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EVALUATING IMPACTS OF CLIMATE CHANGE ON MAIZE PRODUCTION IN PAKISTAN: USING AN ARDL APPROACH

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Abstract
Climate change is a global concern, and its effects are mostly faced by developing countries like Pakistan, particularly affecting agriculture, the most vulnerable sector directly linked to the climatic variations. It plays a key role in the livelihoods of the people, food security, and to GDP of Pakistan. Maize, the 2nd most important cereal, is also facing the impacts of these variations. This study has analyzed the impacts of changing climate on maize production in Pakistan from 2000 to 2024 using the autoregressive distributed lag (ARDL) approach. Time series data on maize production, cultivated area, rainfall, temperature, water availability, and carbon dioxide emissions were collected from the Economic Survey of Pakistan and the World Bank. The ARDL model was employed to examine both short-run and long-run relationships between these variables. Despite an overall increasing trend in maize area and production, the results reveal that temperature and water availability have significant negative effects on yields in the long run, while rainfall and CO_2 emissions exhibit positive impacts. In the short run, rainfall and cultivated area support production, whereas temperature and water shortages hinder it. The Johansen cointegration test confirms the presence of two significant long-run relationships among the variables. These findings highlight the growing influence of climate change on maize productivity in Pakistan, emphasizing the need for informed policy actions to safeguard the agriculture sector. The study recommends introducing climate-resilient maize varieties, training farmers on climate-smart practices, strengthening early warning systems for extreme weather events, and implementing policies to support farmers during weather-related threats.

INTRODUCTION

Climate change is a global phenomenon referring to long-term shifts in temperature, precipitation, and the frequency of extreme weather events (Eswaran et al., 2024), which ultimately result in reduced agricultural productivity (Lakshmi et al., 2024). Pakistan's agriculture sector plays a crucial role in the country's economy, contributing significantly to its Gross Domestic Product (GDP), employment, and food security. The sector accounts for approximately 24% of Pakistan's GDP and employs around 37.4% of the labor force (GoP, 2024), making it a vital source of livelihood for a substantial portion of the population. Agriculture is also considered an essential sector for ensuring food security, as it provides staple crops such as wheat, rice, and maize for domestic consumption. Maize (*Zea mays* L.) is a crucial cereal crop globally, playing a significant role in food security and economic development. Globally, the demand for maize is expected to increase from 32 to 52 kg per person per year by 2050 (CIMMYT, 2000). Furthermore, most of this increase is expected to occur in developing countries (Murdia et al., 2016). In Pakistan, maize is cultivated for food, animal feed, and fodder, and is also used as a raw material for industry (Hussain et al., 2023). It ranks second in terms of production after wheat; however, it ranks third in terms of cultivated area after wheat and rice crops (GoP, 2021, contributing 0.7% to GDP and 2.9% to agricultural value addition (GoP, 2024). About 97 % of the total maize produced in Pakistan comes from two provinces, Punjab and Khyber Pakhtunkhwa, while Sindh and Balochistan have a share of only 2-3 % (PARC). On average, the yield of Punjab is about 8 thousand kg per hectare, which is much higher than compared of Khyber Pakhtunkhwa province, about 1.92 thousand kg per hectare (Hussain et al., 2023). In 2023-24, maize cultivation decreased by 4.5% to 1.6 million hectares, resulting in a 10.4% decline in production to 9.8 million tons, down from 11.0 million tons the previous year. This decline in production is linked to the reduced cultivation area (GoP, 2024). However, in recent years, climate change has also posed serious threats to Pakistan's maize, resulting in its decline in production. On the other hand, the consumption of maize in Pakistan is expected to reach 4.5 million metric tons by 2026, reflecting an increase of 1.3% from the 4.1 million metric tons recorded in 2021. In recent years, climate change has also posed significant challenges to global agriculture, particularly affecting developing nations like Pakistan, whose economy heavily relies on the agricultural sector. The current climate shifts have threatened the domestic yield and production of maize in Pakistan, highlighting the vulnerabilities within the agricultural sector. Carbon dioxide emissions account for roughly 58.8% of worldwide greenhouse gas emissions (Kapur et al., 2011; Usman et al., 2021), while fluctuations in temperature and rainfall patterns have a considerable effect on the productivity of agriculture (Agovino et al., 2019). The growth and development of crops are supposed to be affected in various ways, including changes in rainfall and direct impacts on the crop water cycle, which introduce water stress in crop development. These continuing climatic changes are likely to drastically affect the growth, water cycle, and output of the staple food crops in many regions of the world (Parry et al., 2004; IPCC, 2007; Khoso et al., 2024) and in Pakistan, where population growth is remarkably high (Usman et al., 2017). In low-income countries, crop yields are hampered by the changing temperature and rainfall levels due to low adaptive measures (Usman et al., 2017; Khushi et al., 2024). Despite growing concerns about climate change and its impact on agriculture, there is a lack of empirical research focused on the long-term relationship between climatic variables on maize production in Pakistan. This study seeks to address this gap by employing econometric analysis to examine how climate-related changes have influenced maize yield and production trends in recent decades. By identifying the challenges posed by climate change, the study seeks to provide practical recommendations to help policymakers address these issues and support sustainable agriculture in the country. Objectives of the current study were: to analyze the trends in maize area and production, to evaluate the impact of climate change on maize production and to suggest recommendations for policy making.

METHODOLOGY

Data collection

The main aim of this study was to determine the impacts of changing climatic conditions on the production level of maize in Pakistan. Time series data on maize production, area, rainfall, water availability, and temperature were collected from the Economic Survey of Pakistan, whereas the data on carbon dioxide were from the World Bank. The data on all the variables were collected from 2001 to 2024.

3.2 Analytical measures

The collected data was analyzed using the autoregressive distributive lag (ARDL) approach through E Views software. ARDL has been chosen to be used in this study as it is considered the modern technique, with several benefits, including being capable of analyzing both short- and long-term associations and being appropriate for small samples (Agbodji & Johnson, 2021).

3.3 Specification of the model

The ARDL co integration approach is employed to estimate this hypothesis through the following equation. The relationship between maize production and the key variables under study is defined as follows-

Maize production = $\beta_0 + \beta_1 AR + \beta_2 RF_2 + \beta_3 TP + \beta_4 WA + \beta_5 CO_2 + \epsilon t$ (1)

In Eq. (1), AR shows the area under the maize production, RF indicates the rainfall, TP indicates the temperature, WA indicates the water availability, CO_2 shows the carbon dioxide emissions, and ε_t is the error term in the model. Instead of using the basic linear model as follows, a log-linear model has been created using a linear combination that provides appropriate and competent results from Equation (1):

LNMP = $\beta_O + \beta_1 LNAR + \beta_2 LNRF + \beta_3 LNTP + \beta_4 LNWA + \beta_5 LNCO2 + \epsilon_t$ (2)

The ARDL technique, represented by equation (3), looks at the long-term relationship between the selected study variables, which are as follows:

$$\Delta LNMP_t = \beta o + \sum_{x=1}^{g} \beta_{1x} \Delta LNAR_{t-x} + \\ + \sum_{x=1}^{g} \beta_{2x} \Delta LNRF_{t-x} + \sum_{x=1}^{g} \beta_{3x} \Delta LNTP_{t-x} + \sum_{x=1}^{g} \beta 4_x \Delta LNWA_{t-x} \\ + \sum_{x=1}^{g} \beta\, 5_x \Delta LNCO2_{t-x} + \\ \vartheta LNMP_{t-1} + \vartheta_2 LNAR_{t-1} + \vartheta_3 LNRF_{t-1} + \vartheta_4 LNTP_{t-1} + \vartheta_5 LNWA_{t-1} + \vartheta_6 LNCO2_{t-1} + + \epsilon_t \quad (3)$$

The representation of the null hypothesis is as follows:

$[H_0 = \vartheta_1 = \vartheta_2 = \vartheta_3 = \vartheta_4 = \vartheta_5 = \vartheta_6 = \vartheta_7 = \vartheta_8 = 0]$

The alternative hypothesis, which is examined in the manner described below, is in opposition to it.

$[H_0 \neq \vartheta_1 \neq \vartheta_2 \neq \vartheta_3 \neq \vartheta_4 \neq \vartheta_5 \neq \vartheta_6 \neq \vartheta_7 \neq \vartheta_8 \neq 0]$

The short-term relationships between maize production, area under maize production, rainfall, temperature, water usage and carbon dioxide (CO2) emissions were also examined using an ECM technique; Eq. (4) may be expressed in the manner described below:

$$\Delta LNMP_t = \beta_o + \sum_{u=1}^{n} \beta_{1u} \Delta LNAR_{t-u} + \sum_{u=1}^{n} \beta_{2_u} \Delta LNRF_{2t-u} + \sum_{u=1}^{n} \beta_{3u} \Delta LNTP_{t-u} + \\ \sum_{u=1}^{n} \beta_{4u} \Delta LNWA_{t-u} + \sum_{u=1}^{n} \beta_{5u} \Delta LN\,CO2_{t-u} + \epsilon_t \quad (4)$$

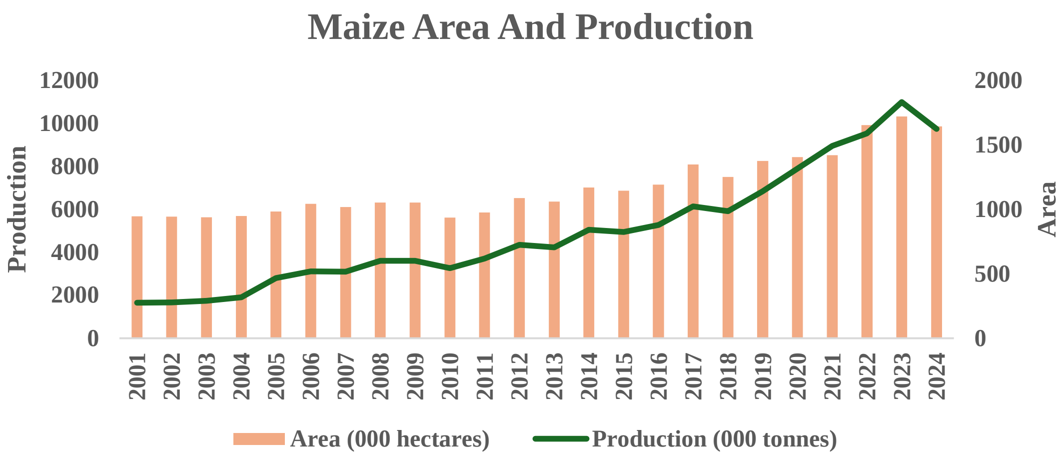
RESULTS AND DISCUSSION

This chapter presents the econometric methods used to analyze the impact of climatic and agricultural factors on maize production in Pakistan. The ARDL model is applied to estimate both short-run and long-run relationships using variables such as cultivated area, temperature, rainfall, water availability, and CO_2 emissions.

Maize production and area

This graph illustrates how both the area under maize cultivation and its production have grown from 2001 to 2024. While the cultivated area steadily increased, production experienced a sharper rise, particularly after 2018, reaching its peak in 2023. In 2024, production slightly declined despite a substantial cultivated area, possibly due to weather or input-related challenges.

Trends of maize production and area
Source: Economic Survey of Pakistan (2024)



Descriptive statistics

Most of the climatic variables, including rainfall with an average of 6.25, temperature with an average of 2.82, and CO_2 concentration with an average of 5.12, exhibited stable and balanced trends over time. Maize production and the area under cultivation also remained consistent throughout the study period. In contrast, water availability, with an average of 4.89, displayed irregular patterns and noticeable instability. Based on the descriptive statistics, all variables appear to be uniformly and independently distributed.

Descriptive statistics

Statistic	LnMP	LnMA	LnRF	LnTMP	LnWA	LnCO2
Mean	8.367	7.053	6.252	2.819	4.890	5.121
Median	8.361	6.979	6.306	2.817	4.902	5.084
Maximum	9.304	7.450	6.543	2.861	4.932	5.467
Minimum	7.404	6.841	5.803	2.779	4.737	4.730
Std. Dev.	0.571	0.195	0.211	0.024	0.043	0.218
Skewness	-0.133	0.704	-0.396	0.198	-2.152	-0.259
Kurtosis	2.129	2.270	2.038	2.315	7.925	2.092
Jarque-Bera	0.829	2.513	1.553	0.626	42.775	1.092
Probability	0.661	0.285	0.460	0.731	0.000	0.579
Sum	200.805	169.271	150.053	67.648	117.370	122.897
Sum Sq. Dev.	7.490	0.874	1.024	0.013	0.043	1.089
Observations	24	24	24	24	24	24

Correlation

The correlation analysis shows that the area under maize cultivation and carbon dioxide emissions have a weak but statistically significant positive relationship with maize production, with coefficients of 0.099 and

0.113, respectively, both significant at the 1% level. Water availability has a weak but significant negative correlation of –0.014. In contrast, both rainfall and temperature present very weak correlations with maize output, with correlation coefficients of 0.040 and 0.003, respectively; however, these relationships are statistically insignificant given their higher p-values.

4.3 Correlation among variables

Covariance	LnMP	LnMA	LnRF	LnTM	LnWa	LnCo2
Production	0.312 -----					
Area	0.099*** 12.112 0.000	0.036 ----- -----				
Rainfall	0.040* 1.752 0.093	0.009 1.228 0.232	0.042 ----- -----			
Temperature	0.003 1.450 0.161	0.001 1.454 0.159	-0.001 -1.016 0.320	0.000 ----- -----		
Water availability	-0.014*** -3.509 0.002	-0.005*** -5.170 0.000	-0.000 -0.316 0.7544	-0.000 -1.093 0.286	0.001 ----- -----	
Co_2	0.113*** 14.972 0.000	0.035*** 7.990 0.0000	0.012 1.363 0.186	0.001* 2.059 0.051	-0.004** -2.428 0.023	0.045 ----- -----

The significance level is shown as *** indicates 1%, ** indicates 5%, and * indicates 10%.

Unit root test

The Augmented Dickey-Fuller (ADF) test results indicate that all variables are stationary either at the level or first difference. LNAR (area), LNPR (production), LNWA (water availability), and LNCO2 (carbon emissions) are stationary at first difference I(1), while LNTEMP (temperature) and LNRF (rainfall) are stationary at level I(0). All variables have statistically significant p-values (less than 0.05), confirming no unit root and suitability for further time series analysis.

Unit root test results

Augmented Dickey Fuller Test (ADF)			
Variables	Test-statistics	Prob-value	Level of integration
LNPR	-5.046672***	0.0006	I(1)
LNAR	-6.00201***	0.0001	I(1)
LNRF	-4.797765***	0.0009	I(0)
LNTEMP	-4.74892***	0.0010	I(0)
LNWA	-6.371341***	0.0000	I(1)
LNCO2	-4.338155***	0.0030	I(1)

The significance level is shown as *** indicates 1%, ** indicates 5%, and * indicates 10%.

4.5 ARDL bound test

The co integration analysis reveals that the F-statistic of 4.033 exceeds the upper bound value of 3.38 at the 5% significance level, confirming the existence of a long-term equilibrium relationship. Results showed that area under cultivation, rainfall, temperature, CO_2 emissions, and water availability significantly influence maize production in the long run.

4.5 ARDL bound test for co integration

ARDL Bound Test		
F-statistic	**K**	
4.033136	5	
C value bounds		
Level of significance	**I(0)**	**I(1)**
At the 10%	2.08	3
At the 5%	2.39	3.38
At the 2.5%	2.7	3.73
At the 1%	3.06	4.15

4.6 ARDL Long Run and Short Run Results

The long-run ARDL estimation reveals that multiple climatic factors significantly impact maize production in Pakistan. Temperature and water availability show strong negative effects, with coefficients of -6.87 and -6.11, respectively, indicating that higher temperatures and reduced water supply substantially lower maize output. In contrast, rainfall and CO_2 emissions positively influence maize production, with coefficients of 0.48 and 2.61, suggesting that increases in these variables contribute to higher yields. Although cultivated area has a negative coefficient of -0.88, it is not statistically significant. The model explains about 87.66% of the variation in maize production, with the F-statistic of 24.96, with a p-value of 0.000.

The results of our study are supported by Khan et al. (2019) and Gul et al. (2022), who found that rising temperatures reduce crop yields, but contrast with Ahsan et al. (2020), who reported a strong positive effect of cultivated area. Unlike Gul et al. (2022), our results show a positive long-run relationship between CO_2 emissions and maize production.

In the short run, area under cultivation and rainfall significantly positively impacted maize production, with coefficients of 1.047 and 0.229, respectively. Temperature showed a negative effect, while water availability had a strong and significant negative influence. CO_2 concentration had a positive but statistically insignificant impact. The error correction term was negative and highly significant, indicating a stable adjustment toward long-run equilibrium.

In contrast to our results, Rizwanullah et al. (2023) found that in the short run, all the variables, like average temperature, rainfall, and CO_2 emissions, had a positive and significant impact on maize yield. Similar to our results, Gul et al. (2022) also mentioned an indirect relationship between water availability and rice production in Pakistan.

4.6 ARDL long run and short run results

Long-run Estimates				
Variables	Coefficients	Std. Error	T-Statistic	Probability
LNAR	-0.879807	0.643252	-1.367747	0.2137
LNRF	0.477641**	0.178934	2.669369	0.0320
LNTEMP	-6.872887**	2.244111	-3.062632	0.0183
LNWA	-6.110420**	2.051963	-2.977842	0.0206
LNCO2	2.614361***	0.386121	6.770828	0.0003
C	47.46401**	15.92095	2.981230	0.0205

Short-run Estimates				
Variables	Coefficients	Std. Error	T-Statistic	Probability
DLNAR)	1.047216***	0.183319	5.712548	0.0007
DLNAR (-1)	0.787014***	0.222365	3.538336	0.0095
DLNRF	0.229780***	0.049847	4.609665	0.0025
DLNTEMP	-0.836633	0.469221	-1.787286	0.1170
DLNTEMP (-1)	2.141931**	0.431004	4.969551	0.0122
DLNWA	-1.759667***	0.407764	-4.316370	0.0032
DLNWA (-1)	1.298594**	0.415001	3.126439	0.0159
DLNCO2	0.375116	0.291038	1.288706	0.1317
Cointeq (-1)	-0.832413***	0.114960	-7.240909	0.0002
R^2	0.876559			
Adjusted R^2	0.800595			
F-Statistics	24.96			
P (F-Statistics)	0.0000			

*** shows 1%, ** indicates 5%, and * reveals a significance level of 10%.

4.7 Johnson co-integration

The Johansen co integration test confirms the presence of two significant long-run relationships at the 5% level. This indicates a stable association between maize production and factors such as area under cultivation, water availability, temperature, rainfall, and CO_2 emissions in Pakistan. These variables move together over time, suggesting they are interdependent in the long run, even if short-term fluctuations occur. Similar results were given by Gul et al. (2022) in their study, showing a long-term correlation between rice production with area, temperature, and CO_2.

Johnson co-integration test

Unrestricted Co integration Rank Test (Trace)				
H-No. of CE(s)	E values	T statistic	C values at 0.05	Prob-values
None*	0.883	130.538	95.754	0.0000
At most 1*	0.815	82.247	69.819	0.0029
At most 2	0.628	46.153	47.856	0.0717
At most 3	0.503	23.404	29.797	0.1839
At most 4	0.340	9.140	15.495	0.3526
At most 5	0.030	0.008	3.841	0.9296
Unrestricted Co integration Rank Test (Maximum Eigen value)				
H-No. of CE(s)	E values	Max-Eigen statistic	C values at 0.05	Prob-values
None*	0.883	47.291	40.078	0.0065
At most 1*	0.815	37.095	33.877	0.0199
At most 2	0.628	21.749	27.584	0.2335
At most 3	0.503	15.264	21.132	0.2708
At most 4	0.340	13.132	14.265	0.2753
At most 5	0.030	0.008	3.841	0.9296

*indicates a 0.05 level of significance in the hypothesis.

CONCLUSION AND RECOMMENDATIONS

This study assessed the impact of climate change on maize production in Pakistan from 2000 to 2024 using the ARDL model. Despite an overall increasing trend in both maize area and production, the results reveal that temperature and water availability negatively affect yields in the long run, while rainfall and CO_2 emissions have positive impacts. In the short run, rainfall and cultivated area support production, whereas temperature and water shortages hinder it. These insights highlight the growing influence of climate variables on maize output, emphasizing the urgency for informed policy actions to safeguard agricultural productivity. Based on the findings the study suggests recommendations like:

1. Introducing climate-resilient maize varieties
2. Train farmers on climate-smart farming practices
3. Must strengthen the early warning system for extreme weather conditions
4. Policies must be made and implemented to favor farmers during weather threats

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