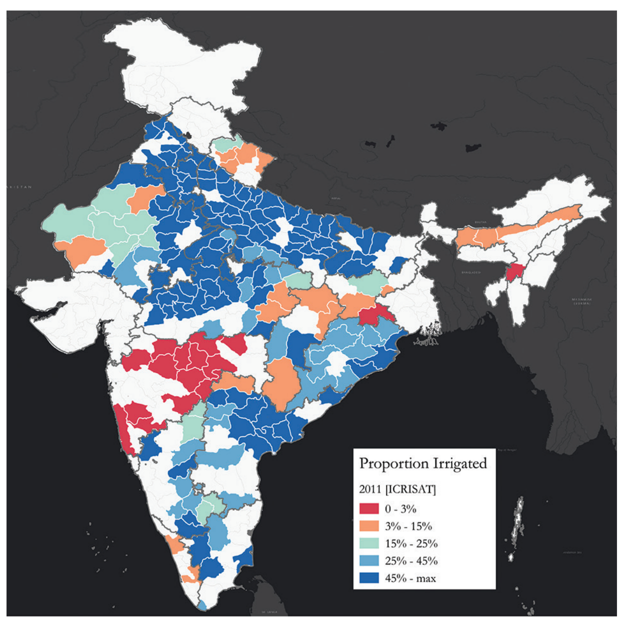


Figure 14b. Irrigated Proportion (2011)

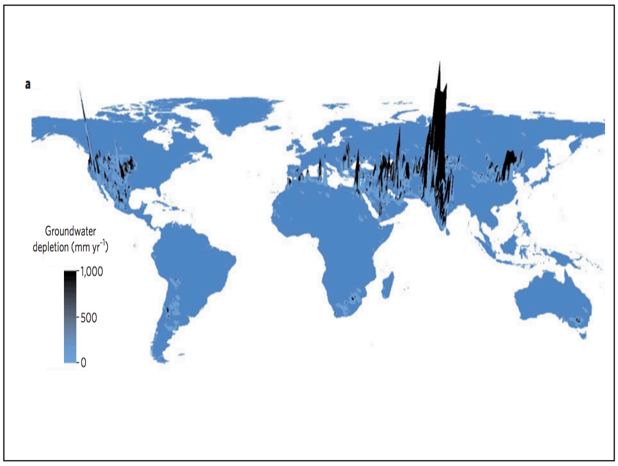


Source: Survey calculations from ICRISAT data.[15]

[15] Areas in white are missing in the ICRISAT database

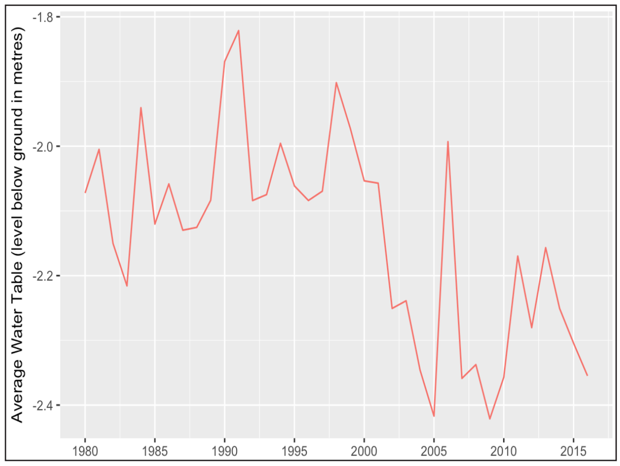
Figure 15. Groundwater Depletion

Figure 15a. World Depletion in Groundwater



Source: Aeschbach-Hertig, et al, 2012.

Figure 15b. Groundwater Depletion in India



Source: Survey calculations from Ministry of Water Resources data.

direct benefit transfers so that power use can be fully costed and water conservation furthered.

6.50 Another conclusion is the need to embrace agricultural science and technology with renewed ardor. Swaminathan (2010) urged that anticipatory research be undertaken to pre-empt the adverse impact of a rise in mean temperature. Agricultural research will be vital in increasing yields but also in increasing reliance to all the pathologies that climate change threatens to bring in its wake: extreme heat and precipitation, pests, and crop disease. The analysis shows that research will be especially important for crops such as pulses and soyabean that are most vulnerable to weather and climate.

6.51 Of course, climate change will increase farmer uncertainty, necessitating effective insurance. Building on the current crop insurance program (Pradhan Mantri Fasal Bima Yojana), weather-based models and technology (drones for example) need to be used to determine losses and compensate farmers within weeks (Kenya does it in a few days).

6.52 While the findings in this chapter are stark, they re-inforce a larger policy message on agriculture, elaborated in Subramanian (2017). In thinking about agricultural policy reforms in India, it is vital to make a clear distinction between two agricultures in India. There is an agriculture—the well-irrigated, input-addled, and price-and-procurement-supported cereals grown in Northern India—where the challenge is for policy to change the form of the very generous support from prices and subsidies to less damaging support in the form of direct benefit transfers.

6.53 Then there is another agriculture (broadly, non-cereals in central, western and southern India) where the problems are very different: inadequate irrigation, continued rain dependence, ineffective procurement, and insufficient investments in research and technology (non-cereals such as pulses, soyabeans, and cotton), high market barriers and weak post-harvest infrastructure (fruits and vegetables), and challenging non-economic policy (livestock).

6.54 It is easy to say what needs to be done. How this will happen given that agriculture is a state subject is an open political economy question.

Clearly, the Hirschmanian bottom-up forces of "voice" and "exit" along with benevolent-and-strategic top-down planning and reforms will all have to play a key part. The cooperative federalism "technology" of the GST Council that brings together the Center and States could be promisingly deployed to further agricultural reforms and durably raise farmers' incomes.

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