CHALLANGES AND PROSPECTS FOR TOMATO PRODUCTIVITY IN RESPONSE TO CLIMATIC VARIATIONS: EVIDNECES FROM KHYBER PAKHTUNKHWA-PAKISTAN

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ABSTRACT

Climate change is the momentous and persisting change in the world's temperature, precipitation, humidity, and other climatic variables. This study, therefore estimated the impact of climatic variations on tomato productivity across agro ecological zones of Khyber Pakhtunkhwa, Pakistan. Panel data for 28 years (1991-2018) across the six districts of the agro ecological was used due to availability of data on tomato productivity and climatic variables. Yield of tomato, area, maximum temperature and rainfall were included in the final estimated model. The results indicate that the average maximum temperature and average maximum temperature square have a significant impact on tomato yield. Average maximum temperature has positive coefficient while the average maximum temperature square has a negative coefficient. This demonstrates that, at first, the tomato yield increases as the temperature rises. It reaches the maximum at the critical temperature (34.95ºC) but shows a decline once the temperature rises from the critical value.

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Introduction

Climate change is a serious global issue faced by the mankind (Auffhammer, 2018). It is the momentous and persisting change in the world's temperature, precipitation, humidity, and other climatic variables (Birtahl et al 2021). Studies have identified several human activities, industrial waste, vehicles' emissions, and overall global pollution, among others, as driving forces behind global climate change (Lough, 2008). The world's economy depends on three major sectors; agricultural, industrial, and services. Out of these three sectors, agriculture is the most vulnerable to climate change (Parry, 2019) because of its strong dependence on weather patterns. Climatic variations in the globe have a significant impact on this sector of the world economy. Crop yields, net farm revenue, and agricultural land productivity have all been found to be declining in various parts of the world. Global institutions on climate change aim at conducting research on climate change and ensuring a sustainable global environment. The IPCC being a responsible institution for climate change has forecasted that the global temperature will rise to 3°C by the beginning of the next century (IPCC, 2007). According to reports from the IPCC climate change has caused damage on a global scale. It is responsible for an increase in cyclone activity, an increase in areas facing drought, and an increase in heat waves (Bouwer, 2011). From 2007-2016, global agricultural activities have polluted the earth by emitting 13% of CO2 and more than 80% of nitrous oxide. These emissions rise to about 37% if the emissions from pre- and post-production activities are added to them (IPCC, 2019).

Pakistan ranked the 5th most sensitive country to global climatic variation (Abubakar, 2020). Reasons behind this include lack of policies, less awareness, and increased population (Fahad et al., 2020). Climate change is observed impacting agriculture as temperature and precipitation are inputs for agricultural production (Feres, Reis, and Speranza, 2008) It is more serious issue for farmers of developing countries (Seo et al., 2009). Being an agricultural country climate change impact on the agriculture of Pakistan is a serious challenge for its people and economy. Climate variability has affected the production of major crops in Pakistan. During 2018-19, crops in Pakistan showed a decline in growth by 4.43%. Production of sugarcane, the major cash crop of Pakistan showed a decline of 19.4%. Whereas, production of cotton and rice showed a decline of 17.5% and 3.3%, respectively [Government of Pakistan (GOP), 2019]. This shows that climate change harms the productivity of major crops in Pakistan. The impact of climate change can be reduced by using adaption and mitigation strategies (Chen and Gong, 2021).

Tomato (Solanum Lycopersicum) is one of the climate-sensitive vegetables consumed by people all around the world. The study of the climatic variations' impact on tomato productivity in Pakistan shows that climate change has a significant role in declining the yield and production of this vegetable. Due to this, tomato growing farmers in Pakistan usually prefer subsistence farming. The use of pesticides for growing this crop contributes to a significant share in the emission of gases. These gases boost climate change (Ozkan et al. 2011). The yield of tomatoes in the world was recorded at 38,272.40 kg/ha in 2018. According to Food and Agriculture Organization USA is the top yielder with estimated yield of 96,807.90 kgha-1, while in Pakistan the yield is 9,441.2 kgha-1 which shows that Pakistan has still the potential to increase its tomato yield per hectare. This higher difference in the yield is because of several factors like choice of farmers for crop and acreage allocation, output prices, rain fall, soil type and temperature (Birthal et al., 2021)

The rise in temperature due to climate change decreases the production of vegetables (Hipro and Gebeyehu, 2019). Changes in climate scenarios also have economic consequences for consumers, such as an increase in commodity prices and a decrease in the utility of consuming commodities. The price rise is strongly felt in the case of vegetables and fruits due to their strong dependence on climatic conditions. Among many other reason climate change is considered as the major one that affect the quality of tomato. The other effects of climate change on tomatoes are; tip burn and reduced fruit set. Since 2010, the yield of tomatoes in Pakistan has been declining. In 2010, a 9% decline in the yield of tomatoes was recorded. In the preceding years, yield kept on showing a decline and failed to recover (GOP, 2018). The above-mentioned decline in tomato yield could be due to many possible reasons but this research attempts to determine the role of climate change in this regard. The decrease in yield is causing an imbalance in the supply and demand of tomatoes in Pakistan. For food security purposes, there is a need to implement effective policies to maintain the yield of tomatoes in the country (Ahmad and Farooq, 2010). The equilibrium in the tomato market would ensure future food security and would bring a fall in the import of tomatoes. This study aims to examine the impact of climate variations on tomato productivity across agro-ecological zones of Khyber Pakhtunkhwa province of Pakistan.

Materials and Methods

Universe of the Study and Data

The universe of the study of this research was Khyber Pakhtunkhwa (KPK), Pakistan. KPK is the third largest province in the country in terms of population. Most of the people living in KPK are associated with agriculture for earning their livelihood. The province has an influential geographical position that makes it a hub of trade and agriculture. It has Gilgit-Baltistan in its north, Afghanistan in the west, Kashmir in the east, and Punjab in the south. KP is well-known for the production of many agricultural commodities because of different climatic conditions across the province from northern to southern areas. The province is divided into 4 agro-ecological zones by the Environmental Protection Agency of this province [Environmental Protection Agency (EPA), 2016]. These zones are; Northern (A), Eastern (B), Central (C), and Southern (D). Districts from zone A, C, and D are selected based on tomato productivity and availability of data. Panel data for 28 years (1991-2018) was used for the study. Data on climatic variables; average maximum temperature, average maximum temperature square, average rainfall and average rainfall square was gathered from the Regional Meteorological Department (RMD) Peshawar. The data on production, area, and yield of tomatoes in selected districts was taken from Crop Reporting Services (CRS) government of Khyber Pakhtunkhwa Pakistan.

Conceptual framework

Several research studies have analyzed the relationship of climate change with crop choices, acreage response and its influence on crop comparative advantage (Wang et al., 2010; caho and McCarl, 2017; Birthal et al., 2021). To analyze the impact of climate change on the productivity of any cereal crop, fruit, or vegetable, a researcher can use cross-sectional, time series, or panel data as evident from the literature. The selection of the type of data depends on the objectives of the research (Guiteras, 2009). In the current research panel data was used to determine the impact of climate variability on tomato productivity. The general model for panel data can be presented as;

$$Y_{it} = \alpha + \beta_{xit} + \varepsilon_{it} \qquad (1)$$

Where in the model Y is the dependent model, X represents the various variables, i and t represent cross section and time whereas α,β and β are used for intercept, coefficient and error term respectively. Much of the confusion about method of analyzing panel data arises due to the fact that different discipline tend to produce solutions according to their unique features. This resulted in an astonishing series of notational orthodox, terminological variant and various software used. Depending on the researcher's background various models are used for the analyses of Panel data. In literature the most widely used model for the panel data are Fixed effect model and Random effect model (Niekerk et al., 2022). A detailed discussion of the advantages of the both model can be found in (Gujarati, D.N., and D.C. Porter. 2009). Fixed-effects model is also called an unobserved effect model. It can be presented as;

$$yit = (\alpha + \mu i) + \beta Xit + Vit \qquad (2)$$

(α+ μi) in the model shows that the intercept is time-invariant. It means that μi will only change for its district. The purpose of introducing intercepts in this model is to control the time-invariant features (Torres-Reyna, 2007). There are some limitations while using the fixed-effect model. These are; the intercepts created for every section that would require a degree of freedom and creating dummies increases the possibility of strong multicollinearity (Gujarati and Porter, 2009). However, the random effect model doesn't introduce fixed constants for units or sections and considers random parameters as intercepts of sections. The Random-effects model forms with the assumption of non-correlation of error term with independent variables (Wooldridge, 2013). One simple way of understanding the random-effects model is to consider it as a regression model with a random intercept or constant (Elhorst, 2014). The generalized form of random effects model can be written as;

$$yit = \alpha + \beta Xit + (\mu i + Vit) \qquad (3)$$

In this general form of the model, the μi is time-variant. It means that there will be no separate intercepts for districts (Bell, and Jones, 2015). In this paper based on the result of the Durbin Wu Hauman test we will decide to use the fixed effect or the random effect model (Gujarati and Porter, 2009).

Empirical Model

Several studies have examined the effect of climate change on agriculture. In order to find out the impact of climatic variations on tomato productivity across agro ecological zones econometric analysis was performed following the existing literature (Bouwer, L.M. 2011; Cho and McCarl, 2017; Auffhammer, M., 2018; Hipro and Gebeyehu. 2019; Chen, and Gong. 2021). Kuamr and singh (2014) estimated that due to rise in temperature of about 2.3 0C to 4.5 0C in 2070 to 2099 the food crop grown will be declined by 4 percent to 12 in South Asia and Sub-Saharan Africa. The impact of climatic and non-climatic on agriculture production have been assessed by many empirical studies in the world (Afrin et al., 2017; Chandio et al., 2020; Chao et al., 2014; Omoregie et al., 2018; Van et al., 2018 and Agbodi et al., 2019). Sarkal et al., (2014) conducted a study in Bangladesh and revealed that maximum and minimum temperature affects the productivity of agriculture crops. Chandio et al., (2021) also pointed out that along with temperature, rainfall, flood, solar radiation and drought have an adverse effect on the agricultural productivity. Variation in precipitation and temperature adversely affect resources of water and land, which heavily affect the agriculture productivity negatively (Mahmood et al., 20122). Ahmad et al., (2020), ahsan et al (2020). and Pickson et al., (2020) proposed in their study that rainfall and temperature are suitable proxies for climate change. Due to the availability of the data on rain fall and temperature the proposed model for estimation is provided as:

$$Lny = \beta 0 + \beta 1\, lnarea + \beta 2\, lnmaxtemp + \beta 3\, lnmaxtemp2 + \beta 4\, lnrainfall + \beta 5\, lnrainfall2 + Uit \quad 4)$$

Where lny is the dependent variable which show tomato yield in kgha-1, lnarea is the area under tomato production in ha, B's are the expected coefficients that need to be estimated, Maxtemp and Maxtemp2 represents the average maximum and average maximum temperature square, Rainfall and Rainfall2 shows the average rainfall and rainfall square, ln is the natural log, U is the error term while I and t represents the cross section and time period for the study.

Model Diagnostics

Several test are used to test which model fits the data well. In the case of the fixed effects model, there is a need for several model diagnostic tests as there are chances of several issues like; the problem of cross-sectional dependence, heteroscedasticity, and time effect autocorrelation (Bakirtas and Akpolat, 2018) in the fixed-effects model. To check these issues, different tests were employed. Pesaran test was employed to test the first issue. This test was conducted using different statistical software (De Hoyos and Sarafidis, 2006). If the p-value of the test is significant there exists a problem of cross-sectional dependence. The second problem in the fixed-effects model could be heteroskedasticity. This problem was identified by the Wald test of group-wise heteroskedasticity. The significant p-value in results shows that group-wise heteroskedasticity exists. The third possible issue in the fixed-effects model is of time effect autocorrelation. This was checked by employing a test called Wooldridge test of serial autocorrelation. The significant p-value shows the presence of first-order serial correlation in panel data (Drukker, 2003).

With the development in panel data analysis has pointed out the need for cointegration and stationarity tests in panel data. The stationarity tests of panel data are more advanced than the tests of time series (Bouwer, 2011). The reason is the heterogeneity factor in panel data. Some of the simple panel unit-root tests are given. The Im, Pesaran, and Shin (IPS) and Breitung tests are two common methods for determining panel data stationarity. Due to the problems of cross-sectional dependence, heteroskedasticity, and serial correlation in the data set, the panel corrected standard errors (PCSEs) model was used to analyze final results. This is an advanced form of fixed effects model and estimates results considering the above-mentioned issues in the data.

Results and Discussion

In this chapter summary statistics of variables used in the model, results of the analysis derived through utilizing the panel corrected standard errors model (PCSE), and critical temperature and its impact on tomato yield are presented.

Impact of Climatic Variations on Tomato Productivity

Summary Statistics of Variables

The summary statistics of the variables used in the model is provided in table 1. The total observations are 168 i.e., N=6, T=28 and N*T=168. The mean log of yield was 9.00 kg/ha with a standard deviation of 0.55. The Second variable log of area was in the range of 3.40-8.53 ha with a mean of 5.68 and a standard deviation of 1.42.

Table 1. Summary statistics of variables

Variables	Obs	Mean	Std. Dev.	Min	Max
lny (Yit)	168	9.00 (9207.70)	0.55 (3645.74)	6.00 (3272.73)	9.59 (14620.69)
lnarea (Areait)	168	5.68 (863.56)	1.42 (1452.74)	3.40 (30.00)	8.53 (5051.00)
lnmaxtemp (Maxtemp)	168	3.55 (34.81)	0.07 (2.21)	3.35 (28.58)	3.66 (38.93)
lnmaxtemp^2 (Maxtemp2)	168	12.59 (1216.56)	0.46 (150.10)	11.24 (816.82)	13.41 (1515.16)
lnrainfall (Avrainfall)	168	3.90 (59.60)	0.63 (35.32)	2.26 (9.63)	5.29 (198.30)
lnrainfall2 (Avrainfall2)	168	15.64 (4792.17)	4.84 (5827.25)	5.13 (92.74)	27.98 (39322.89)

Source: Estimated from data, 1991-2018.

The mean of lnmaxtemp was observed to be 3.55 with a standard deviation of 0.07. Log of maxtemp^2 is the fourth variable of the model. Its mean was observed to be

12.59 i.e., in the range of 11.24-13.41 and its standard deviation was 0.46. lnrainfall is the model's fifth variable. Its mean is 3.90 with a standard deviation of 0.63. The range of mean is 2.26-5.29. The Log of rainfall square is the last variable of the model. It has a mean of 15.64 with a standard deviation of 4.84.

Panel Unit Root Tests

Panel unit root tests were performed to ensure data stationarity. Stationarity was checked for all the six variables used in the model. IPS and Breitung panel unit root tests were utilized for this purpose. Stationarity in yield was tested using IPS and Breitung test. The results showed that the yield was non-stationary when tested with trend. While it became stationary when intercept was added to the trend. It means that the significant p-values were obtained when tests included intercept of the yield along with its trend.

Table 2. Panel Unit Root Tests

Level					
		With Trend		**With Trend and Intercept**	
Variables		**Statistic**	**P-values**	**Statistic**	**P-values**
Yield (kg/ha)	IPS	-1.4405	0.0749	-3.2036	0.0007***
	Breitung	-0.5880	0.2783	-1.9513	0.0255**
Area (ha)	IPS	-0.8434	0.1995	-2.7580	0.0029***
	Breitung	0.5392	0.7051	-1.9025	0.0286**
Average Max. Temperature (ºC)	IPS	-6.0091	0.0000***	-6.4910	0.0000***
	Breitung	-5.1154	0.0000***	-6.3217	0.0000***
Average Max. Temperature Square (ºC)	IPS	-6.0059	0.0000***	-6.4878	0.0000***
	Breitung	-5.1156	0.0000***	-6.3115	0.0000***
Rainfall (mm)	IPS	-6.7616	0.0000***	-6.8424	0.0000***
	Breitung	-6.2615	0.0000***	-6.3718	0.0000***
Rainfall Square(mm)	IPS	-6.8782	0.0000***	-6.9517	0.0000***
	Breitung	-6.2545	0.0000***	-6.3597	0.0000***

Source: Estimated from data, 1991-2018.

Note: level of significance, ***p<0.01(1%), **p<0.05(5%)

For checking stationarity in the area i.e., the second variable of the model, both IPS and Breitung test were utilized. The result of both tests showed that the area is non-stationary when tested with trend only. However, adding intercept with trend made the variable stationary. The p-value of IPS for trend and intercept is highly significant and shows that the variable is stationary. Average maximum temperature is the third variable of the model. Both of the tests of panel unit root show that this variable is stationary with trend and with trend and intercept. P-values obtained are highly significant in the case of this variable. The same is the case with the fourth variable of the model, i.e., maximum temperature square. Both the IPS and Breitung tests show that rainfall is stationary. The p-values obtained for trend and trend and intercept are highly significant i.e. 0.0000. The values obtained for rainfall square are also significant and show that the variable is stationary.

Test for Cross-Sectional Dependence and Serial Correlation

The cross-sectional dependence of data was checked using Pesaran's test of cross-sectional dependence having value of 4.000 with Pr value of 0.0001 indicating the existence of cross sectional dependence in the data. To check the heteroscedasticity problem Wald test was also employed and the results obtained show that [chi^2 (6) = 3174.45] with P value of 0.000 showing highly significance and the presence of heteroscedasticity problem in the data. Panel data autocorrelation was also tested using the Wooldridge test for autocorrelation. A highly significant p-value (Prob>F = 0.000) was obtained and it was observed that autocorrelation exists in data.

Estimates of PCSE Model for Panel Data (1991-2018)

In order to decide which model will be suitable for our data set, we used the Hausman test to decide between fixed effects model and random effects model. The result obtained from this test shows (Prob>chi2 = 0.0000) highly significant p-value and that the best fitted model is fixed effects model. For this study Panel corrected standard errors (PCSEs) model was used to analyze final results. This is an advanced form of fixed effects model and estimates results considering the issues in the data. Table 3 shows results for variables used in the model. Area is the first variable used in the study. Results reveal that a 1% increase in area will have a positive impact on productivity as it will rise by 0.12%. The second variable used in the model was average maximum temperature. The significant p value shows that the average maximum temperature has a significant impact on the productivity of tomato. The Positive coefficient shows that this impact is positive i.e., an increase in temperature will the result in increase in tomato productivity.

By looking at the position of temperature in the table, it can be interpreted that the average maximum temperature and average maximum temperature square are significantly affecting the tomato yield. The average maximum temperature has positive coefficient while the average maximum temperature square has a negative coefficient. This implies that the tomato yield initially increases as the temperature rises. It reaches the maximum at the critical temperature but shows a decline once the temperature rises from the critical level. Peña and Hughes (2007) Lipper *et al.* (2009), Shakoor *et al.* (2011), Loum and Fogarassy (2015), and Ghalib *et al.* (2017) and Hamdullah *et al.* (2020) find out similar finding in their studies. The average rainfall and average rainfall square have an insignificant impact on the productivity of tomatoes in districts studied for this research. Our results are in line with results estimated by Islam *et al*. (2009), GCISC (2009), and Khan *et al*. (2018). The reason behind the insignificant impact of rainfall on tomato productivity is the fluctuation observed in the rainfall pattern due to climate change.

Table 3. Estimates of PCSE model for panel data (1991-2018)

Group variable		Districts	Number of obs	168
Time variable:		Years	Number of groups	6
Panels		correlated (balanced)	Obs per group: min	28
Autocorrelation		panel-specific AR(1)	Avg	28
			Max	28
Estimated covariances		21	R-squared	0.9754
Estimated autocorrelations		6	Wald chi2(5)	64.67
Estimated coefficients		6	Prob > chi2	0
Panel-corrected				
lny	**Coef.**	**Std. Err.**	**Z**	**P>|z|**
lnarea	0.1195406	0.0297735	4.02	0.000***
lnmaxtemp	129.4095	55.68353	2.32	0.020**
lnmaxtemp2	-18.20628	7.785943	-2.34	0.019**
lnrainfall	-0.1110128	0.3007725	-0.37	$0.712^{n.s}$
lnrainfall2	0.0229631	0.0436393	0.53	$0.599^{n.s}$
_cons	-221.5111	99.47644	-2.23	0.026
rhos=	0.5237469	0.4038742	0.9387789	0.8580381

Source: Estimated from panel data, 1991-2018.

Note: level of significance, ***p<0.01(1%), **p<0.05(5%), ns shows non-significant

Variation in Yield in Response to Change in Temperature

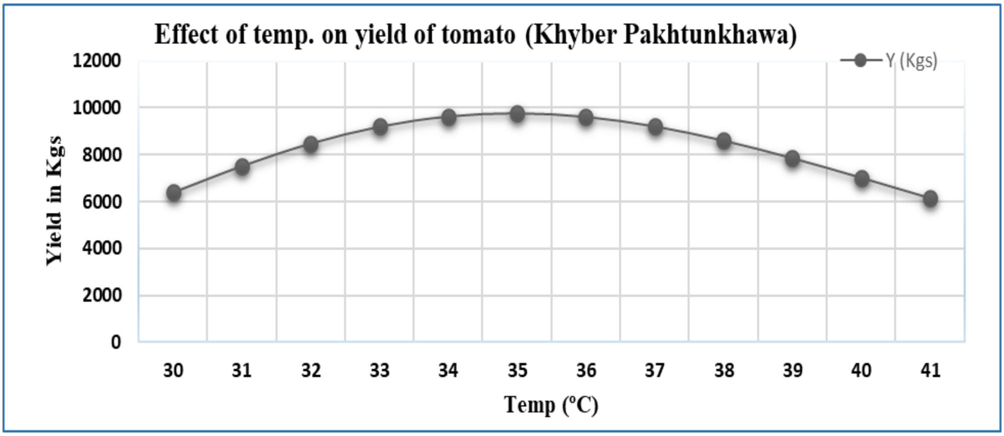
The critical temperature for tomato productivity was also calculated from the values given in table 3 by using the following formula.

Critical temperature = exp (β_1/2* β_2) (5)

= exp((-129.4095)/(2*(-18.20628))) = 34.95 ºC

The critical temperature for the province indicates that tomato yield will be highest in districts where the temperature reaches 34.95ºC during the vegetable's kharif cropping season. The maximum yield at critical temperature for the province is estimated to be 9763.050kh/ha. However, the yield will start declining when the temperature increases this critical value. A graph provided below was constructed to illustrate this relationship. Based on this graph and estimated critical temperature for the province, the critical temperature for every district used in the study was also estimated.

Figure 1. Variation in yield in response to change in Temperature.



Source: Authors' estimated from PCSE model for panel data, 1991-2018.

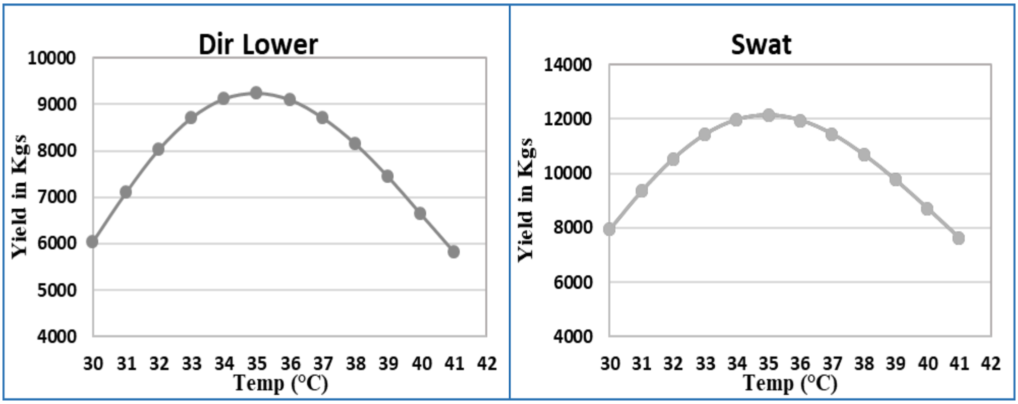
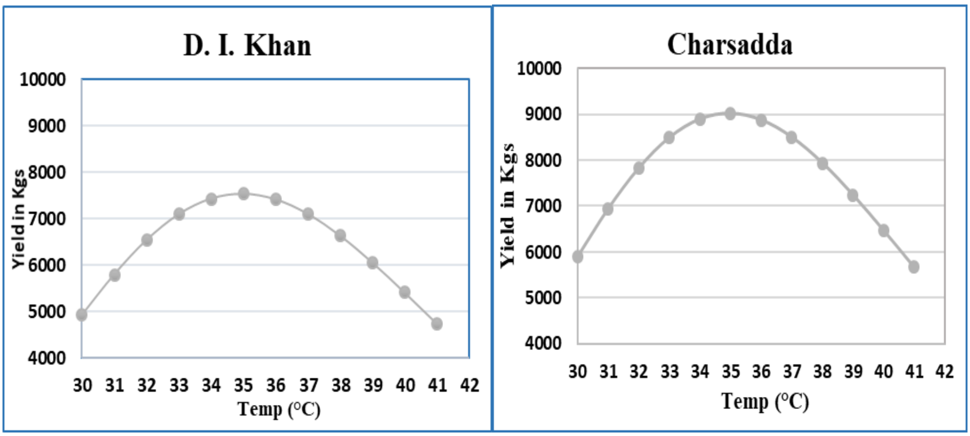
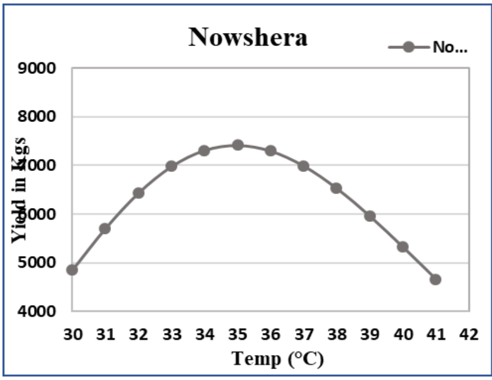
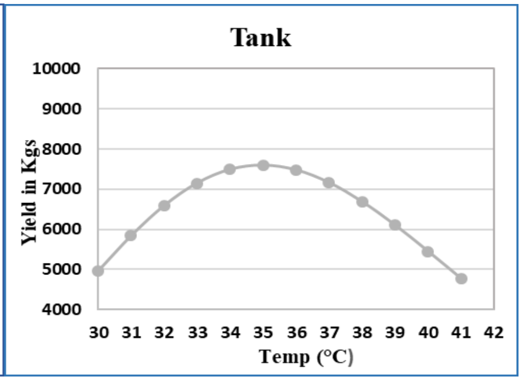


Figure 2. Variation in yield in response to change in temperature for districts





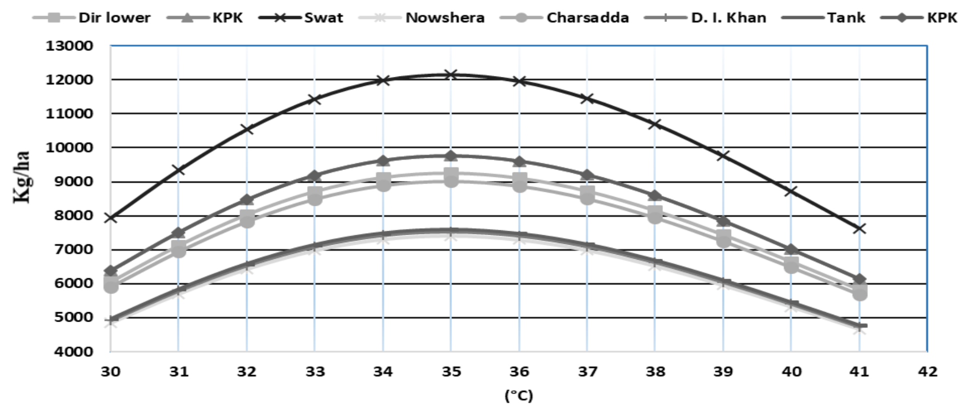


Source: Authors' estimated from PCSE model for panel data, 1991-2018.

Variation in Yield in Response to Change in Temperature for Districts

Figure 2 represents maximum yield points for their respective districts. The maximum yield at critical temperature (34.95 º C) in Dir Lower will be 9245.93 kg/ha. The yield is estimated to decline to 9100.52 kg/ha with a rise in temperature to 36 ºC. For Swat, the maximum yield at critical temperature is estimated to be 12143.47 kg/ha. The graph shows that this yield will decline to 11952.49 kg/ha with rise in temperature to 36 ºC. The maximum yield for Nowshera at 34.95 ºC is estimated to be 7416.12 kg/ha. This yield will decline to 7299.49 kg/ha with a 1ºC rise in temperature. In Charsadda, the maximum yield is estimated to be 8871.42 kg/ha. A decline to 8871.42 kg/ha is estimated with 1ºC rise in temperature. In D.I. Khan this yield is estimated to be 7530.69 kg/ha at critical temperature. It is expected to decline by 118.43 kg/ha with a 1ºC rise in temperature. While in the Tank the maximum yield is expected to be 7590.62 kg/ha. With a 1ºC rise in temperature this yield will decline by 119.37 kg/ha. All the graphs show that the yield for respective districts is highest at critical temperature and starts to decline with rise in the temperature.

Figure 3. Zone-wise variation in yield in response to Temperature



Source: Authors' estimate from PCSE model for panel data, 1991-2018.

Forecasting the Impact of Rising Temperature on Yield of Tomato According to Different Climate Change Scenarios

To study the climate trend in the country, the meteorological department of Pakistan and the Global Change Impact Studies Centre (GCISC) have carried out several studies (Islam *et al.* 2009). Tables 4 and 5 present a future scenario for temperature rise in relation to tomato impact based on their research. Table 5 shows the response of yield to rise in temperature more than 34.95 ºC i.e., critical temperature. The table shows that one degree rise in temperature will lower the yield of selected districts by 1.57%. This means that tomato growers across zones will suffer losses in terms of yield. The table also explains the impact of a 2 ºC rise in temperature on yield. It is estimated that this rise in temperature will lower tomato yield in selected districts by 5.73%. This reveals that climate change in the long-run is significantly harmful to tomato yield across agro-ecological zones of Khyber Pakhtunkhwa.

Table 4. Forecasting the impacts of temperature rise on tomato yield in Khyber Pakhtunkhwa according to different climate change scenarios

Climate change scenarios	Yield (Kg/ha)	Yield (%age)
Temperature increase by 1 °C	-153.54	-1.6%
Temperature increase by 2 °C	-559.26	-5.7%

Source: Authors' estimate from PCSE model for panel data, 1991-2018.

Table 5. Zone wise forecasting the impact of rising temperature on yield of tomato according to different climate change scenarios

Districts	Temperature	Yield (Kg/ha)	Yield (%age)
Dir Lower	1 °C	-145.41	-1.57%
	2 °C	-529.64	-5.73%
Swat	1 °C	-190.98	-1.57%
	2 °C	-695.62	-5.73%
Nowshera	1 °C	-224.49	-1.57%
	2 °C	-817.35	-5.73%
Charsadda	1 °C	-141.75	-1.57%
	2 °C	-516.31	-5.73%
D I khan	1 °C	-118.44	-1.57%
	2 °C	-431.39	-5.73%
Tank	1 °C	-119.38	-1.57%
	2 °C	-434.82	-5.73%

Source: Authors' estimate from PCSE model for panel data, 1991-2018.

Lowest and highest maximum temperature for districts

Table 6 shows the lowest maximum and highest maximum temperature for districts used in the study. The highest maximum temperature in Dir Lower shows that tomato yield in the district will increase with the rise in temperature as the district's temperature hasn't crossed the critical temperature value i.e. 34.95ºC. However, temperature rise in the second district of this zone i.e. Swat will cause a decline in tomato yield as the district's highest maximum temperature has already crossed the critical value of 34.95 ºC. Nowshera and Charsadda, are already experiencing losses in the yield due to the highest maximum temperature of 38 .93 ºC. Also, districts taken from zone D have the highest maximum temperature more than the critical value calculated in the study. This means that in these four districts the tomato yield is declining.

Table 6. Lowest and highest maximum temperature for districts

Districts	Lowest maximum temperature	Highest maximum temperature
Dir Lower	28.58 °C	32.08 °C
Swat	31.86 °C	35.42 °C
Nowshera	34.6 °C	38.93 °C
Charsadda	34.6 °C	38.93 °C
D I Khan	34.08 °C	38 °C
Tank	34.08 °C	38 °C

Source: Authors' estimate for panel data, 1991-2018.

Conclusions and Recommendations

This study is aimed at estimating the impact of climate change on tomato productivity across agro ecological zones of Khyber Pakhtunkhwa (KP), Pakistan. Three agro ecological zones of KP i.e. A, C, and D were selected for this study. Districts from each zone are taken based on tomato productivity and data availability. The total districts are six i.e. Dir Lower and Swat from zone A, Nowshera and Charsadda from zone C, and D.I. Khan and Tank from zone D. Panel data was used for studying the impact and following variables. Secondary data for both climatic and non-climatic variables were used. Data on climatic variables was collected from the Regional Meteorological Department (RMD) Peshawar. While data on non-climatic variables was gathered from Crop Reporting Services (CRS). Fixed effects model was selected based on the results of the Hausman test. The Data set was also tested for contemporaneous correlation, heteroskedasticity, serial correlation, and stationarity. Results revealed that cross-sectional dependence, Heteroskedasticity, and serial correlation exist in data. Final results were estimated using panel corrected standard errors (PCSEs). The average maximum temperature and average maximum temperature square have a significant impact on tomato yield. The average maximum temperature has a positive coefficient while the average maximum temperature square has a negative coefficient. This implies that the tomato yield initially increases as the temperature rises. It reaches the maximum at the critical temperature but shows a decline once the temperature rises from the critical level. The average rainfall and average rainfall square have insignificant impact on the productivity of tomato in districts studied for this research. These results are in line with results estimated by Islam *et al*. (2009), GCISC (2009), and Khan *et al*. (2018). The reason behind the insignificant impact of rainfall on tomatoes productivity is the fluctuation observed in the rainfall pattern due to climate change.

The Critical temperature for the maximum yield of tomato was calculated to be 34.95ºC. It was estimated that the yield in all districts of the study showed a decline with a rise in temperature above critical temperature. Based on the results of this study, it is recommended that policymakers should encourage tomato growers in Dir Lower and Swat so that yields in these districts can be increased. To reduce temperature rises, the government must concentrate and accelerate tree planting in districts such as Charsadda, Nowshera, D.I. Khan, and Tank. Also, heat resistant varieties of tomato should be developed for farmers of Nowshera, Charsadda, D.I. Khan and Tank to cope with the increase in temperature. Extension officers have to provide required guidance to farmers producing tomatoes in selected districts regarding climate change and its impacts.

Limitations of the Study

The study has several limitations. District Mansehra is top produced tomatoes from zone B, but this district was omitted due to statistical discrepancies in data on area under tomato and tomato production. Therefore, it can be said that the study doesn't cover all four agro-ecological zones of the province. Individual dummies for districts were not created because of the high variation in the data. The model used for the study used four basic climatic variables i.e., maximum temperature, maximum temperature square, rainfall, and rainfall square. Other important climatic variables could also be used for study. These include; minimum temperature, humidity, and sunshine.

Conflict of interests

The authors declare no conflict of interest.

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