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RESEARCH PAPER

Climate Variability and Wheat Crop Yield in Pakistan: Analyzing Food Security Prospects in Selected Agro Climatic Zones

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ABSTRACT

Wheat is the staple crop of Pakistan constituting major share of dietary needs of its population. This study examines the impact of climate variability on wheat crop yield in the selected agro-ecological zones of Pakistan. The data on annual aggregate wheat yield, mean variation of temperature and rainfall in the sowing season of wheat crop, and fertilizer was collected from 1994 until 2018 on 15 districts of five agro-climatic zones. The production function approach was employed, and empirical model was tested using fixed effect regression (FEM). Results indicate that increase in temperature variability will decrease wheat yield by 1.53%. However, the impact has varied implications for selected zones. In high temperature zones, a slight variability of temperature in sowing season can decrease annual wheat yield while in other regions where temperature follows normal trend in sowing season, it can enhance wheat yield. Considering varying geographical characteristic of agro-ecological zones, the region specific policies need to be devised to address adverse implications of climatic variations on the availability of staple food.

Introduction

Temperature variability is expected to increase by 2.3 ° C to 4.5 ° C, and rainfall variability is likely to rise from 10 % in year-2050 to 17% by 2099, resulting in the enormous agricultural misfortunes. Increasing variability of temperature and rainfall has emerged as one of the main determinants of worldwide food production (Nicholson, 2001). Due to high dependence on agriculture in terms of its contribution to the jobs provision, economic growth and exports the climatic challenges bears special significance for developing economies (Mbaye, 2017).South Asian region experiences variations in temperature and rainfall (Cline, 2007).

Pakistan is no exemption in this regard as the consequences of climate variations makes it one of the most susceptible nations around the globe (FAO, IFAD, UNICEF, 2017). However, analyzing the impact of climate variation on agriculture sector is a daunting task compared to looking at a theoretical explanation of production function in agriculture (Gornall et al., 2010).

In Pakistan, agriculture makes significant contributions to Gross Domestic Product and job provision. However, Pakistan's agricultural sector is highly volatile considering its overall performance. Unusual Climate variation is an important cause behind these poor results, along with other socioeconomic and political elements(Seaman et al., 2014). Increased temperature and reduced rainfall coupled with the price increase of wheat in Pakistan has resulted in the increased vulnerability of families at the farm level (Rosenzweig et al., 2018). Majority of the labour force (42.3%) is residing in rural areas mainly relies upon farm income to satisfy their basic needs. A good majority of them is vulnerable to undernourishment due to extreme climatic conditions. Increasing temperatures are observed harming the agriculture yield in warmer and rain fed areas of Pakistan (Ahmed, 2014).

Climate change adapting strategies has a certain role to play in this regard. These strategies based on experience or knowledge can reduce the vulnerability of being food insecure. Adaptive strategies opting farmers experience better scenarios of food safety than those who do not at farm level(Ali & Erenstein, 2017).As climate change gains momentum around the world, there should be more focus on the research regarding climatic variations, so that, well- designed and more targeted policies could be formulated to tackle the concerned issue.

The literature has found significant variation in geographical conditions among different parts of the country coupled with water shortages which makes climate a major predictor of growth in the agriculture sector (FAO, IFAD, UNICEF, 2017). Due to the limited water resources, intense temperatures cause greater reliance on irrigation and rainfall (Shakoor et al., 2011).

In case of Pakistan, only a few studies have examined the impact of climate variability on staple crop yield using food availability approach. However, the previous studies have not filled the void for various reasons. Firstly, most of the studies aimed to analyze the food availability in selected districts of a particular province (Tariq et al., 2014)(Siddiqui et al., 2012), which fails to provide a complete scenario of climate variability affecting food production at the wider scale in Pakistan. Hence, the results drawn from these studies are hardly helpful in devising an integrated climate change-food security policy which can be applied to various regions in the country. Secondly even if analysis was extended for entire country (Mamoon & Ijaz, 2017) recent values of temperature and rainfall have been used to capture climate variability, which is clearly not a suitable method. It does not provide any information about how these variables are varying from their long- term average value. Thirdly, previous research (Hanif et al., 2010)(Janjua et al., 2010)has focused merely on climatic variables in the analysis, and has not incorporated impacts of non-climatic variables which can be equally important contributing factor in the process of food production. (Munir Ahmed, 2014) investigated impact of climate variation on wheat crop yield for Pakistan and incorporated non-climatic variables as well but results are generalized for entire country. There is a need for further investigation because Pakistan has distinct geological and weather patterns for its various regions. Temperature differences have varying magnitudes and impacts. Devising one specific policy for entire country will fail to achieve targeted goals.

Given this backdrop, this study analyzes the impacts of climate variability on wheat production in all arable agro ecological zones of Pakistan using both climatic and non-climatic variables. Furthermore, it will also compare the impact of climate variation for various agro-ecological zones to evaluate whether all zones are equally affected or not by the climatic variations. It includes Zone I of the Indus delta, Zone II of Southern Irrigated Plain, Zone III a, b, Zone IV a, b of Northern Irrigated plains, and Zone V of rain fed land, out of 10 agro-ecological zones. The excluded zones are dry and wet mountains and plateaus where land is mainly used for grazing, and occasional farming.

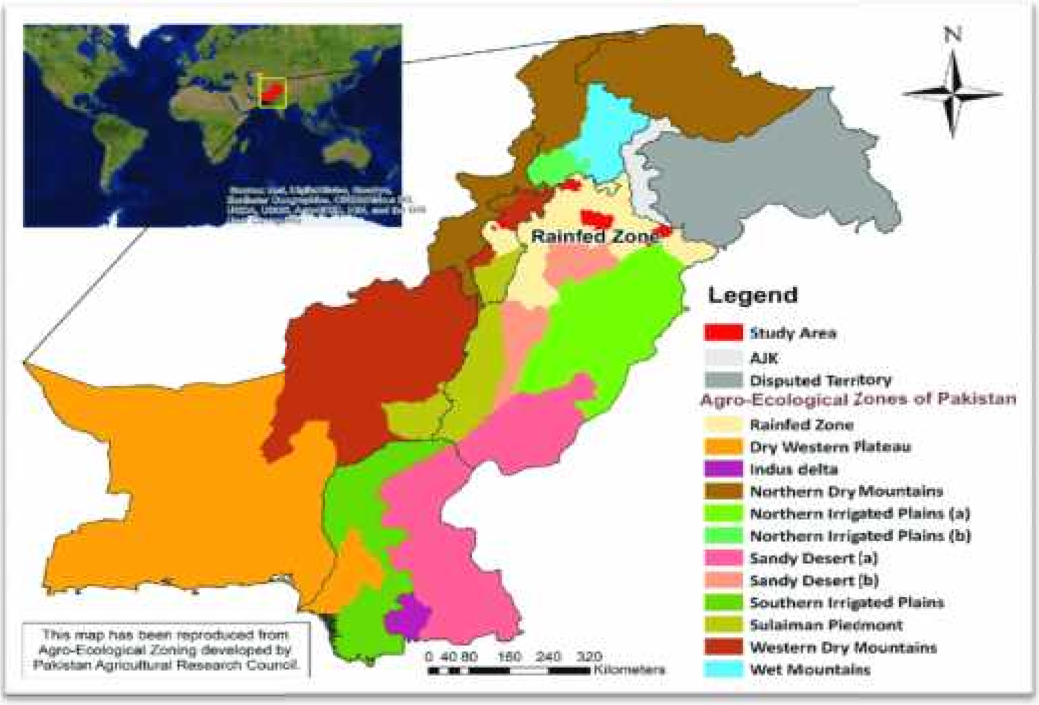

Fig1: Agro-climatic zones of Pakistan

Materials and Methods

Data Collection

This study used the data of temperature and rainfall variability for 15 major districtsof five agro ecological zones of Pakistan over the period of 1994-2018. Out of these selected districts two are from the Indus Delta Zone, four are from Zone of

Southern Irrigated Plain, two from Zone III a, b, four are from Zone IV a, b of Northern Irrigated plains and three are from Zone V of rain fed land. Data was taken from different sources. Data of wheat yield (in thousand metric tons) was taken from Pakistan Bureau of Statistics and ministry of food security and research for the required period on annual basis as wheat crop is cultivated only once a year in Pakistan. Data of fertilizer use was gathered from different issues of provincial development statistics. The rainfall and temperature information were taken from Pakistan Metrological Department; Karachi. This study has some data-related limitations. The data of all districts was not available at the source, as many districts do not have metrological observatory. Likewise, the data of tractor and other mechanical inputs use were also not available for the covered period.

Description of Variables

Following the previous literature (Siddiqui et al., 2012)(A. Hussain & Bangash, 2017), this study used production of staple crop (wheat) as a dependent variable The evidence exists that wheat yield is expected to have a negative correlation with climate variability(S. S. Hussain & Mudasser, 2007).The total area under cultivation is a key factor influencing the availability of food, and consequently food security. In Pakistan, increasing population and lack of the widespread use of intensive cultivation technologies have caused a decrease in the cultivation and affected food production badly. If cultivated land increases, it increases the possibility of the food availability and hence reduces the prospects of food insecurity (Hanif et al., 2010). Present analysis used Monthly average of temperature (max, min) in Celsius for wheat sowing months of November and December for the selected districts, and computed coefficient of variation (CV) as a proxy for temperature variation. Various studies have used CV as proxy for temperature variation (Edame et al., 2011)(Gornall et al., 2010).

Monthly average of rainfall of November and December (wheat sowing season in Pakistan) in millimeters has been calculated. The variation in rainfall has been calculated using coefficient of variation (CV), It is referred as a proxy for rainfall variation (Krishnakumar et al., 2009)(K et al., 2018). Rainfall variability is expected to have a positive impact on annual wheat yield. Data on the use of fertilizer (in thousands, nutrient tones) has been taken from various volumes of provincial development statistics for the reference period Fertilizer off take (N+P+K) at a district level was included in the analysis as proxy of fertilizer use in production of wheat (Elahi et al., 2015). Collective value of these nutrients off take at a district level is available in provincial annual statistics year book.

Model Specification

Three approaches are generally used to analyze the climate variability impacts on agricultural output in the literature: Ricardian approach, Production function, and simulation models. Simulation models and Ricardian Approach both techniques are generally used for analyzing climate variability. The former allows crop substitution and adaptations to assess climate variation's impact on mainly farm net value (Shakoor et al., 2011), whereas the latter is more suitable in situations where future yield is forecasted using current climate changes (Shakoor et al., 2011). However, these two approaches cannot be used in Pakistan due to the lack of proper documentation of land rent. This study assesses the impact of climate variation on wheat yield of the selected agro-ecological zones by using a Linear Production Function Approach, which is a suitable methodology in the present context and has been used in similar studies (Tariq et al., 2014).

The Linear Production Function is selected after performing preliminary checks on the data of explanatory variables. The dependent variable for the present study is wheat yield, measured in thousand tones. Explanatory variables of the analysis included land area allocated to production of wheat at a district level, variations in temperature and rainfall and fertilizer off-take.

A general Cobb-Douglas functional form is as follows:

$$Y_{it} = e^{\beta_o+\beta_v C_{var}} * (Ar)^{\beta_a} * (Fertlzr)^{\beta_f} e^{u_{it}} \text{----------------------------------} (1)$$

o is constantand v is vector of unknown parameters of climatic variability for temperature and rainfall. β_a*and β_f are coefficients of area under cultivation and fertilizer off take, $\mu_{it}$is residual term with zero mean and σ^2. After taking natural log of both sides of Equation 1, it can be written as:

$$\ln y_{it}(Wp) = \beta_o + \beta_v (C_{var}) + \beta_a \ln(Ar) + \beta_f \ln(fertzr) + \mu_{it} \text{-------------------------------} (2)$$

impact of climate variability is assessed with following respective equations:

$$\ln y_{it}(Wp) = \beta_o + \beta_t (tempcv) + \beta_r (rainfallcv) + \mu_{it} \text{--------------} (3)$$

β_t and β_r are coefficients of temperature and rainfall variability in respective sowing season of wheat. This equation will specifically analyze the impact of variability of climatic variables only.

$$\ln y_t(Wp) = \beta_o + \beta_v (C_{var}) + \beta_a \ln(Ar) + \beta_f \ln(fertzr) + \mu_{it} \text{--------------} (4)$$

This model will take into account both climatic and non-climatic variables.

$$\ln y_t(Wp) = \beta_o + \beta_v (C_{var}) + \beta_a \ln(Ar) + \beta_f \ln(fertzr) + {}_i\Sigma_i Z_i + \mu_{it} \text{--------------} (5)$$

Above equation analyzes the impact of climatic and non-climatic variables for all zones separately.

Model Selection

This research uses the relevant Hausman model test to choose the appropriate model like other studies (A. Hussain & Bangash, 2017). The Hausman model suggests that REM coefficients are more stable and accurate. The p-value thumb rule is applied to accept the hypothesis (Hausman, 2015). In panel data three approaches are commonly used; pooled regression, random effect approach (REM) and fixed effect approach (FEM). Pooled regression is generally not recommended when heterogeneous characteristics of cross-sectional units make an important part of the analysis. Therefore, REM and FEM are usually employed (Baltagi, 2005).

FEM assigns different intercepts to every single cross -sectional unit. The deviation in intercepts of cross sectional unit may be due to unobserved factors which vary among different units but are consistent over time. REM, meanwhile, assumes randomness between cross-sectional units and zero correlation with explanatory variables for these units. Furthermore, assumption of residual term being uncorrelated with independent variables allows time invariant variables (demographic characteristics) to appear as explanatory variable in the estimation model (Greene, 2012).Generally, panel model takes the following form:

$$Y_{it}=B_{yxt}X_{it}+B_{yzt}Z_i+\lambda_t\eta_i+\varepsilon_{it} \text{--}(6)$$

Y_{it} is dependent variable of the analysis. X_{it} is the vector of time-varying covariates. B_{yxt} is the row vector of coefficients that give the impact of X_{it} on Y_{it} andZ_i is the vector of observed time-invariant covariates with B_{yzt} a row vector of coefficients that give the impact of Z_i on Y_{it}. The η_i is a scalar of all other underlying time-invariant variables that influence Y_{it} and λ_t is the coefficient of the latent time-invariant variable (η_i) and at least one of these $\lambda_t$is set to one to provide the units in which the underlying variable is measured. The ε_{it} is the random disturbance. It also is assumed that ε_{it} is uncorrelated with X_{it} Z_i, and η_i and that $COV(\varepsilon_{it}, \varepsilon_{is}) = 0$ for $t \neq s$. "*i*" is notation of cross sectional unit at the "*t*" time period (Bolan and Brand, 2010).

The test was carried out separately for the above models and the findings are followed:

Table1
Hausman Test for selection of FEM and REM

Equation	P-Value	Decision	Selected Method
Equation 3	0.7898	Ho is not rejected	Random effects
Equation 4	0.0022	Ho is rejected	Fixed effects
Equation 5	0.029	Ho is rejected	Fixed effects

The methodology chosen for the estimation equation 3 is REM, while FEM is the suitable model according to the Hausman test for the other two equations 4 and 5.

Table2
Summary Statistics of Variables of Analysis: Averages (1994-2018)

Region	Temperature Variability	Rainfall Variability	Cultivated area thousand hectares	Wheat yield thousand tons	Fertilizer off take thousand nutrient tons
			Zone1		
Badin	15.22	30.31	33.17	75.72	37.35
Hyderabad	15.88	30.03	60.40	153.09	42.04
			Zone2		
Larkana	12.62	28.71	58.47	132.16	38.63
Nawabshah	11.07	30.52	86.58	294.98	31.21
Jacobabad	12.45	28.4	36.36	66.68	31.46
Sukkur	10.12	25.42	57.12	172.65	28.92
			Zone3		
Bhawalnagar	11.26	27.3	323.71	855.15	103.08
Sargodha	9.21	25.43	212.55	521.81	59.25
			Zone4		
Multan	10.15	26.51	184.57	461.83	150.96
Lahore	11.84	24.27	56.82	155.64	50.67
Faisalabad	8.96	25.39	268.67	763.83	101.92
Jhelum	8.86	25.7	82.82	52.77	3.21
			Zone 5		
Peshawar	8.41	23.84	34.16	72.39	29.00
D.I.khan	8.76	24.11	51.44	75.54	17.54
Sialkot	8.68	26.13	144.28	388.55	38.58

Source: FBS, Ministry of Food Security and Agriculture Research, PMD

Table3
Summary Statistics of Variables of Analysis: Maximum/Minimum (1994-2018)

	Temperature Variation	Rainfall Variation	Cultivated area thousand hectares	Wheat Yield thousand tons	Fertilizer off take thousand nutrient tons
Max	Hyderabad (15.8)	Nawabshah (30.52)	Bhawalnagar (323.7)	Bhawalnagar (855.1)	Multan (150.96)
Min	Peshawar (8.41)	D.I.Khan(24.1)	Badin(33.17)	Jhelum (52.77)	D.I.Khan (17.5)
Mean	10.8	26.8	112.7	282.8	50.9

Data distribution of temperature and rainfall variability at a district level is seen in the statistics given in Tables 2 and 3.For the district of Hyderabad, temperature variation is found to be the maximum and in the chosen period, temperature difference over time is the lowest for Peshawar. The variability in rainfall is highest for Nawabshah and it is lowest for D.I.Khan. The district of Bhawalnagar happens to be the most fertile one with the highest wheat yield statistic in thousands of metric tons. Multan surpassed all study districts in fertilizer usage and seems to consume 150.96 thousand tons of fertilizer nutrients. In Zone1 of the Indus delta temperature, and rainfall variability is quite high. This zone appears to be the most vulnerable to climate variation as one of its districts (Hyderabad) is experiencing the highest temperature variability. Vulnerable state of the Indus delta zone to climate threat is well recognized in the literature(Asian Development Bank, 2017)(FAO, IFAD, UNICEF, 2017). Zone II of southern plains is also prone to climate variability as district Nawabshah is experiencing the highest rainfall variability in selected sample. Zone III and Zone IV are experiencing minor variations in temperature and rainfall while rain fed region of Zone V of appears to have the slightest degree of climate variations.

Results and Discussion

Impact of climate variations on wheat yield

This paper used a balanced pseudo panel data spanning from 1994 to 2018to analyze the effect of climate variations on wheat yield at a district level in selected agro-ecological zones of Pakistan

Table 4
Results of the Impact of Climate Variation on Wheat Yield

Variables	Coefficient	Standard Error	P-Value	[95% Conf.Interval]	
Temperature	-1.538127	.148792	0.000***	-1.829754	-1.2465
Rainfall	4.66293	1.12865	0.000***	2.45083	6.87504
_cons	11.8057	.3310929	0.000	11.15677	12.45463

*** *p<0.001*

The results given in table 3 showed an important and negative influence of temperature fluctuations on wheat yield in the overall sample during the sowing season. Results show that increased variability in temperature contributes to decrease wheat yield. More specifically, REM indicates that an increase in temperature fluctuations would minimize wheat yield by 1.53 percent. These findings are consistent with the fact that temperature changes will inhibit wheat yield at the time of germination or sowing(Lopez-Feldman, 2013). The variability of rainfall has an important and positive effect on the yield of wheat i.e. increased rainfall fluctuations would increase the yield of wheat in the wheat cultivation process. Statistically, the data show that rise in the variability of rainfall would increase the wheat yield by 4.66%. A good deal of research is well- supported by this fact (Panda & Sahu, 2019).Considering the fact in mind that wheat yield in a particular period is not only affected by weather or climatic conditions but many other non-climatic variables accounts for its yield. The next equation takes into account this consideration and includes the area of production and use of fertilizer as explanatory models. (See detailed equation 4 in under methods and analytical framework).

Combined effects of climatic and non-climatic variables on wheat yield

Table 5
Results of Impact of Climate Variation and Non-Climate variables on Wheat Yield

Variables	Coefficient	Standard Error	P-Value	[95% Conf.Interval]	
tempcv	-1.631799	0.1453032	0.000***	-1.91756	-1.34604
rainfallcv	4.57392	1.138718	0.000***	2.334482	6.813359

lnfertzr	0.2034968	0.0399673	0.000***	0.124896	0.282098
_cons	9.741846	0.4768931	0.000	8.803973	10.67972

*** $p<0.001$

The results of FEM regression show that inclusion of non-climatic variables did not affect significantly the magnitude and direction of the impacts of climatic variation on wheat yield. It appears that both temperature and rainfall variability have significant impact on wheat yield in sowing season at a district level in Pakistan. Use of fertilizer also has a significant and positive impact on wheat yield as fertilizer contains required nutrients to make cultivated land more fertile. In recent times, lands are reserved for whole year for the purpose of cultivation of different crops to fulfill the dietary requirements of population. It leads to reduce natural abundance of essential nutrients and this gap is fulfilled by using fertilizers frequently (Rietra et al., 2017). Estimation results support this evidence that increase in use of fertilizer can enhance wheat yield by 0.2%. (Jamal & Fawad, 2019)(Danlami et al., 2016) have concluded similar results.

The results of equation 4 and 5 represent empirical analyses of climate variability's impact on wheat yield for entire districts collectively. However, this can be deceptive to some extent based on collective analysis a suitable policy cannot be formulated as climate variations differ according to varying geographical conditions. There is a room for further specific analysis at agro-climatic zone level to witness either temperature or rainfall variations have varying trend and magnitude for each zones separately. For this purpose, this study further expands analysis to explore more insight picture temperature and rain variability's impact on wheat production at agro climatic zones separately (see Equation 5in section methods and analytical framework).The results are reported in Table 6.

Table6
Zone Wise Impact of Climate Variations on Wheat Yield

Zone1	-2.142028*** (0.000)	-1.264553 (0.655)	0.9830957*** (0.000)
Zone2	3.027043 (0.223)	0.0301325 (0.974)	0.0375991 (0.647)
Zone3	-1.23203 (0.171)	2.020417 (0.188)	0.806826*** (0.000)
Zone4	0.3466215 (0.648)	5.201599*** (0.001)	0.760576 (0.105)
Zone5	-0.759588 (0.438)	6.274203*** (0.015)	10.1881913 (0.061)

*** $p<0.001$

The effect of variations in temperature and rainfall depends on every region's geographical characteristics. Climate fluctuations are significant determinants of its yield, but soil existence will alter the effect of climate variability entirely differently from geographical position (Arnell et al., 2019). In the winter season, wheat has expanded and the cool weather sprouts the seeds at a better rate. Higher temperatures in high temperature regions and rainfall at the time of wheat sowing or germination will hamper its yield. In cold areas, however, this increased temperature and precipitation will potentially support wheat production in the sowing cycle (Ludwig & Asseng, 2006).

The evidence provided by this study is well-supported by FEM outcomes. Zone I of the Indus delta is primarily a high-temperature region. Results indicate that major and negative impact of temperature and rainfall fluctuations on wheat crop yield are negative in this area (Yang et al., 2015).

Zone II (Southern Irrigated Plain) FEM forecasts do not capture the major effect of climate variability and fertilizer use on the production of wheat. The slope coefficient of fertilizer usage is highly important for Zone III (Northern Irrigated Plains) and shows a favorable influence on wheat production. Growing fertilizer usage will increase wheat yield by 0.8 percent. The temperature and rainfall variability slope coefficients show predicted indicators, but are not statistically statistical. The only major determinant in Zone IV (Northern Irrigated Plains) is rainfall variability, which can increase wheat production by 5.20 percent. Increase in rainfall variability will increase wheat yield by 6.27 percent in Zone V (Rain fed Region) rainfall variability turns out to have predicted positive sign and is a highly significant determinant of wheat production. Using or fertilizer also has a favorable 10.1 percent effect on wheat production. Similar findings were obtained by (Ogenga et al., 2018). As mentioned under discussion of descriptive statistics, the temperature variability of this area is very small, which is why its effect on the wheat yield of this region is negative but statistically negligible enough to draw any conclusions or devise any strategy.

Conclusion

This research analyzed the effect of major climate variables (rainfall and temperature) on staple crop yields, i.e. wheat, across five agro-climate zones in Pakistan. REM and FEM empirical estimates conclude that temperature and rainfall variability, together with other non-climate factors, are imperative determinants of wheat yield. Temperature variability typically results in a substantial and negative effect on wheat yield and variability in rainfall tends to increase wheat yield positively, although this is not equivalent for any region of the world. Comparative analysis of climate variation for agro climatic zones reveals that temperature and rainfall variation has a different impact and magnitude for each region differently due to change in geographical condition. In high temperature experiencing zone of Indus delta temperature and rainfall variations overtime can significantly reduce wheat production thus can put food security state of this region at a greater risk. Based on research findings this study recommends to give due attention to climate variability to encourage formulation of new wheat varieties that are more immune to temperature and variability of rainfall. In addition, more targeted and regional strategies can be structured individually to resolve climate variability concerns across each region of the country.

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