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Climate Change and Cereal Crops Productivity in Afghanistan: Evidence Based on Panel Regression Model

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Abstract: Afghanistan frequently faces drought and other climate change-related challenges due to rising temperatures and decreased precipitation in many areas of the country. Therefore, acquiring a thorough comprehension of the implications of climate change on the cultivation of key cereal crops is of the utmost importance. This is particularly significant in the context of Afghanistan, where the agricultural sector plays a pivotal role, contributing close to a quarter of the country's national gross domestic product and serving as the primary source of employment for 70% of the rural workforce. In this paper, we employ a panel regression model to evaluate the relationship between climate change and cereal productivity in Afghanistan's agro-climatic zones. Temperature had a significant negative impact, implying that a mean temperature increase of 1 °C decreased wheat and barley yields by 271 and 221 kg/ha, respectively. Future medium- and high-emission scenarios (RCP4.5 and RCP8.5, respectively) for the period 2021–2050 were considered for future yield predictions. To project future climate change impacts, the estimated panel data regression coefficients were used to compute the projected changes in cereal yields. During the period 2021–2050, the mean yield of wheat is projected to decrease by 21 or 28%, the rice yield will decrease by 4.92 or 6.10%, and the barley yield will decrease by 387 or 535 kg/ha in the RCP4.5 and RCP8.5 emission scenarios, respectively, further emphasizing the need for targeted actions to tackle the effects of climate change on agriculture in Afghanistan in alignment with SDG 2 (Zero Hunger) and SDG 13 (Climate Action).

Keywords: Afghanistan; cereal crops; climate change; SDGs; fixed-effect; random-effect

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1. Introduction

Global warming, encompassing both warming and cooling conditions, serves as the primary catalyst for climate change [1,2]. Climate change signifies alterations in long-term weather patterns within specific regions [3]. The IPCC (Intergovernmental Panel on Climate Change) describes climate change as any temporal change in climate, irrespective of whether it results from natural climate variability or human activities [3–5]. In contrast, according to the United Nations Framework Convention on Climate Change (UNFCCC), climate change refers to any modification in climate that directly or indirectly affects the composition of the atmosphere and is linked to human activity, as well as natural climate variability observed within an analogous time frame [4]. Climate change involves a transformation in the "average weather" of a given region, encompassing elements such as temperature, wind patterns, and precipitation [2].

Climate change exerts direct and indirect effects on various aspects, including agriculture, food security, the environment, water resources, infrastructure, and human livelihoods [3]. Farmers in less developed nations, like Afghanistan, bear a disproportionate burden from variations in weather patterns, and their vulnerability remains high due to the limited resources available for adaptation [6]. Farmers' livelihoods face substantial risks from severe weather events, including droughts and floods, which are among the most notable consequences of climate change. Additionally, climate fluctuations affect crop and animal husbandry by influencing growth, transpiration rates, photosynthesis, moisture availability, and overall productivity [3].

Within the framework of the Sustainable Development Goals (SDGs), our study is closely related to SDG 2 (Zero Hunger) and SDG 13 (Climate Action). SDG 2 is dedicated to eradicating hunger, ensuring food security, enhancing nutrition, and promoting sustainable agriculture, while SDG 13 is centered around urgent measures to address the challenges of climate variability and its consequences. The paper sheds light on the direct and indirect consequences of climate fluctuations on agriculture and food security, placing special emphasis on the specific context of Afghanistan. It emphasizes the vulnerability of farmers in Afghanistan to extreme weather events and limited resources for adaptation, which aligns with SDG 2's goal of achieving sustainable agriculture and ending hunger. Additionally, this study underscores the imperative of implementing robust adaptation strategies to mitigate the adverse impacts of climate change on the agricultural sector. This aligns with the objectives of Sustainable Development Goal 13, which aims to combat climate change and its consequences through proactive measures. By identifying vulnerable agro-climatic zones and facilitating future studies on adaptation measures and coping strategies, this paper contributes to the broader efforts towards achieving SDG 2 and SDG 13 in Afghanistan and beyond.

Projections of global warming scenarios suggest a potential increase of 1.4–5.8 °C in the global average surface temperature by 2100. Climate models have also indicated a consistent rise in global temperatures over time. In South and Southeast Asia, changes in precipitation patterns have resulted in reduced rainfall, leading to more frequent and severe droughts since the 1970s [3]. Developing countries, as highlighted by the United Nations Millennium Development Goals, are particularly vulnerable to the impacts of climate change, given their limited technological, financial, and social resources to implement effective adaptation strategies [7,8].

Adaptation is widely recognized as a crucial component of climate change response policies, enabling farming communities to better navigate an uncertain future and mitigate the adverse effects of shifts in climatic conditions. The extent of its impact on the agricultural sector hinges upon its adaptive capacity, which denotes its capability to adapt to significant climate fluctuations and manage the repercussions of climate change by adjusting its attributes in accordance with external circumstances [9]. To reduce the vulnerability of the agricultural system, effective implementation of adaptation strategies is essential [10,11]. These strategies include weather forecasting, early warning systems, improved water management practices, various crop insurance schemes, biodiversity conservation, and enhanced risk management [12]. Without such adaptation measures, the agricultural sector would struggle to mitigate these impacts.

Afghanistan, being a traditionally agrarian nation, heavily relies on the agricultural sector, which contributes 22% of the national gross domestic product. Agriculture plays a vital role in providing livelihood opportunities [6,13], with around 70% of the rural population in the country being employed in this sector [14]. Farmers in Afghanistan, compared to other countries, have faced relatively higher susceptibility to the impacts of severe weather events and encountered challenges due to limited resources for adaptation, thereby increasing their vulnerability [6].

Situated 37° north of the equator, Afghanistan showcases the traits of an arid and semi-arid continental climate nestled within the arid sub-tropics [15,16]. In most regions of Afghanistan, precipitation has decreased in recent years [17]. From 1960 to 2008, the mean annual temperature in Afghanistan increased by 0.13 °C and rainfall decreased by 2% per decade. The country is characterized by large areas with little to no precipitation, and it has experienced prolonged drought in recent years [15]. Environmental shifts that lead to drought affect a significant proportion of the rural population, and of all the weather hazards in the country, drought causes the most economic damage [14]. However, there is a limited body of research on the impacts of climate change, adaptation strategies, and coping mechanisms in Afghanistan. Thus, this study aims to assess the quantifiable effects of climate change on major cereal crops and identify vulnerable agro-climatic zones in order to facilitate future studies on farmers' perceptions, various adaptation measures, and factors influencing coping strategies to mitigate the evolving climate scenario in Afghanistan.

The impact of climate variability poses a significant challenge to the sustainable development of agriculture. Recent studies have observed a decline in production due to the adverse effects of fluctuations in the climate. Scientific evidence indicates that climate change is already exerting a negative effect on agriculture in developing countries, and this situation is expected to worsen due to factors such as low capital intensity, incomplete markets, the predominance of agriculture, and relatively warm baseline climates in these countries. The projected increase in temperatures and decrease in precipitation in Afghanistan are likely to result in reduced crop yields in the future. Notably, Afghanistan has faced significant constraints on agricultural production over the past four decades, including war and water scarcity. However, early adaptation efforts can contribute to sustaining agricultural production. Hence, the objective of this study is to quantify the impact of climate change on the productivity of major cereal crops in Afghanistan. Therefore, the present study recommends suitable adaptation strategies and piloting them in selected locations based on the farmers' preferences, along with several ongoing government programs.

2. Materials and Methods

2.1. Design and Method of Data Collection

The secondary database used in this study was obtained from various sources. Data on the productivity of major cereal crops were collected from various issues of the Afghanistan statistical yearbook published yearly by the National Statistics and Information Authority (NSIA), the Islamic Republic of Afghanistan, and the Ministry of Agriculture, Irrigation and Livestock. Relevant climatic observation data were collected from the Afghanistan Meteorological Department for all provinces in the country for the period from 2005 to 2018. The productivity of major cereals (e.g., wheat, barley, and rice) and climatic variables (e.g., rainfall and maximum and minimum temperatures) were compiled for the seven agro-climatic zones based on the provinces located in the respective zones.

2.2. Panel Data Regression Model

Panel data refers to a collection of observations made for a specific set of units, such as households, zones, countries, or firms, over multiple time periods [18]. It is a type of pooled data where the same units are observed in the same spatial and temporal dimensions throughout the study period [19]. One of the key advantages of panel data is its heterogeneity across time and cross-sections [20]. According to Baltagi [18], panel data offers several benefits: (i) it captures the heterogeneity of cross-sectional units over time, (ii) combining the time-series of cross-sectional observations yields more informative and efficient results with greater variability, less collinearity, and more degrees of freedom; and (iii) it enables better detection and measurement of effects compared to pure cross-sectional or time-series data. Taking these advantages into account, panel data can significantly enhance empirical analyses when compared to relying solely on cross-sectional or time-series data [18,19,21].

Many country-level studies were undertaken using the panel data approach to study the economic impact of climate change on agriculture in the United States [22,23], Asian countries [24], and India [25,26]. The economic impact of climate change on the productivity of major crops revealed a 10% decline in rice yield by the end of this century in Tamil Nadu, India [27]. While Senthilnathan et al. (2018) [21] noted the increase in rabi season rice yield by 10 to 12 percent and 5 to 33 percent during the mid and end of the century. Zeleke (2021) [28] studied the impact of climate change on wheat yield in south-east Australia and found that the wheat yield would decrease by 9%, 15%, and 19% under RCP4.5 and by 9%, 18%, and 27% under RCP8.5 scenarios by 2030, 2050, and 2070, respectively. Another study conducted by Khan et al. (2020) [29] in Pakistan revealed that climate change-induced the loss of wheat and rice productivity by 2050 to be 19.5 billion dollars on Pakistan's Real Gross Domestic Product. The study performed by Ahmad et al. (2014) [30] would reduce the wheat yield by 7.4 percent due to an increase in mean temperature of 1 °C during the sowing time in Pakistan.

The fixed-effects model (FEM) and random-effects model (REM) are the two primary panel data models frequently used in panel data analysis. These models serve as fundamental techniques for analyzing panel data. One key distinction between FEM and REM lies in the nature of their intercepts. In the fixed effects model, the intercept incorporates a fixed-effect time-invariant dummy variable for each cross-sectional unit. Conversely, the random effects model's intercept consists solely of time-variant dummy variables. In this study, the fixed effects regression model is used to account for the unique characteristics of each of the seven agro-climatic zones. It does this by assigning a specific intercept value for each zone, allowing for variations or differences among them. The term "fixed" refers to the fact that these intercept values do not change over time, remaining constant across time periods that do not vary. On the other hand, the random effects model assumes that all seven agro-climatic zones share a common average intercept value without considering their individual distinctions.

When estimating panel data models, it is often necessary to choose between FEM and REM. To select the appropriate model, the Hausman test was used to check which one was most suitable [20,31] according to the chi-square (χ^2) test for consistency [20]. The test is based on the results of the statistically significant *p*-value, using the FEM where appropriate and otherwise using the random effect model.

The panel data regression model was constructed based on the existing observed climatic variables for the period from 2005 to 2018 for the seven agro-climatic zones of Afghanistan. In this model, the dependent variables were the productivity of major cereal crops, including wheat, rice, and barley, and the independent variables were climatic parameters. The panel data regression model, which is specified as follows, was analyzed using STATA version 14.1 [21,27].

$$Y_{it} = \beta_0 + \beta_1 RF_{it} + \beta_2 T_{it} + \beta_3 RF_{it}^2 + \beta_4 T_{it}^2 + \beta_5 RF_{it} * T_{it} + \phi t + Z_i + \varepsilon_{it} \quad (1)$$

where:

Y_{it}—yield of cereals for agro-climatic zone *i* at time *t*,
RF_{it}—rainfall (mm) in zone *i* and year *t*,
T_{it}—mean temperature (°C) in zone *i* and year *t*,
β_0–β_5—vector of regression coefficients to be estimated,
ϕt—trend variable is presumed to capture the technological changes attributed to hybrid cultivation, as well as the advancements in farm management and the adoption of adaptation practices.
Z_i—agro-climatic zone level fixed-effect, which equals 1 for observations from zone *i* and 0 otherwise,
ε_{it}—error term

2.3. Description of the Study Area

Afghanistan is part of south-central Asia, located between 33°56′2.54′′ N and 67°42′12.35′′ E. Afghanistan is bordered to the east and south by Pakistan; to the north by the Central Asian countries of Turkmenistan, Uzbekistan, and Tajikistan; and to the west by Iran. It also has a short border with China at the end of the Wakhan corridor in the extreme northeast zone of the country (Figure 1). The 2018–19 census revealed that the total population of Afghanistan was around 31.6 million, with 75.02% living in rural areas and 24.98% living in urban areas [32,33]. Afghanistan has been classified into seven agro-climatic zones (Figure 1a), based on geographical formation, climate, physiography, rainfall distribution, soil characteristics, irrigation, cropping patterns, and other natural resources [34]. Wheat is the major crop cultivated in all the zones (Figure 1b), followed by rice (Figure 1c) and barley (Figure 1c).

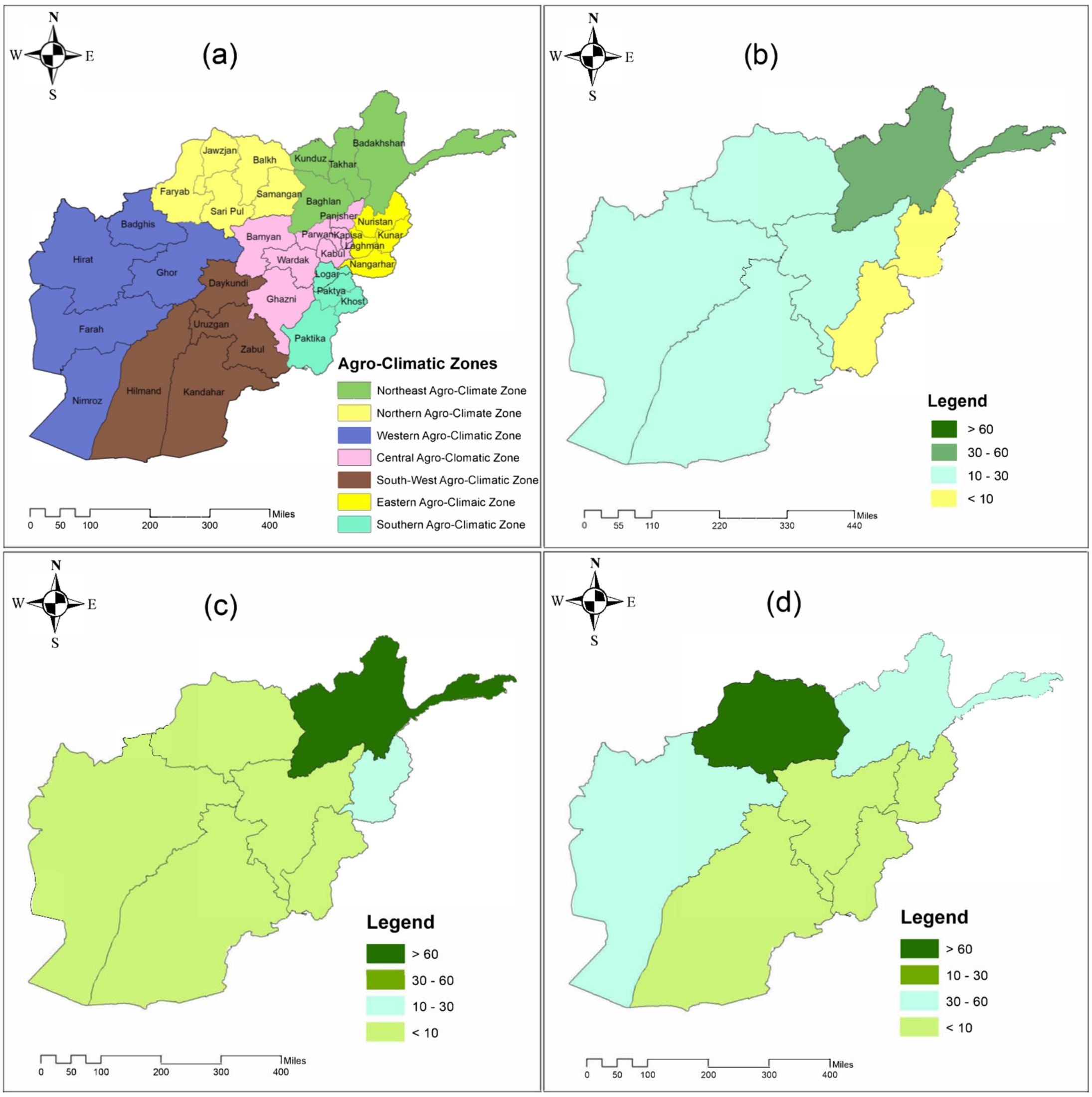

Figure 1. (**a**) Agro–climatic zones of Afghanistan (**b**) percentage of wheat area to the total gross sown area of each zone of Afghanistan (**c**) percentage of rice area to the total gross sown area of each zone of Afghanistan (**d**) percentage of barley area to the total gross sown area of each zone of Afghanistan. Source: Authors.

The land-use patterns of Afghanistan are presented in Table 1. Afghanistan encompasses a total geographical area of 65,439 thousand hectares. Within this vast expanse, permanent pastures occupy 45.84% of the land, while 39.14% is classified as other land. When combined, these two categories constitute approximately 85% of the country's overall geographical area. Furthermore, the land used for agriculture accounts for only 12.26% of the geographical area and is mostly made up of fallow land (8.39%).

A variety of crops are grown in Afghanistan. Understanding the cropping pattern of the study area is important because it can allow for better management of available resources to be identified. The cropping patterns in Afghanistan are presented in Table 2. Wheat is the predominant crop in Afghanistan, accounting for 61.30% of the total cropped area. Paddy rice is the next most cultivated crop, accounting for 4.41% of the cropped area, followed by grapes and barley, accounting for 3.28% and 3.15% of the cropped area, respectively. The other major crops in the country are maize (2.72%), fresh fruits (2.16%), melon (1.34%), potato (1.21%), and apple (1.06%). On a broader scale, food grains are the major crops in Afghanistan, accounting for 73.87% (1,970,291 ha) of the cropped area. Fruits are the second most cultivated crop, accounting for 10.39% (277,222 ha) of the cropped area, followed by oil seeds (3.14%) and vegetables (3.05%).

Table 1. Land use pattern of Afghanistan (2018–19).

Land Use Category	Area (×1000 ha)	% of Total Area
Irrigated area	1949	2.99
Rain-fed area	368	0.56
Permanent crops	216	0.33
Fallow land	5493.5	8.39
Forests and woodland	1800	2.75
Permanent pasture	30,000	45.84
Other land	25,613	39.14
Total land area	**65,439**	**100.00**

Source: Ministry of Agriculture, Irrigation and Livestock.

Table 2. Cropping pattern of Afghanistan (2018).

Crop	Area (ha)	% of Total Cropping Area
Wheat	1,635,000	61.30
Paddy rice	117,539	4.41
Barley	84,147	3.15
Maize	72,439	2.72
Total cereals	1,909,125	71.58
Total pulses	61,166	2.29
Total food grains	**1,970,291**	**73.87**
Grapes	87,517	3.28
Apricot	18,510	0.69
Apple	28,381	1.06
Peach	7799	0.29
Melon	35,798	1.34
Watermelon	25,519	0.96
Citrus fruits	1700	0.06
fresh Fruits	57,731	2.16
Other fruits	14,267	0.53
Total fruits	**277,222**	**10.39**
Potato	32,400	1.21
Onion	10,551	0.40
Other vegetables	38,502	1.44
Total vegetables	**81,453**	**3.05**
Sugar beet	196	0.01
Sugar cane	1766	0.07
Total oilseed	**83,817**	**3.14**
Others	252,355	9.46
All	**2,667,100**	**100.00**

Source: National Statistics and Information Authority (NSIA, 2019) [35].

3. Results

3.1. Quantifying the Impact of Climate Change on the Productivity of Major Cereals

Projected alterations in climate patterns hold significant implications for future agricultural production. In this section, we present an in-depth analysis that focuses on the precise impacts of climate change on the productivity of major cereal crops in Afghanistan using a panel regression model.

3.2. Descriptive Statistics of Yield and Climatic Variables

Table 3 displays the summary statistics of the crop yield and climate variables used in this study from 2005 to 2018. In Afghanistan, wheat is a major crop that is grown for food, both with irrigation and in rain-fed areas [36]. Wheat cultivation covers about 85% of the total land area and makes up around 88% of the country's food consumption. On average, the wheat yield was 2187 kg per hectare, with a variation of 586 kg per hectare. The average rice yield was approximately 2286 kg per hectare, with a variation of 392 kg per hectare. The average barley yield was 1601 kg per hectare, with a variation of 281 kg per hectare. Over the 14-year period studied, the average annual rainfall was 271 mm, with a variation of 109.7 mm, and the average annual temperature was 17.6 °C, with a variation of 4.1 °C.

Table 3. Summary statistics of the climate yield and climate variables during the period 2005–2018.

Variable	Unit	Mean	Standard Deviation	Minimum	Maximum
Wheat Yield	kg/ha	2187.4	585.9	595.3	3509.3
Rice Yield	kg/ha	2285.7	392.1	1200.0	3866.6
Barley Yield	kg/ha	1601.1	281.5	543.8	2020.0
Rainfall	mm	270.9	109.7	13.8	656.5
Temperature	°C	17.6	4.1	9.8	23.0

3.3. Panel Data Regression Estimation

Panel data models using fixed and random effects were employed. Fixed effect and random effect models are the basic techniques for estimating panel data, but a choice must be made between the two models. For this selection, the Hausman test was used to check which model was most suitable [20,31] by using the chi-square (χ^2) test [20], which indicated the statistically significant *p*-values. The fixed effect model was used where appropriate, and otherwise the random effect model was used.

To analyze the impact of climate variables on the yield of major cereals, the Hausman specification test was used to select the appropriate model. The results of the Hausman test showed that the null hypothesis was not rejected for wheat yield. Hence, the fixed effects model was appropriate for wheat yield. The results for the barley and rice yields were not significant; hence, the random effect model was most appropriate. The results of the Hausman test for the major cereals (wheat, rice, and barley) are presented in Table 4.

Table 4. Hausman test results for the selection of the appropriate model.

Variable	χ^2 Statistic	Pro > χ^2	Selection of Appropriate Model
Wheat Yield	73.75	0.0000 ***	Fixed effect
Rice Yield	5.26	0.3853	Random effect
Barley Yield	1.84	0.7652	Random effect

*** Significant at the 1% level.

3.4. Impacts of Climate Change on Wheat Yield

Table 5 presents the impact of climatic variables on wheat yield. The findings reveal that the temperature coefficient was statistically significant at the 5% level and had a negative effect on wheat yield. According to the regression coefficients, a 1 °C increase in average temperature led to a 271 kg/ha decrease in wheat yield. While the rainfall coefficient showed a negative correlation with wheat yield, it did not reach statistical significance. However, the significant squared term for temperature suggests that the nonlinear effects of this climate variable played a significant role. By employing the fixed effects panel regression, the model's R^2 value was determined to be 0.11. This means that the explanatory variables considered in the model accounted for 11% of the variations observed in wheat yield. The F-test indicated that the regression model was overall significant, indicating a good fit to the data.

Table 5. Estimated parameters from the panel regression fixed effects model for wheat.

Variable	Wheat	
	Coefficient	*p*-Value
Trend	8.741	0.224
Rainfall	−1.004	0.708
Rainfall Square	−0.0003	0.917
Temperature	−271.317 **	0.018
Temperature Square	8.483 *	0.059
Rainfall × Temperature	0.213	0.123
Constant	3690.59 ***	0.000
F-test	2.88 **	0.013
Number of observations	98	
R^2	0.11	

*, **, and *** represent significance at the 10, 5, and 1% levels, respectively.

3.5. Impacts of Climate Change on Rice Yield

The regression results for rice yield using random effects are presented in Table 6. The findings indicate that rainfall had a significant negative impact on rice yield. Specifically, a 1 mm increase in rainfall was associated with a decrease in the average rice yield by 11.77 kg/ha. The significance of the interaction term suggests that the nonlinear effects of climate variables play a significant role. The R2 value of 0.13 indicates that the explanatory variables considered in the model explain approximately 13% of the variation observed in rice yield. Both rainfall and temperature demonstrated statistical significance at the 10% level. The significant positive coefficients for these trends suggest notable technological advancements in rice production over the study period. These advancements include the adoption of high-yield varieties, improved irrigation methods, and better pest and disease control.

Table 6. Estimated parameters from a panel regression random effects model for rice.

Variable	Rice	
	Coefficient	*p*-Value
Trend	26.45 ***	0.006
Rainfall	−11.77 *	0.091
Rainfall Squared	0.0083487	0.523
Temperature	−73.37	0.715
Temperature Squared	0.9821084	0.823
Rainfall × Temperature	0.476056 *	0.052
Constant	3261.72	0.148
Wald χ^2	13.70 **	0.0332
Number of observations	98	
R^2	0.13	

*, **, and *** represent significance at the 10, 5, and 1% levels, respectively.

3.6. Impacts of Climate Change on Barley Yield

The results of the estimated empirical panel data random effects model for barley yield are presented in Table 7. The results showed that temperature had a highly significant negative effect on barley yield. This implied that a 1 °C increase in temperature induces a decrease of 221 kg/ha in mean barley yield. The R2 value of the panel regression model with random effects indicated that 23% of the variation in barley yield was explained by the explanatory variables included in the model. The square term for temperature was highly significant, implying that the nonlinear effects of temperature were important. The significant negative coefficient value of the trend implied that technological progress, such as the use of high-yield varieties and improved agronomic practices, did not have a considerable impact on improving the barley yield over the study period.

Table 7. Estimated parameters from the panel regression random effects model for barley.

Variable	Barley	
	Coefficient	***p*-Value**
Trend	−20.027 ***	0.002
Rainfall	2.494	0.201
Rainfall Squared	−0.001	0.592
Temperature	−221.273 **	0.014
Temperature Squared	7.397 ***	0.002
Rainfall × Temperature	−0.067	0.386
Constant	2931.553 ***	0.001
Wald χ^2	27.260 ***	0.000
Number of observations	98	
R^2	0.23	

** and *** represent significance at the 5 and 1% levels, respectively.

3.7. Climate Change Scenarios

Future climate change projections were obtained from the Coordinated Regional Climate Downscaling Experiment—South Asia (CORDEX-SA) data, which were downscaled by Aich et al. for Afghanistan [32]. There are four future emission scenarios, called the Representative Concentration Pathways (RCPs), included in the future climate projection models: RCP2.6, RCP4.5, RCP6.0, and RCP8.5. Each RCP represents the radiative forcing and CO_2 concentration reached by the year 2100. For this study, mid-century projections from 2021 to 2050 and two future climate change scenarios representing medium- and high-emission scenarios (RCP4.5 and RCP8.5, respectively) were considered for the future yield predictions. RCP4.5 represents an increase in radiative forcing of ~4.5 W/m^2 and a CO_2 equivalent of ~650 ppm by 2100, which stabilizes after 2100 without any overshoot relative to pre-industrial conditions. In contrast, RCP8.5 represents an increase in radiative forcing of >8.5 W/m^2 and a CO_2 equivalent of >1370 ppm by 2100, which continues to rise even after 2100 [37].

The climate change scenarios predicted for 2021–2050 used in this study are listed in Table 8. The RCP4.5 scenario projects that the mean temperature will increase by 1.7 °C and rainfall will decrease by 1.6% by 2050. In contrast, the high-emission RCP8.5 scenario indicated that the mean temperature would increase by 2.3 °C and the mean rainfall would decrease by 3.8% by 2050 [32].

Table 8. Climate change scenarios for future projections from 2021 to 2050.

Period	Scenarios	Future Projections (2021–2050)	
		Change in Temperature (°C)	**Change in Rainfall (%)**
2021–2050	RCP4.5	1.7	−1.6
	RCP8.5	2.3	−3.8

Source: Aich et al., 2017 [32].

3.8. Projected Estimates of Wheat, Rice, and Barley Yields under Different Climate Change Scenarios

To project future climate change impacts, the panel data regression coefficients estimated in the previous section were used to compute projected changes in the yields of major cereals in Afghanistan. The projected mean yield changes for wheat, rice, and barley in Afghanistan are presented in Table 9. According to the RCP4.5 and RCP8.5 scenarios, there will be a substantial reduction in the wheat yield during the period 2021–2050. The reduction in the mean wheat yield is projected to be 20.90 or 28.11% by 2050 according to the medium- and high-emission scenarios, respectively. For rice, there will be a marginal reduction in yield during the period 2021–2050. The reduction in the mean yield is projected to be 4.92 or 6.10% according to the RCP4.5 and RCP8.5 scenarios, respectively, at the end of 2050. The parameter estimates from the regression model show that barley yield is expected to decrease 24% (387 kg/ha) under the medium-emission scenario and by 34% (535 kg/ha) under the high-emission scenario. The magnitudes of the yield reduction for wheat, rice, and barley were similar to the findings of another study conducted by Reddy et al. [17]. Similarly, Sharma et al., (2015) [38] indicated that the previous decade's rainfall reduced by up to 100 mm during the wheat season, and more reduction is estimated by 2050 in Afghanistan. Due to increased temperature-induced impacts on agriculture, especially on wheat, rice, sorghum, maize, barley, and grain productivity.

Table 9. Predictions of wheat, rice, and barley yield changes in Afghanistan.

Crops	Projected Mean Yield (2021–2050)			
	RCP 4.5 Scenario		RCP 8.5 Scenario	
	Yield Change (kg/ha)	Percentage Change	Yield Change (kg/ha)	Percentage Change
Wheat	457.56	20.90	615.30	28.11
Rice	112.33	4.92	139.31	6.10
Barley	386.98	24.35	534.61	33.64

4. Discussion and Conclusions

Global warming, which encompasses both warming and cooling conditions, serves as the primary catalyst for climate change. According to the Intergovernmental Panel on Climate Change (IPCC), climate change refers to any long-term alteration in climate, whether caused by natural climate variations or human activities. The UNFCCC (United Nations Framework Convention on Climate Change) defines climate change as any modification in climate directly or indirectly influenced by human activities that impact the atmosphere's composition, as well as changes in natural climate patterns observed over comparable timeframes. Climate change has far-reaching impacts on various aspects, including agriculture and food security, water resources, the environment, infrastructure, and human livelihoods. The occurrence of severe weather conditions like droughts and floods significantly affects farmers' means of living. Moreover, climate change disrupts agricultural and related sectors, affecting crop and livestock production by influencing growth, transpiration rates, photosynthesis, moisture availability, and overall productivity. To reduce the adverse effects of climate change, it is crucial to implement effective adaptation strategies in the agricultural sector. These strategies encompass measures such as weather forecasting, early warning systems, improved water management practices, diverse crop insurance schemes, biodiversity conservation, and enhanced risk management techniques. By adopting these adaptation strategies, the vulnerability of agricultural systems can be significantly reduced, enabling the sector to better manage the effects of climate change.

Afghanistan, as a traditionally agrarian nation, relies heavily on the agricultural sector, which contributes 22% to the national gross domestic product. The agricultural industry serves as a significant source of livelihood, employing 70% of the rural population. Compared to other populations, farmers in Afghanistan face heightened vulnerability due to the impact of extreme weather events and limited resources for adaptation. Geographically, Afghanistan falls within the arid and semi-arid continental climate of the arid sub-tropics, situated 37° north of the equator. Recent trend analyses reveal a decrease in precipitation across most regions of the country. Between 1960 and 2008, Afghanistan experienced an average increase in temperature of 0.13 °C annually and a decrease in rainfall of 2% per decade. Prolonged droughts have become increasingly common, affecting large areas with minimal precipitation. Given the frequent occurrence of drought and other climate change-related hazards resulting from rising temperatures and reduced rainfall, it is necessary to understand the impact of climate change on major cereal production. In this paper, we quantify these impacts and provide policy recommendations to farmers and governments, helping them mitigate risks associated with climate variability and extreme weather events.

The data was collected from various sources. Information on the productivity of major cereal crops, namely wheat, rice, and barley, was obtained from different issues of the Afghanistan statistical yearbook, published annually by the NSIA (National Statistics and Information Authority) and the Ministry of Agriculture, Irrigation, and Livestock. In addition, observed climatic data for all provinces in Afghanistan, covering the period from 2005 to 2018, were collected from the Afghanistan Meteorological Department.

To estimate the impact of climatic variables on cereal crop yields, a panel data regression model was employed. The mean yields for wheat, rice, and barley were found to be 2187 kg/ha, 2286 kg/ha, and 1601 kg/ha, respectively, over the 14-year study period. The average annual rainfall was recorded at 271 mm, while the mean annual temperature was 17.66 °C. Based on the Hausman test results, the fixed effects model was deemed most suitable for analyzing wheat yield, while the random effects model was more appropriate for barley and rice.

The findings of the panel data regression model revealed that temperature had a statistically significant negative impact on wheat yield. A 1 °C increase in mean temperature was projected to lead to a reduction of 271 kg/ha in wheat yield. Furthermore, rainfall was found to have a significant negative effect on rice yield, with an increase of 1 mm in rainfall associated with a decrease of 11.77 kg/ha in mean yield. Interestingly, the positive coefficient for temperature indicated that technological advancements, such as the use of high-yield varieties, improved irrigation methods, and better control of pests and diseases, contributed to progress in rice production during the study period. The temperature coefficient also had a significantly negative impact on barley yield, suggesting that a 1 °C temperature increase would result in a mean yield decrease of 221 kg/ha.

Moreover, we considered the mid-century period from 2021 to 2050 and two climate change scenarios (RCP4.5 and RCP8.5) to predict future impacts. Using the estimated regression coefficients, we calculated the projected changes in major cereal crop yields in Afghanistan. The mean yield is expected to decrease by 21% or 28% under the medium- and high-emission scenarios, respectively. For rice, there will be a marginal reduction in yield of 4.92% or 6.10% under RCP4.5 and RCP8.5, respectively, from 2021 to 2050. Barley yield is expected to decrease by 387 kg/ha (medium-emission) or 535 kg/ha (high-emission). The results of the present study are also supported by Khalily (2022) [39], who states that the yields of wheat, rice, and corn have continued to decline because of the recent drought in Afghanistan, indicating the negative impact of climate change.

Based on the analysis and findings of this study, the following recommendations are provided to reduce the risks related to climate variability and enable farmers and governments to better address the future impacts of climate change:

- The government of Afghanistan should establish automatic weather stations at the provincial and sub-provincial levels to provide better agro-advisory services to the farming community through high-quality weather information.
- The information from all weather stations should be maintained on a web portal.
- Coordinated efforts should be undertaken to develop new varieties of major cereal crops that could withstand rising temperatures.
- Climate-smart agricultural practices should be taught to farmers by personnel trained in sustainable agriculture in Afghanistan.
- Technological innovations such as greenhouse and poly-house technologies, drought-tolerant varieties, and improved irrigation systems should be adopted to mitigate the effects of climate change on agriculture.

In the context of SDGs, SDG 2 (Zero Hunger) and SDG 13 (Climate Action) are related to his study. SDG 2 aims to end hunger, achieve food security, improve nutrition, and promote sustainable agriculture, while SDG 13 focuses on taking urgent action to combat climate change and its impacts. This paper highlights the effects of climate change on agriculture and food security in Afghanistan. It emphasizes the vulnerability of farmers in Afghanistan to extreme weather events and limited resources for adaptation, which aligns with SDG 2's goal of achieving sustainable agriculture and ending hunger. Additionally, the study emphasizes the need for effective adaptation strategies to reduce the negative effects of climate change on the agricultural sector, which is in line with SDG 13's goal of taking action to combat climate change. By identifying vulnerable agro-climatic zones and facilitating future studies on adaptation measures and coping strategies, this study contributes to the broader efforts towards achieving SDG 2 and SDG 13 in Afghanistan and beyond.

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