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Research Article

IMPACT OF CLIMATE CHANGE ON RICE PRODUCTIVITY IN KHYBAR PAKHTUNKHWA, PAKISTAN

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Abstract

Climate change is currently the most significant concern on the planet. This study examined the impacts of climate change on rice yield across agro-ecological zones of Khybar Pakhtunkhwa, Pakistan. This study focused only on four districts across four agroecological zones in Khybar Pakhtunkhwa based on the availability of data on areas under rice, rice production, and meteorological variables. Districts Swat from Zone A, Mansehra from Zone B, Mardan from Zone C, and D.I. Khan from Zone D were selected. This study covered 33 years (1986-2018) of data across these four districts. Panel unit root tests of LLC and IPS suggested that all variables included in the model were stationary. Durbin Wu Hausman's test favored the fixed effect model compared to the random effect model. Diagnosis of fixed effect model results showed that it was plagued with problems of cross-sectional dependency, heteroscedasticity, and autocorrelation. Final findings were estimated using the Feasible Generalized Least Squares (FGLS) model to overcome the problems in the fixed effect model. Results revealed that area under rice crop has a positive and significant effect on rice yield. The estimated critical temperature for the maximum yield of rice was 34.48 ºC in the sowing stages, 35.85 ºC in the vegetative stages, and 29.43 ºC in the maturity stages, and Rainfall in the vegetative stages was 152 mm. It is concluded that rice yield showed a decline when temperature and rainfall exceeded the critical levels. The government needs to use afforestation and other appropriate measures to keep the temperature from rising in these three zones (zones A, C and D). The extension department needs to inform rice growers about adaptation strategies to climate change.

Keywords: Rice Productivity, Climate Change, Panel Data, FGLS Model, Pakistan.
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1. INTRODUCTION

Climate change is happening all around the world, and no country is immune to its negative consequences (Hanif et al., 2010). According to experts, climate change is expected to lower crop productivity in several countries worldwide in the following decade (Falco et al., 2011). The rapid increase of greenhouse gases in the atmosphere has become a significant source of global warming (Aydinal and Cresser, 2008). It is known that the main source of these emissions of greenhouse gases is the developed nations of the world, and around 75% of discharges related to greenhouse gases are from developed countries. In contrast, developing countries contribute a low share in this emission (Farooqi et al., 2005). The greenhouse gases which include nitrogen oxide, methane, carbon dioxide, and fluorinated gases [hydro fluorocarbon (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF6), and nitrogen trifluoride (NF3)], directly affect the rainfall pattern, increases in temperature, which leads a negative effect on water and land resources. The risks are growing higher and higher due to human activity. The emission of greenhouse gases will ultimately lead to high temperatures and high precipitation (Malhi et al., 2021).

Temperatures are expected to rise roughly 3 degrees by 2040 and around 5-6 degrees by the end of the century, according to projections. Monsoon rains will be greatly reduced, but they will be much more intense. Droughts and floods are also expected in South Asia (IUCN. 2011). According to the climate model, evaporation and precipitation and the frequency and severity of rainfall are expected to increase. Some areas may get wetter, while others may be impacted by an enhanced hydrological cycle, resulting in soil moisture loss and increased erosion (Bossello et al., 2005).

Around the globe, the main challenges caused by climate change are a country's water, energy, and food security (GOP, 2017). Water supply for agriculture will be altered by climate change in a variety of ways, including shifting rainfall and production patterns. High temperatures can reduce production by promoting crop development and causing plant cell damage (Myers et al. 2017; Bossello et al., 2005). The growth and health of some plants may be improved because of the chilling and freezing environment; on the other hand, crops' health may be damaged due to the high temperature (Bossello et al., 2005).

In Pakistan, climatic changes have also become a big concern to researchers, water authorities, agriculturists, policymakers, and other public and private organizations stakeholders, and NGOs have shown serious concerns over climate change issues (Rehman et al., 2017). Every year, many glaciers in legendary mountainous regions are already melting up to a meter. The rapid melting of these glaciers, combined with the consequence of global warming, gives rise to intense precipitation, which is expected to be one of the greatest sources of river flooding. As soon as the mountainous glaciers melt completely, the river flow will decrease dramatically (Ahmed and Javed, 2016). The impact of this change is now visible in the agriculture sector and its production (Rehman et al., 2017) Pakistan is one of the world's largest rice producers, and rice is the 2nd staple food consumed (Sarwar et al., 2021). Moreover, Pakistan is also one of the victims of severe climate change, and the future climatic scenarios for Pakistan are even more challenging (Rehman et al. 2017). Khybar Pakhtunkhwa province has vast climatic conditions in Pakistan, and various crops are cultivated here. Many researchers studied the impact of climate change using different approaches. The cross-section approach deals with one-time points or for a short period, e.g., Kumar (2009), Ernest et al. (2007), and Khan et al. (2018) used the Ricardian cross-sectional model to examine the effect of climate on crop revenue. Time series methods deal with observations, each being recorded at a specific time. Perron and Estrada (2012) and Ali et al. (2017) examined the changing climate upshots of key agricultural crops using a time series method. The panel data approach deals with the behavior of entities observed across time. It is considered best because the panel data approach has more boons than a cross-section and time series. Moreover, the panel approach has more observations that give us more precise estimates (Wang, 2010). Thus, Panel data was used to estimate the impact of climate change on rice productivity in the study area. No analytic research work has yet been undertaken by any researcher to quantify climate variability's impact on rice productivity in Khybar Pakhtunkhwa through a panel data approach. Rice growers can benefit from the adaptation to changing environments. Investigators can equate their results with this study, and most importantly, from the findings of this study, policymakers may get help in framing policies for better production of rice crops.

2. Materials and Methods

2.1. *Universe of the study*

This research was carried out in Pakistan's Khybar Pakhtunkhwa province. Khybar Pakhtunkhwa is located in Pakistan's northwest (Khybar Pakhtunkhwa Climate Change Policy, 2016). Total area of Khybar

Pakhtunkhwa is 74521 square kilometers, with mountains and rocks accounting for 70% of the land (White Paper, 2015). Extreme climatic variation is found in Khybar Pakhtunkhwa weather; the northern area of Khybar Pakhtunkhwa has extremely cold and snowy winters with a huge rate of rainfall and a pleasant summer as compared to the southern region of Khybar Pakhtunkhwa, which has less severe winter, rainfall, and a very hot summer. Khybar Pakhtunkhwa is divided into 4 agroecological zones, i.e., zone A (Northern), zone B (Eastern), zone C (Central), and zone D (Southern), according to their climatic nature based on rainfall and temperature altitude (Khybar Pakhtunkhwa Climate Change Policy 2016) (Table 1).

Table 1: *Agro ecological zones of Khybar Pakhtunkhwa with districts*

Climatic zones	**Description**	**Districts**
Northern (A)	Higher northern mountains, Northern mountain,	Chitral, Swat, Bunir, Shangla, Upper Dir, Lower Dir
Eastern (B)	Wet mountains, Sub humid eastern mountains	Batagram, Haripur, Mansehra, Torghar, Kohistan, Abbottabad
Central (C)	Central plain valley	Peshawar, Charsadda, Mardan, Swabi, Nowshera, Kohat
Southern (D)	Piedmont plain, Suleiman piedmont	Bannu, Karak, Lukky Marwat, Tank, D. I. Khan

Source: Environmental Protection Agency of Khybar Pakhtunkhwa, 2016.

Zone A, which are higher mountains or northern mountains, consists of six districts, which are Chitral, Bunir, Swat, Shangla, Upper Dir, and Lower Dir. Batagram, Haripur, Mansehra, Torghar, Kohistan, and Abbottabad come under Zone B, which are sub-humid eastern mountains or wet mountains. Similarly, the Central Plain valley, which includes Swabi, Mardan, Charsadda, Peshawar Nowshera, and Kohat, lies in Zone C., while Zone D, known as Piedmont Plain, Suleiman Piedmont, includes Bannu, Karak, Lakki Marwat, Tank, D. I. Khan (Fig. 1).

Fig. 1 *Map of Khybar Pakhtunkhwa province*

2.2. *Data and data sources* `

Panel data over time and across major rice-producing districts in four climatic zones of Khybar Pakhtunkhwa was used in this study. Time period and major rice-producing districts across four climatic zones were selected for which data on non-climatic and climatic variables were available. Data on rice production in thousand tons, area under rice crop in thousand hectares, yield of rice in kilograms per hectare, temperature in ℃ and precipitation in mm were collected. Production, area, and yield of rice data were gathered from the Pakistan Bureau of Statistics and Development Statistics of Khybar Pakhtunkhwa. Data on climatic variables was collected from the Pakistan Meteorological Department, Peshawar.

Due to fluctuations in climatic conditions throughout different phases of crop growth, which have varied effects on crop production, the temperature and precipitation variables were computed using three phonological stages of rice crop (Auffhammer et al., 2012). Nursery growth, transplanting, and tillering are covered in the first stage, vegetative growth, blooming, and milking are covered in the second stage, and rice maturity and harvesting are covered in the third stage. The first stage of rice lasts from June to July. The second is from August to September, and the third is from October to November (Ahmad et al., 2016), (Segerson and Dixon, 1999), (Cabas et al., 2010), and (Cheng and Chang, 2002).

2.3. *Conceptual framework*

Traditionally, the impact of climate alteration was measured by many researchers. The production function, which is also known as product modeling, is based on empirical or experimental production, and many researchers use this model to investigate the relationship between yield and climatic variables (Deressa et al., 2005). In the same way, The Ricardian approach is another useful tool for determining the total climatic influence on a specific geographical area. It has been used in both developed and developing countries in a variety of geographical areas (Salvo et al., 2013) Mishra and Sahu (2014), Salvo et al. (2013), Deressa and Hassan (2009), Kabubo-Mariara and Karanja (2006), Deressa et al. (2005), Gbetibouo and Hassan (2005), Mendelsohn and Dinar (2003), Mendelsohn and Dinar (2003), Mendelsohn and Dinar (2003), Mendelsohn and Dinar (2003), Mendelsohn and Din

At the global, country, and regional levels, the time series approach has been widely used to explore the impact of climate variables on crop yields (Maharjan and Joshi, 2012). Rahim and Puay (2017), Zaied and Zouabi (2015), Amponsah et al. (2015), and Alam (2013) used time series analysis to investigate the relationship between climate variables and agricultural product yield.

Advanced Ricardian (Panel Data) Approach is also used by researcher to assess the impact of rainfall and temperature change on agriculture production such as Loum and Fogarassy (2015), Sarker et al. (2014), Dasgupta (2013), Barnwal and Kotani (2013) Dell et al. (2012), Akram (2012) Lobell et al. (2011) , Brown et al. (2010), Guiteras (2007). The basic advantage of this approach is that it takes into account, the fluctuations that occur randomly year-to-year in the weather conditions (Deschenes and Greenstone, 2007).

2.4. *Panel data approach*

Panel data is the blend of both time series and cross-sectional data. When data is collected over more than two dimensions, i.e., different cross sections, and over time, it is known as Panel data. Variables that cannot be observed or measured and change over time but not across entities variables can be controlled through Panel data. Moreover, Panel data can include variables at different stages of analysis.

The efficiency of the panel data is greater because it has a variety of advantages over cross-sectional and time series data. In panel data, there are more observations, which gives more precise estimates, more information, and fewer collinearity issues in data. It also resolves the misspecification problem that arises from omitted variables (Jintian, 2010).

The panel data approach can be simply presented as follows:

$$Yit = \alpha + \beta xit + \varepsilon it \qquad (1)$$

Y = dependant variable
X = independent variable
α and β = coefficients
i and t = directories for cross section and time
ε_{it} = error term

The error (ε_{it}) component is the most important factor in the panel data method equation because it tells us whether to use a fixed effect model or a random effect model (Gardinar et al. 2009).

Three approaches are used in the literature for the analysis of panel data (Baltagi, 2008).

i. Pooled effect model

The pooled effect, also known as the common constant effect, is the same as simple regression. In the pooled effect model, no panel information is used as it is observed that every variable is uncorrelated with others, ignoring panel and time.

The simple pooled model can be expressed as follows: $Yit = \beta 0 + \beta xit + \varepsilon it$ (2)

The pooled effect assumes that every observation performs in the same way and never experiences autocorrelation and heteroscedasticity, which is why only a simple regression model can be used to estimate the model. Mostly, pooled effect models are more restrictive than fixed effect and random effect. The pooled model should be used when the fixed effect is not efficient.

ii. Fixed effect model

Deschenes and Greenstone (2007) presented the fixed model approach, which removed the problems associated with the hedonic approach and is considered the ideal model due to its quick response time to sudden changes in weather conditions, and it also controls the effect of unobserved variables (Mendelsohn and Dinar, 2009).

Because fixed effect organizes all time-invariant changes between entities, the projected coefficients of fixed effect cannot be skewed by excluding time-invariant properties. Because it is constant for each cross-section, a time-invariant feature cannot produce such a change (Torres-Reyna, 2007).

$Yit = \alpha i + \beta xit + \varepsilon it$ t = 1… T and i = 1… N (3)

Where:

Yit = Dependent variable

αi = Correlated with x and unobserved time-invariant individual effect for every cross-section

εit = Error term.

(β) = a parameter representing slope (same for all cross sections & doesn't changeable).

For two or more than two time period data sets, a fixed effect model is suitable. For estimation of fixed effect model least square dummy variable (LSDV) is used.

iii. Random effect model

In the random effect model, time-variant variables are included. The logic behind the random effect is that the variation across the entities is assumed to be random and is uncorrelated with the cross-section or independent variables included in the models (Torres-Reyna. 2007). The constants for each part are treated as random parameters in the random effect model.

$$Yit = (\alpha i + vi) + \beta xit + \mu it \quad (4)$$

$$Yit = \alpha i + \beta xit + vi + \mu it \quad (5)$$

Individual effects are randomly spread crosswise in a random effect, and αi is uncorrelated with x. When the random impact is considered to be that the unit's error terms are not associated with the cross-section, time-invariant variables play a function as an explanatory variable. Random effects should be employed if variations between entities have an impact on the dependent variable.

iv. Empirical model

The yield of rice across districts and over time is expected to be a function of the area under rice crop, minimum and maximum temperature, and precipitation during the crop season. The model for panel data estimation is given as:

$$LNYIELDit = \beta 0 + \beta_1 LNAREAit + \beta_2\, LNTmax\_Sit + \beta_3\, LNTmax\_Vit + \beta_4\, LNTmax\_Mit + \beta_5\, (LNTmax\_Sit)^2 + \beta_6\, (LNTmax\_Vit)^2 + \beta_7\, (LNTmax\_Mit)^2 + \beta_8\, LNRain\_Sit + \beta_9\, LNRain\_Vit + \beta_{10}\, LNRain\_Mit + \beta_{11}\, (LNRain\_Sit)^2 + \beta_{12}\, (LNRain\_Vit)^2 + \beta_{13}\, (LNRain\_Mit)^2 + \beta_{14} T + Uit \quad (6)$$

Where:

LNYIELD=Natural log of rice yield (kg/ha)

LNAREA = Natural log of area (000 ha)

LNTmax_S = Natural log of maximum temperature for sowing stage

LNTmax_V = Natural log of max. temperature for vegetative stage

LNTmax_M = Natural log of max. temperature in maturity stage

$(LNTmax\_S)^2$ = Natural log of max. temperature square in sowing stage

$(LNTmax\_V)^2$ = Natural log of max. temperature square in vegetative stage

$(LNTmax\_M)^2$ = Natural log of max. temperature square in maturity stage

LNRain_S = Natural Log of rainfall in sowing stage

LNRain_V = Natural Log of rainfall in vegetative stage

LNRain_M = Natural Log of rainfall in maturity stage

$(LNRain\_S)^2$ = Natural Log of rainfall square in sowing stage

$(LNRain\_V)^2$ = Natural Log of rainfall square in vegetative stage

$(LNRain\_M)^2$ = Natural Log of rainfall square in maturity stage

β1-13 = Estimated parameters
T = Trend (Time in years)
U = Error term
i = Cross section
t = Time period

2.5. *Model selection*

The following test was conducted for the selection of the appropriate model.

1. Durbin Wu Hausman test

For selection between random and fixed effect models, the Durbin Wu Hausman test was conducted (Gardiner *et al*. 2009). Durbin Wu Hausman's test constructs the following hypothesis.

H_O: The random effect model is efficient
H_1: The fixed effect model is efficient

The following static are used in the Hausman test:

$H = (\beta^{\wedge FE} - \beta^{\wedge RE})' - [Var\ (\beta^{\wedge FE}) – Var\ (\beta^{\wedge RE})]^{-1} (\beta^{\wedge FE} - \beta^{\wedge RE}) \sim \chi^2\ (k)$ (7)

Hausman test follows the chi-square distribution. If the chi-square value is found insignificant, then the null hypothesis of the random effect model will be accepted, and vice versa.

2. Breusch-Pagan Lagrange Multiplier (LM) test

Breusch-Pagan Lagrange Multiplier (LM) test assists in deciding between pooled effects and random effects models. The LM test's hypothesis:

H_0: Variance of the random effect is zero: Var[ui] = 0
H_1: Variance of the random effect is not zero: Var[ui] $\neq$ 0

LM test follows chi square distribution.

Critical temperature and its impact on yield

Critical temperature is the temperature where the yield is maximum or minimum. This temperature can be calculated using the formula provided below.

Critical temperature = $\exp\ (-(\beta_2/2 * \beta_3))$ (8)

3. Results and Discussion

3.1. *Summary statistics of variables*

Table 2 shows the summary statistics for the variables included in the model. The total number of observations is 132, which is equal to N=4, T=33, and N*T=132. Having a standard deviation of 0.22, with the natural log (ln) mean of yield was 7.67 kg/ha. The natural log of area for the second variable ranged from 0.26-3.02.53 hactare, having a mean of 1.37 and a standard deviation of 0.75. The log of maximum temperature for sowing months mean is 3.53 with a standard deviation of 0.84 and has a mean range of 3.20-3.71. The log of maximum temperature for vegetative months ranges between 3.33 and 3.68, with a mean value of 3.51 and a standard deviation of 0.67. log of maximum temperature for maturity months mean value is 3.40, has a standard deviation of 0.75, and a mean ranging between 3.07-3.55. The temperature maximum square for sowing months mean is 12.51 with a standard deviation of 0.59, and the range of mean is 10.24-13.80. The Square of the Temp-max for the vegetative months range is 11.09-13.55, with a mean value of 12.33 having a standard deviation of 0.47. Temp-max square for maturity months mean it is 11.60 with a standard deviation of 0.50, the mean range is 9.42-12.60. The log of rainfall for sowing months mean is 4.42 with a standard deviation of 0.49 and has a mean range of 3.26-5.21. LNRain_V ranges in between 4.38-5.22 with a mean value of 4.92 having standard deviation of 0.17. LNRain_M mean value is 3.80, has standard deviation of 0.49, mean ranging in between 2.75-4.61.

The rainfall square for the sowing months mean is 19.81 with a standard deviation of 4.20, and the mean range is 10.67-27.22. LNRain_V2 range is 19.20-27.15 with a mean value of 24.24 and a standard deviation of 1.74. The rainfall square for maturity months is 14.69 with a standard deviation of 3.67, and the mean range is 7.56-21.29.

3.2. Panel unit root tests

Panel unit root tests were used to ensure that the series were stationary. All fourteen variables in the model were tested for stationarity. Unit root testing for the LLC (Levin-Lin-Chu) and IPS (Im-Pesaran-Shin) panels. The LLC and IPS tests were used to determine yield stationarity. When

Table 2: *Summary statistics*

Variables	Obs	Mean	Std. Dev.	Min.	Max.
LNYIELD (YIELD)	132	7.67 (2196.17)	0.22 (458.35)	6.97 (1070.40)	8.07 (3203.70)
LNAREA (AREA)	132	1.37 (5.14)	0.75 (3.62)	0.26 (1.3)	3.02 (20.6)
LNTmax_S (Tmax_S)	132	3.53 (34.46)	0.84 (2.85)	3.20 (24.55)	3.71 (41.1)
LNTmax_V (Tmax_V)	132	3.51 (33.58)	0.67 (2.27)	3.33 (27.95)	3.68 (39.7)
LNTmax_M (Tmax_M)	132	3.40 (30.23)	0.75 (2.23)	3.07 (21.55)	3.55 (34.85)
(LNTmax_S)2 (Tmax_S)2	132	12.51 (1195.67)	0.59 (196.06)	10.24 (602.70)	13.80 (1689.21)
(LNTmax_V)2 (Tmax_V)2	132	12.33 (1133.38)	0.47 (154.84)	11.09 (781.20)	13.55 (1576.09)
(LNTmax_M)2 (Tmax_M)2	132	11.60 (919.28)	0.50 (134.83)	9.42 (464.40)	12.60 (1214.523)
LNRain_S (Rain_S)	132	4.42 (92.86)	0.49 (37.59)	3.26 (26.25)	5.21 (184.5)
LNRain_V (Rain_V)	132	4.92 (139.01)	0.17 (23.40)	4.38 (80)	5.22 (185)
LNRain_M (Rain_M)	132	3.80 (50.13)	0.49 (22.99)	2.75 (15.65)	4.61 (101)
(LNRain_S)2 (Rain_S)2	132	19.81 (3615.49)	4.20 (5023.82)	10.67 (15.60)	27.22 (34040.25)
(LNRain_V)2 (Rain_V2)	132	24.24 (31864.74)	1.74 (53353.03)	19.20 (12.60)	27.25 (373932.3)
(LNRain_M)2 (Rain_M)2	132	14.69 (4187.34)	3.67 (7261.17)	7.56 (3.61)	21.29 (43701.9)

Source: Authors' estimates from panel data, 1986-2018

Note: Figures in parentheses show values at level (linear)

the yield was tested, both with and without a trend, the results showed that the yield was stagnant. The LLC and IPS tests were used to confirm stationarity in the area, which is the model's second variable. When LLC tests were conducted using merely a trend, the results revealed that the area was non-stationary. When the intercept was combined with the trend, the variable became stationary. The IPS p-value for trend and intercept is extremely high, indicating that the variable is stationary. The same test was carried out to see the stationarity of all the temperature variables (LNTmax S, LNTmax V, LNTmax M, and their Squares) for all the phonological phases, including sowing, vegetative, and maturity months. In both situations, the panel unit root tests indicate that this variable is stationary with trend and with trend and intercept. Estimated p-values are extremely significant.

3.3. *Model specification test*

3.3.1. *Durbin Wu Hausman test (FE vs RE)*

The Hausman test was used to choose between fixed and random effects models. The outcome of this test is shown in the table below.

Prob>chi2 = 0.0000

Table 3: *Panel unit root tests*

		Without Trend		With Trend	
Variables		**Statistic**	**P-values**	**Statistic**	**P-values**
Yield (kg/ha)	LLC	-3.4765	0.0003***	-3.4884	0.0002***
	IPS	-4.4368	0.0000***	-5.1596	0.0000***
Area (ha)	LLC	-2.2174	0.0133***	-4.2094	0.0000***
	IPS	-1.3381	0.0904	-3.3055	0.0005***
LNTmax_S (ºC)	LLC	-6.3515	0.0000***	-5.6485	0.0000***
	IPS	-6.5976	0.0000***	-6.5932	0.0000***
LNTmax_V (ºC)	LLC	-3.2995	0.0005***	-3.1185	0.0009***
	IPS	-6.2707	0.0000***	-6.8737	0.0000***
LNTmax_M (ºC)	LLC	-2.9292	0.0017***	-2.5273	0.0057***
	IPS	-4.6180	0.0000***	-4.9888	0.0000***
LNTmax_S2 (ºC)	LLC	-6.4391	0.0000***	-6.4391	0.0000***
	IPS	-6.5702	0.0000***	-6.5709	0.0000***
LNTmax_V2 (ºC)	LLC	-3.3158	0.0000***	-3.1350	0.0009***
	IPS	-6.2780	0.0000***	-6.8801	0.0000***
LNTmax_M2 (ºC)	LLC	-2.9375	0.0017***	-2.5341	0.0056***
	IPS	-4.6173	0.0000***	-4.9876	0.0000***
LNRain_S (mm)	LLC	-5.1500	0.0000***	-3.8847	0.0001***
	IPS	-6.7194	0.0000***	-6.7728	0.0000***
LNRain_V (mm)	LLC	-3.7117	0.0001***	-3.6833	0.0001***
	IPS	-4.6492	0.0000***	-5.0655	0.0000***
LNRain_M (mm)	LLC	-3.6349	0.0001***	-3.3057	0.0005***
	IPS	-4.6835	0.0000***	-5.2976	0.0000***
LNRain_S2 (mm)	LLC	-5.1252	0.0000***	-3.8743	0.0001***
	IPS	-6.7331	0.0000***	-6.7906	0.0000***
LNRain_V2 (mm)	LLC	-3.7379	0.0001***	-3.7124	0.0001***
	IPS	-4.6520	0.0000***	-50681	0.0000***
LNRain_M2 (mm)	LLC	-3.5623	0.0002***	-3.2469	0.0006***
	IPS	-4.7020	0.0000***	-5.3317	0.0000***

Source: Valued from data, 1986-2018.

Note: level of significance, ***p<0.01, **p<0.05

Due to the high significance of the p-value, the best-fitting model is the fixed effects model, which was selected for further research.

Test for cross-sectional dependence

Pesaran's cross-sectional dependence test was used to determine whether data were cross-sectionally dependent. The following are the outcomes.

Pesaran's test of cross-sectional independence = -0.256, Prob = 0.7981

The average absolute value of the off-diagonal elements = 0.210

The test's non-significant value indicates no cross-sectional dependence in the data.

3.3.2. *Wald test for heteroskedasticity*

Using STATA 12, the Wald test for heteroskedasticity was performed, giving the following findings.

chi2 (4) = 41.82

Prob > chi2 = 0.0000

A very significant value indicates that the data set has heteroscedasticity issues.

3.3.3. *Serial correlation*

The autocorrelation of panel data was also examined using the Wooldridge autocorrelation test. The following are the outcomes.

Prob > F = 0.1524

This demonstrated that there is no autocorrelation in data.

Table 4: *FGLS estimates for panel data (1986-2018)*

Coefficients			Generalized least squares	
Panels			Heteroskedastic	
Correlation			No autocorrelation	
Estimated covariance's		04	No. of obs	132
Estimated autocorrelations		0	No. of groups	4
Estimated coefficients		15	Time period	33
			Wald chi2(14)	199.39
			Prob > chi2	0.0000
Variables	**Coefficients**	**Std. Err.**	**z-values**	**P>|z|**
LNAREA	.1566248	.0257844	6.07	0.000***
LNTmax_S	23.88759	7.271321	3.29	0.001***
LNTmax_V	- 56.28832	24.3481	-2.31	0.021**
LNTmax_M	- 57.00566	18.93379	-3.01	0.003***
(LNTmax_S)^2	- 3.373466	1.043716	-3.23	0.001***
(LNTmax_V)^2	7.862926	3.439045	2.29	0.022**
(LNTmax_M)^2	8.426952	2.764805	3.05	0.002***
LNRain_S	.1950235	.5702567	0.34	0.732^{ns}
LNRain_V	15.62666	3.94158	3.96	0.000***
LNRain_M	- .3036746	.3997954	-0.76	0.448^{ns}
(LNRain_S)^2	- .0170238	.070239	-0.24	0.808^{ns}
(LNRain_V)^2	- 1.554174	.4025644	-3.86	0.000***
(LNRain_M)^2	.0394931	.0530368	0.74	0.456^{ns}
Trend	.0089139	.0014007	6.36	0.000***
Constant	122.8388	40.9811	3.00	0.003***

Source: Projected from panel data, 1986-2018.

Note: level of significance, ***p<0.01, **p<0.05, ns shows non-significant

3.3.4. *FGLS estimates for panel data (1986-2018)*

The findings of the variables used in the study in the model are shown in Table 4. Results revealed that a 1% increase in the area has a positive impact on rice yield, increasing it by 0.15 percent; the result is in line with Hussain, A., & Bangash, R. (2017). Rice yield is affected by the average maximum temperature for sowing months and the average maximum temperature for sowing month square.

The co-efficient of LNTmax S is positive, whereas its square (LNTmax S2) is negative; the same results were also observed by Ahmed *et al*. 2016 & Cabas *et al*. (2010). This demonstrates that a rise in temperature causes an increase in rice yield at first. When the temperature exceeds the critical temperature, i.e., 34.48 °C. it shows a fall after reaching its maximum at the critical temperature.

Temperature maximum of vegetative months and maturity months P-values are significant and are in opposite directions as compared to the Temperature Maximum in Sowing months, as the LNTmax_V and LNTmax_M have a negative co-efficient and their Squares have positive co-efficient. This means that temperature in vegetative and maturity months hurts rice yield. Rainfall in Vegetative months P-value is highly significant and positively affects rice yield. The coefficient of LNRainfall_V is positive, and its square (LNRainfall_V2) is negative. The results are in line with Ahmed *et al*. 2016, Cabas *et al*. (2010), Chaudhary, *et al*. (2002), & Siddiqui *et al*. (2012).

This means that a rise in rainfall causes an increase in rice yield at first. When the rainfall exceeds the critical rainfall, i.e., 152.55 mm. It shows a fall after reaching its maximum at the critical rainfall.

3.4. Impact of temperature on rice yield

3.4.1. Rice yield in response to temperature in the sowing stage

Calculating the rice yield in sowing months using the formula (8).

Critical temperature = 34.48 ºC

According to the critical temperature, the rice yield reached a maximum temperature of 34.48 ºC during the sowing stages of the crop. Overall districts, the highest yield at critical temperature was assessed to be 2218.493 kg/ha. When the temperature exceeds this critical temperature, the yield begins falling. The graph below was made to demonstrate the relationship.

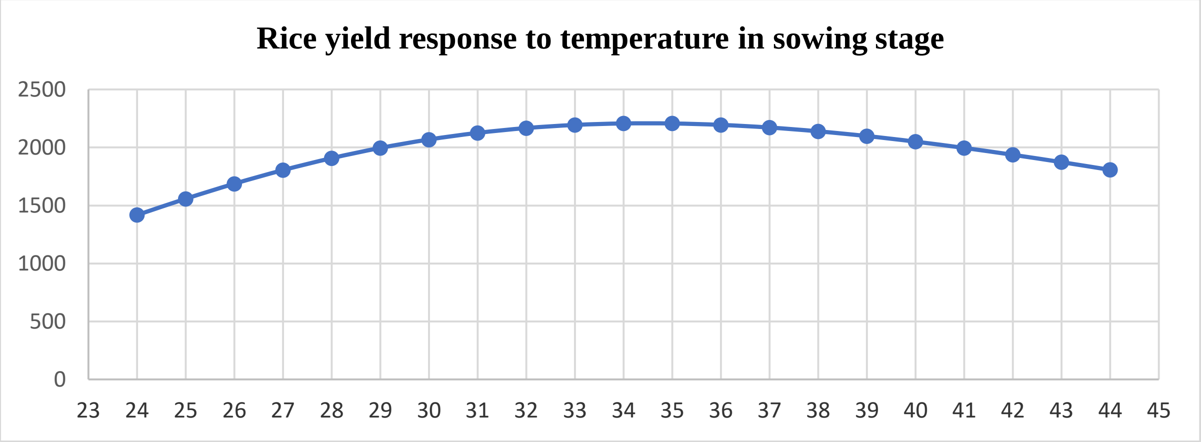

Fig. 2 Rice yield in response to temperature in sowing stage

Source: Authors estimates from FGLS estimates of panel data, 1986-2018.

3.4.2. Rice yield in response to temperature in vegetative stage

Calculating the rice yield in sowing months using the formula (3.9).

Critical temperature = 35.85 ºC

The critical temperature in the vegetative stage demonstrates that the rice yield would be minimal when the temperature reaches 35.85ºC during the vegetative months of the crop. However, the yield would increase when the value exceeds the critical temperature. The highest yield at critical temperature for all the districts is expected to be 2028.23 kg/ha.

3.4.3. Rice yield in response to temperature in the maturity stage

Formula (8) was used to calculate the critical temperature in the maturity stage.

Critical temperature = 29.43 ºC

The rice yield would be highest when the temperature reaches 29.43°C during the crop's maturity stage. It is projected that the maximum yield at critical temperature is 1990 kg/ha. The yield will begin to fall when the temperature rises above the critical temperature.

3.4.4. Rice yield in response to rainfall in the vegetative stage

Formula (8) was used to calculate the critical rainfall in the vegetative stage for rice yield.

Critical rainfall = 152.52 mm

According to the critical rainfall, the rice yield would be the highest when rainfall

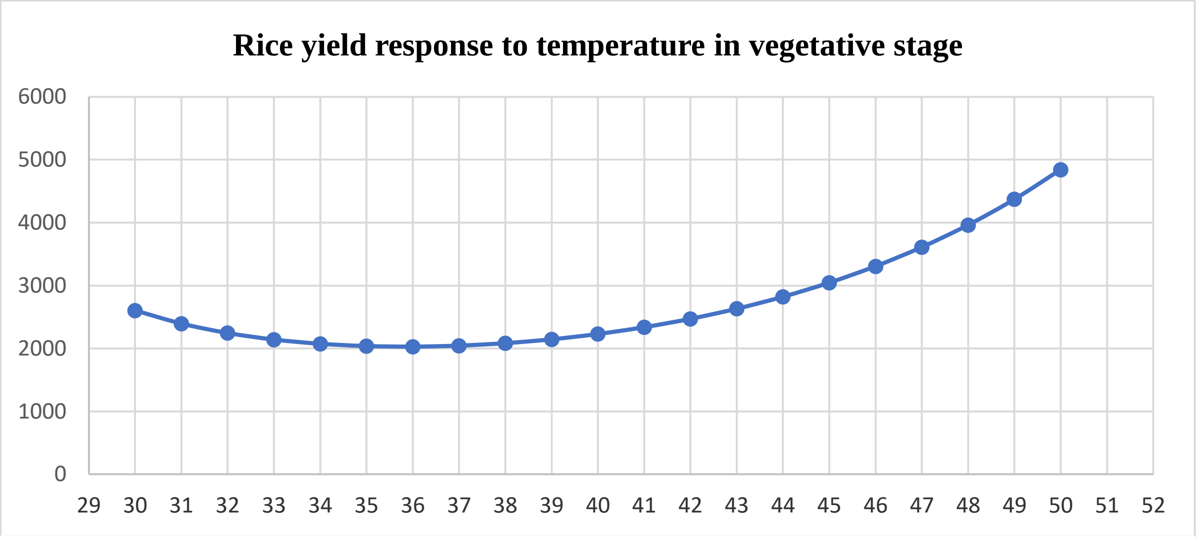

Fig. 3 Rice yield in response to temperature in vegetative stage
Source: Authors estimates from FGLS estimates of panel data, 1986-2018.

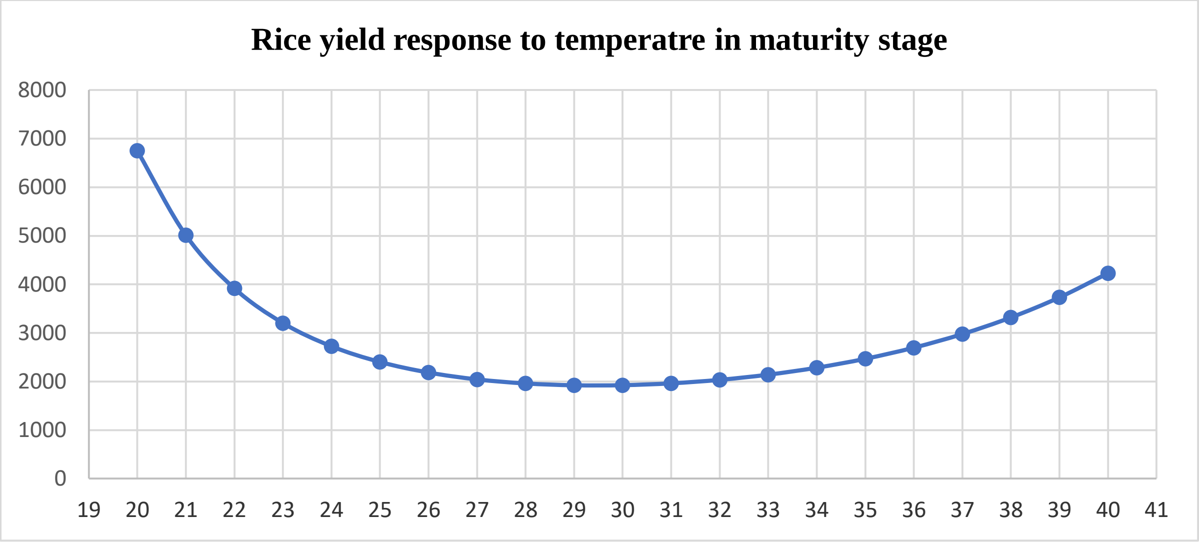

Fig. 4 Rice yield in response to temperature in the maturity stage
Source: Authors estimates from FGLS estimates of panel data, 1986-2018.

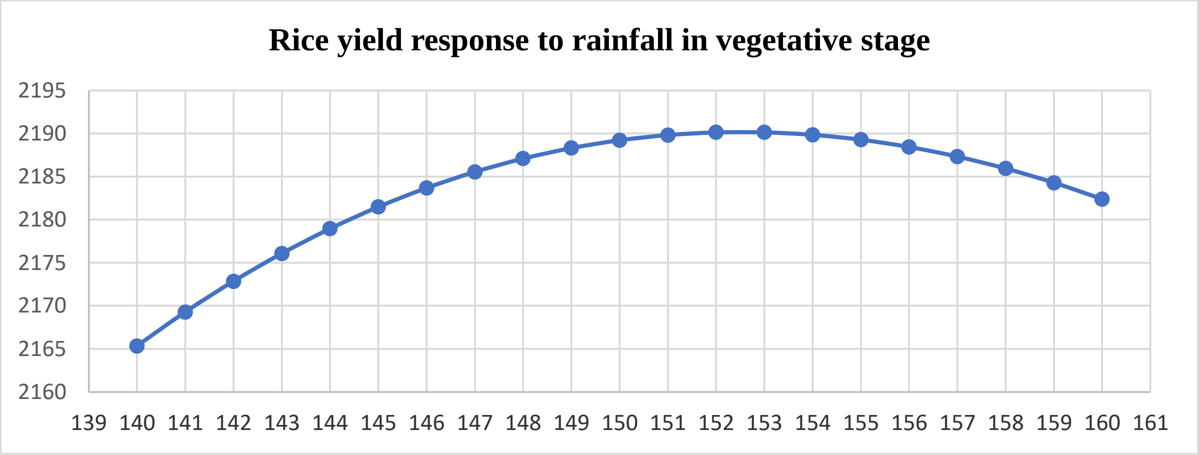

Fig. 5 Rice yield in response to rainfall in the vegetative stage
Source: Authors estimates from FGLS estimates of panel data, 1986-2018.

hits 152.52 mm during the vegetative stage of the crop. The maximum yield at critical rainfall is expected to be 2190 kg/ha. When the rainfall exceeds critical rainfall, the yield begins to decline.

4. Conclusions and Recommendations

The FGLS estimation technique was used to estimate the impact of climate change on rice productivity among the selected districts of Khybar Pakhtunkhwa. Panel data from 1986-2018 was used, including variables, i.e., area, the average maximum temperature in sowing, vegetative and harvesting stages, average maximum temperature square in sowing, vegetative, and harvesting stages, average rainfall, and rainfall square in sowing, vegetative, and harvesting stages.

Results revealed that area and maximum temperature in the sowing stage positively affect rice yield. Temperature square in the sowing stage was detected as negatively affecting the rice yield. Maximum Temperature in vegetative and maturity stages and its square also has a negative impact. While rainfall in vegetative stages has a positive impact on the yield of rice in nominated districts. The critical temperature for the maximum yield of rice was calculated to be 34.48 ºC in the sowing stages, 35.85 ºC in the vegetative stages, and 29.43 ºC in the maturity stages, and Rainfall in the vegetative stages was 152 mm. It was projected that yield in the study districts showed a decline when temperature and rainfall rose above critical levels.

Policymakers need to encourage rice cultivators in Mansehra to allot more cultivated land for rice cultivation, as the district's uppermost temperature in the sowing month is 33.80 ºC, which is below the critical temperature (34.48 ºC), implying that rice yield will rise as the temperature rises. The highest maximum temperature in the districts of D.I. Khan and Mardan is 41.20 ºC and 38.32 ºC, respectively, considerably over the average critical temperature. As a result, the government needs to use afforestation and other appropriate measures to keep the temperature from rising. The extension department needs to inform rice growers about adaptation strategies regarding climate change and its effects on rice yield.

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5.2. *Competing Interests*

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5.3. *Author Contributions*

Data collection and first draft of the manuscript was written by Hikmatyar Khan. Main idea of this study and data analysis was performed by Shahid Ali. Manuscript final review and editing was performed by Farhana Gul.

5.4. *Ethical Approval*

N/A

5.5. *Consent to Participate*

All authors are willing to participate

Consent to Publish

All authors are willing to publish their article in your journal.

5.6. *Availability of data and materials*

Data and materials are available and will be provided upon request.

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