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Climate Change, Economy, and Food Security Nexus: An ARDL Analysis of Pakistan's Agriculture

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ABSTRACT

This study examines the short and long-term impacts of climate vulnerabilities, demographic shifts, and economic development on cereal yields and food security in Pakistan. Analyzing time series data for 1980-2022 this study establishes dynamic relationship, which is analyzed by employing Autoregressive Distributed Lag (ARDL) technique. Temperature increases exhibit an unambiguously negative effect on yields, while precipitation and sustainable land use have positive lagged effects. Population pressure demands immediate resource depletion but adds long term value through growth in agriculture. Its ability to affect food security is however hampered by structural factors even though there is economic development. The results highlight the need for proactive polices with regard to climate change and sustainable development that will help to reduce food insecurity in climate-sensitive countries.

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1. Introduction

Food security is probably one of the biggest issues of the twenty-first century and gets international significance. According to the United Nations Food and Agriculture Organization (FAO), about 828 million people were living in hunger in 2021, evidencing the chronic failure of the food systems to address growing demand (Food and Agriculture Organization, 2022). Hunger vulnerability in developing countries is worst because of climate change, population increase, and socio-economic disparities. Changes in climate, including volatile weather, heat, and changes in rainfall patterns, affect crops and food production adversely thus causing food insecurity to millions that depend on these climate-sensitive food systems (Intergovernmental Panel on Climate Change, 2022). Similarly, other factors like economic development, population density, and land conversion create other social factors which interact with environmental risks to bear more challenges to the enhancement of sustainable food systems internationally. Some of these difficulties are not new to Pakistan, a country whose economy mainly concentrates in agriculture. Estimated to be among the five countries most at risk from climate change impacts, agricultural production, a major economy earner at 19.5% of GDP and an employer of over 38% of Pakistan's labor force, is under exceptional climate and non-climatic pressures (Pakistan Bureau of Statistics, 2023). Volatility in weather patterns through droughts and early busting of the monsoon, irregular rainfall patterns, and increasing mean temperatures have both adversely impacted the yields of cereal grains like the wheat, rice, and maize; the key staples in most Pakistani homes. At the same time, the population grows at a fast pace, the economic development is quite uneven, and agriculture is rather inefficient to address these vulnerabilities, that makes Pakistan an essential case study for examining the interplay of climate and socioeconomic dynamics on agricultural yields and food security.

The need to evaluate food security in Pakistan is informed by its poor ranking in the Global Hunger Index (Von Braun et al., 2021). In this research, we have developed Hunger Index only for Pakistan using the GHI approach taking into account the country specific factors. Including this index with other variables like, cereal yields, ND-Gain index[1], and socioeconomic indicators, this research work is an effort to provide policy solutions to food security in Pakistan. While research on climate change and food security has increasingly gained attention hardly any effort has been made to examine jointly the effect of climate change dynamics and socioeconomic environment on agriculture productivity and food insecurity in Pakistan. Current research typically examine these dimensions separately which poses a challenge on the use of such knowledge for integrated policymaking. Pakistan faces a dual challenge of declining agricultural productivity and rising food insecurity due to the combined pressures of climate change and socioeconomic indicators. This study aims to bridge this gap by analyzing complex relationships between climatic fluctuations, socio-economic factors, and population growth with cereal yields and food security in Pakistan as measured by a Hunger index developed in this research. This research study makes significant contributions by following ways; 1) we have developed Pakistan specific Hunger Index from 1980-2022 by employing methodological steps proposed by Global Hunger Index[2], 2) we have examined the impact of climatic dynamics on food insecurity by using ARDL models, and 3) we have investigated the role of socio economic factors, e.g., economic growth, population growth, and agricultural land utilization on agricultural productivity and food insecurity.

2. Literature Review

Food security means that access by all people at any time to sufficient, safe, nutritious, and quality food that meets their dietary needs and food preferences for a healthy and active life (Food and Agriculture Organization, 2022). Eradicating hunger for improved food security is among the goals of sustainable development laid down in the United Nations SDG-02. However, global food systems are under threat today because of climate changes, population pressure, and limited resources (Von Braun et al., 2021). Most of these challenges are unique to developing countries in which agriculture is still a dominant sector as well as a source of employment (Barrett, 2013). Global climate change has become one of the leading causes of agricultural risk with impacts on yields and food chains globally as stated by IPCC 2022. Changing climate is affecting productivity in agriculture by increasing global temperatures, altering precipitation patterns and creating more frequent and intense weather conditions that impacts food security (Rosenzweig et al., 2014). When heat stress is not buffered, wheat and maize production may drop by as much as 6% and 7% per degree Celsius of global warming respectively (Lobell, Schlenker, & Costa-Roberts, 2011). Such changes are more significant to these countries particularly the developing nations in South Asia because they have low adaptive capacity (Hertel & Lobell, 2014).

It is important to realize that climate change is only one of the factors that influence food insecurity – in fact socioeconomic factors including population growth and development and land use attract similar attention. For example, high population density leads to high demand for food, which may cause high pressure on agricultural related aspects and the environment (FAO, 2016). On the other hand, income divides and ineffective use of resources for agricultural production limit the potential of nations to meet these demands (Godfray et al., 2010). Investment in the technologies and infrastructures enhanced to improve food security through higher GDP growth is not always affirmative (World Bank, 2021). Pakistan is among the top ten producers of the core cereals like the Wheat and rice but its agricultural production is on the declining stage due to number of climatic and socio-economic factors (Pakistan Bureau of Statistics, 2023). Agriculture accounts for 19.5% of the GDP and employs over 38% of the labor force, making it a critical sector for economic stability and food security (Government of Pakistan, 2023). However, bad methods in farming, loss of soil fertility, and compelling scarcities in water supply have confined development prospects (Qureshi & Perry, 2021). Pakistan again is in the list of ten most vulnerable countries to climate change in the last twenty years as per Global Climate Risk Index (Eckstein, Künzel, & Schäfer, 2021). New paradigms of temperature increases, monsoon irregularities, and glaciers melting are posing

[1] Notre Dame Global Adaptation Initiative (ND-GAIN), it measures country's vulnerability to climate change and readiness.
[2] Methodology - Global Hunger Index (GHI) - peer-reviewed annual publication designed to comprehensively measure and track hunger at the global, regional, and country levels

new tough problems for Agriculture. Several studies have shown how average temperature in Pakistan has changed significantly over the past decades, with future changes expected to rise until the turn of the century (Karim et al., 2020).

Seasonal rainfall in Pakistan has become highly unpredictable and hydric stress hits various parts of the country repeatedly in the form of flood or long-term drought. These extremes affect the calendar of agricultural activities and lead to low yields (Ali et al., 2017). The regions experience major climate alterations because rain-fed agriculture dominates Pakistan's croplands yet remains susceptible to variable climate patterns (Hussain et al., 2020). These are mostly in the nature of population density and poverty level, which exacerbate impacts of climate change on food insecurity in Pakistan. The population growth rate having hit 2%, which is one of the highest in the region, the demand is still growing much higher than production (World Bank, 2021). Like any other resource, economic inequalities inhibit the achievement of food sovereignty especially for the rural and the marginalized members of the society. The most common indicators used in the measurement of status of hunger are the international indicators known as the Global Hunger Index. It takes undernourishment, child wasting, child stunting, and child mortality and gives them one combined index and this forms the measure of hunger. (von Grebmer et al., 2022). However, it draws data from a global context and therefore a higher degree of regional customization is needed to achieve an increased level of precision (Pinstrup-Andersen, 2009). Cereal yields are one of the barometers of the determine agricultural productivity and food security most importantly in countries such as Pakistan where cereals contributes a decent proportion of the daily diets. It was established that climatic factors affecting the quantity of cereals include temperature and rainfall and these factors have different effects for various cereal crops –(Lobell, Schlenker, & Costa-Roberts, 2011).

ND-Gain Index is an index that integrates the resilience of a country to climate change and preparedness to climate change. The index is therefore unique in that it incorporates exposure, sensitivity and adaptive capacity to offer an overall impression of climate related risk (Chen et al., 2015). This analysis reveals nd-gain score of Pakistan indicating high vulnerability and low readiness level; That's why some quick and specific policies and interventions needed (Eckstein, Künzel, & Schäfer, 2021). The two theoretical frameworks familiar to this study are the Resource-Based View (RBV) and Dynamic Capabilities that can help explain how nations configure resources to address climatic changes in the production of agricultural produce (Teece, Pisano, & Shuen, 1997). The former of these frameworks highlight the need for resilience, which is especially important for Pakistan's climatically susceptible agriculture industry. Various research have revealed that the climax of climate changes poses a serious threat to food security. For instance, (Iizumi & Ramankutty, 2015) observed that climate change cut crop productivity worldwide by 5 % to 10 % in the last two decades. Similar trends have been discerned in south Asian region, where temperature hike and precipitate unsteadiness have forced social agronomical practices (Lal et al., 2011). There seems to be no real statistical data to support the findings especially because most of it is not specific to region. Such global hemoglobin indices as the GHI can be useful for reference but are insufficient to reflect such variations (Food and Agriculture Organization, 2022). This limitation can be solved whenever constructing localized indices, as this study proposes (von Grebmer et al., 2022).

There are established literature on how climate change affects the development of the different countries but the exact relationship between climate and socioeconomic factors in developing countries is not well explained. For example, growth in income can raise people's capacity to adapt to climate change and address other challenges in the process boosts the strength of the economy, but, at the same time, economic growth can cause deterioration of the environment in the absence of the necessary prevention measures (Godfray et al., 2010). Such dynamics are important as they help governments respond appropriately to new dynamics shaping policy making. Irrigation methods, changes of crops to develop resistance to drought and trees for agriculture are other tactics that enhance climate-related risks. Researches conducted in Pakistan have stressed on the opportunities of these approaches, however, there has been identified major discrepancies in the strengthening of such measures (Qureshi, 2018). Studies on food security should feed policy, at different tiers. To address food insecurity in Pakistan, intervention strategies need to assume a complex structure; from climate-smart agriculture to social protection interventions (World Bank, 2021). There are many global bodies that are involved in the fight against global food insecurity some of them include the FAO, IFAD and the World Bank. This aid is in Pakistan where they provide their programs on development of agricultural production, eradicating poverty, and climate change mitigation (Food and Agriculture Organization, 2022).

Previous literature has greatly contributed to understanding of food security in various ways, but research limitations in coupling climate variability and change with socioeconomic factors at the country level are still evident. This study will attempt to fill these gaps by employing a case of Pakistan. Due to the existing climate change and socioeconomic inequalities, there has been a real need to undertake extensive, localized research. A contribution of this study is to develop a Pakistan-specific Hunger Index and estimate the effects of climate and other socioeconomic factors on agricultural yields. The literature underscores the complexity of food security challenges in Pakistan, driven by climate dynamics and socioeconomic factors. By addressing key gaps, this study contributes to the growing body of knowledge on sustainable agriculture and food security in climate-vulnerable regions. Although many studies have explored the effects of climate change on food security, essentially little is known about the dependent effects of climate variability and socio-economic change on food production and food security in developing world including Pakistan. Previous research mostly tends to consider these dimensions individually, that is, either the impacts of climate variables like temperature and rainfall on crop productivity or else the sociology factors affecting food security like population increase and economic inequality (Godfray et al., 2010; Lobell, Schlenker, & Costa-Roberts, 2011). However, how these factors interact and in particular a country as climate prone as Pakistan's case is not well researched. Also, renowned international indexes like the GHI, are general but they lack specific information and specific factors influencing food insecurity at a particular geographical zone or region. This paper fills these research deficits by: firstly, constructing a new and novel Hunger Index for Pakistan based on the GHI approach and secondly, by incorporating climate and socioeconomic data to test their interaction effects on cereal yields and food security. Thus, the research contributes more valuable insights to the understanding of various push and pull factors of food insecurity in Pakistan and is informative for policy making.

3. Data Sources and Methodology

The relationship between climate dynamics, socio economic factors, cereal yields and food security is analyzed using the Autoregressive Distributed Lag (ARDL) model in this study for the short- and long-term periods of Pakistan. This study uses two models: The first investigates the effect of climatic and socio–economic factors on cereal yields and the second, food security determinants as measured by the Pakistan specific Hunger Index. For cereal yield, the specific model is:

$$Cereal\_Yieldt \ = \alpha 0 + \sum_{i=1}^{p} \beta_i \, Cereal\_Yield_{t-i} + \sum_{j=0}^{q} \gamma_j \, X_{t-j} + \varepsilon t \qquad 1$$

where X_{t-j} includes climate variables (ND-Gain Index, temperature, precipitation) and socioeconomic factors (population growth, agricultural land use, and GDP per capita growth). Similarly, the Hunger Index is modeled as:

$$Hunger\_Indext \ = \alpha 0 + \sum_{i=1}^{p} \beta_i \, Hunger\_Index_{t-i} + \sum_{j=0}^{q} \gamma_j \, X_{t-j} + \varepsilon t \qquad 2$$

where Z_{t-j} consists of vulnerability (ND-Gain Index), population growth, agricultural land use, and GDP per capita growth. To guide this analysis, the following hypotheses were formulated:

H1: Climate dynamics (ND-Gain Index), rising temperatures, and variability in precipitation, negatively impact cereal yields in Pakistan.
H2: Socioeconomic factors, such as population growth, GDP per capita growth, and agricultural land use, influence cereal yields.
H3: Vulnerability to climate change significantly exacerbate food insecurity in Pakistan, as measured by the Hunger Index.
H4: Socioeconomic factors (population growth, GDP per capita growth, and agricultural land use) influence food insecurity.

3.1 Data Sources and Variables

Table 1: Description of Variables, Data Sources, and Measurement Units

Variable	Description	Source	Measurement Unit/Approach
Cereal Yield	Agricultural output per hectare of arable land.	World Bank's World Development Indicators (WDI)	Kilograms per hectare
Hunger Index	Combines undernourishment, child stunting, child wasting, and child mortality to measure food security.	Constructed using the Global Hunger Index (GHI) methodology	Index value (0-100, with higher values indicating worse conditions)
ND-Gain Index	Measures climate vulnerability and adaptive capacity.	Notre Dame Global Adaptation Initiative (ND-GAIN)	Composite index (higher scores indicate better preparedness)
Vulnerability	Assesses exposure, sensitivity, and adaptive capacity to climate change.	Derived from ND-GAIN data	Composite index
Population Growth	Annual percentage change in population.	World Bank's World Development Indicators (WDI)	Percentage (%)
Temperature	Annual mean temperature.	World Bank's World Development Indicators (WDI)	Degrees Celsius (°C)
Precipitation	Annual mean precipitation.	World Bank's World Development Indicators (WDI)	Millimeters (mm)
Agricultural Land Use	Proportion of land area used for agriculture.	World Bank's World Development Indicators (WDI)	Percentage of land area
GDP Per Capita Growth	Annual percentage growth in GDP per capita.	World Bank's World Development Indicators (WDI)	Percentage (%)

3.2. Construction of the Hunger Index

The Global Hunger Index (GHI) is a Mean that not only provides a comprehensive, up to date assessment of countries' respective hunger situation, but also monitors the evolution – the path – of hunger over time. The global hunger index (GHI) is intended to raise awareness and understanding of global efforts to combat hunger, to allow comparisons of hunger among countries and regions, and to point to the countries and regions where hunger is most persistently troubling by stressing the need for urgent actions to end hunger. There is no data available on Hunger Index for Pakistan on a year to year basis. Thus, in order to undertake a detailed investigation of the Hunger Index and its association with the effects of climate change, it was necessary to develop a more specific Hunger Index for Pakistan.In order to create the Hunger Index for Pakistan, this study adapted the GHI methodology, and used following indicators:

Table 2: Key Indicators Underlying the Hunger Index and Their Characteristics

Indicator	Definition	Key Characteristics
Undernourishment	The percentage of the population with insufficient caloric intake, highlighting inadequate food access.	• Reflects inadequate access to food and its impact on hunger. • Includes both children and adults in the population. • Serves as an indicator for international hunger targets like SDG 2 (Zero Hunger).
Child Stunting	The percentage of children under five who exhibit low height-for-age, representing long-term undernutrition.	• Considers factors beyond calorie availability, such as diet quality. • Highlights children's vulnerability to nutrition deficiencies. • Sensitive to unequal food distribution in households.
Child Wasting	The percentage of children under five with low weight-	• Indicates the prevalence of acute malnutrition among children.

	for-height, indicating short-term or acute undernutrition.	• Highlights food distribution inequalities and short-term nutritional crises. • Serves as a key nutrition indicator for SDG 2 (Zero Hunger).
Child Mortality	The percentage of children dying before their fifth birthday, partially reflecting the severe consequences of malnutrition.	• Reflects the most severe consequence of hunger: child mortality. • Demonstrates the deficiencies of vital nutrients like vitamins and minerals. • Complements stunting and wasting in capturing undernutrition risks.

Using this set of indicators to measure hunger has a number of advantages. These indicators include both energy inadequacy and dietary inadequacy.

3.3. Calculating GHI Scores: A Three-Step Approach

3.3.1. Data Collection

For the four essential indicators of undernourishment, child stunting, child wasting, and child mortality, collected from reputable sources such as the World Bank. The linear trend in the last (most recent) years was used to estimate missing data for earlier years. Reliability and accuracy were ensured by means of validation steps (residual analysis, RMSE calculations, and regional comparisons). Unlike the global GHI, this study gives a localized view of the situation, something which takes into account Pakistan's specific socioeconomic and climatic hurdles that are different from those of the global map. This approach takes the index’s value as a relevant tool for policy making and targeted intervention.

Table 3: Data Sources, Methodologies, and Validation Techniques for Hunger Index Construction

Indicator	Unit of Measurement	Data Source	Available Data Period	Constructed Data Period	Methodology for Missing Data	Validation Methods
Undernourishment	Prevalence of undernourishment (% of population)	World Bank (WDI)	2001-2021	1980-2000	Linear regression to estimate missing values (1980–2000) based on available data trends (2001–2021).	Residual analysis, RMSE = 2.21
Child Stunting	Proportion of children under 5 years with low height-for-age (%)	World Bank (WDI)	2000-2022	1980-1999	Regression to predict missing values for 1980–1999 using trends from 2000–2022.	Residual analysis, RMSE = 2.56,
Child Wasting	Proportion of children under 5 years with low weight-for-height (%)	World Bank (WDI)	1986, 1991, 1992, 2001, 2011, 2013, 2018	1980-2022	Linear interpolation for short gaps and regression for long gaps	Residual analysis, RMSE = 3.07
Child Mortality	Under-5 mortality rate (converted to a percentage)	World Bank (WDI)	1960-2022	Not Applicable	Converted under-5 mortality rates (per 1,000 live births) into percentages.	Historical and contextual validation

3.3.2. Standardization

Each of these four integrative indicators is given a standardized score explained by GHI. The formulas to standardize each indicator are as follows:

$$\text{Standardized undernourishment value} = \frac{\text{Prevalence of undernourishment}}{80} \times 100 \quad (3)$$

$$\text{Standardized child stunting value} = \frac{\text{Child stunting rate}}{70} \times 100 \quad (4)$$

$$\text{Standardized child wasting value} = \frac{\text{Child wasting rate}}{30} \times 100 \quad (5)$$

$$\text{Standardized child mortality value} = \frac{\text{Child mortality rate}}{35} \times 100 \quad (6)$$

3.3.3. Aggregation

Hunger index score is computed from the standardized scores. Undernourishment and child mortality each contribute one-third of the score, while child stunting and child wasting contribute one-sixth each, as represented below:

Hunger Index Score = $\frac{1}{3}$ (Undernourishment) + $\frac{1}{6}$ (Child Stunting) + $\frac{1}{6}$ (Child Wasting) + $\frac{1}{3}$ (Child Mortality) 7

It produces GHI indices on a zero to 100 scale of Hunger: 0- no hunger and 100- hungriest possible. In practice, neither of them is often reached. The perfect score of 100 means the country has levels of undernourishment, child stunting, child wasting and child mortality at the highest observed level while a score of 0 means none of these problems.

3.4. Research Design

Accordingly, this work uses a quantitative assessment of analyzing the climate variability and socioeconomic variables on agricultural output and food security in Pakistan. The dataset covers the period from the year 1980 to the year 2022 and consists of dependent variables; cereal yield, hunger index, an independent variable; ND-Gain index, Vulnerability to climate change and control variables; population growth, temperature, precipitation, agricultural land use, and GDP per capita growth. In order to complete the analysis and achieve the research objectives, this work uses the Autoregressive Distributed Lag (ARDL) model based on the availability of the data: I (0) and I (1).

Table 4: Augmented Dickey-Fuller (ADF) Test Results for Stationarity Analysis of Variables

Variable Name	ADF Test Statistic	Critical Values (5%)	p-Value	Stationarity Interpretation
Cereal Yield	1.528	-2.964	0.9976	Non-Stationary
Pakistan_Hunger_Index	-0.349	-2.955	0.9182	Non-Stationary
Vulnerability	-0.675	-2.955	0.8532	Non-Stationary
ND-Gain Index	-2.371	-2.964	0.1502	Non-Stationary
Population Growth	-0.903	-2.964	0.7871	Non-Stationary
Temperature	-1.085	-2.964	0.7209	Non-Stationary
Precipitation	-2.884	-2.964	0.0473	Stationary
Agricultural Land	-2.916	-2.964	0.0435	Stationary
GDP Growth	-2.869	-2.964	0.0490	Stationary

The Augmented Dickey Fuller test was then conducted on all the analyses and observations in order to establish the stationarity of all the variables with the result that both dependent variables, Cereal Yield and Pakistan Hunger Index does not only possess the characteristics of unit roots but are also non-stationary at ordinary levels as well. To analyze the peculiarities of cereal yield, Hunger index and vulnerability in the short term, these indicators were also differenced to achieve stationarity. Cereal Yield is affected by short-term climatic and socioeconomic events in an agricultural productivity perspective, while differencing eliminates trends resulting in short-term effects. Capturing their equilibrium relationships with independent variables is central to the study's theoretical framework and objectives (Pesaran & Shin, 2099). The methodological consistency is further ensured by the feature of the ARDL model whereby it can handle mixed integration orders. Using a diagnostic test for the model residuals we tested for stationarity (ADF on residuals), heteroscedasticity, and autocorrelation all of which further confirmed the appropriateness of models.

4. Results

The descriptive statistics, describes the variables used in the study and give an overview of their central tendency, variability, and range. The data consists of 43 observations from 1980 to 2022. Cereal Yield with an average of 2363.66kg/ha (with standard deviation of 589.90) indicating moderate variation. A mean of 37.24 and relatively high dispersion (standard deviation of 8.37) of the Pakistan Hunger Index imply it is an index with significant variation throughout time. The mean of the ND Gain Index was 41.05 and its standard deviation of 2.31 is smaller as compared to the former, indicating some more consistency in the country’s resilience to the challenge of climate. It turns out the log-transformed population variable has a mean of 2.59, and a standard deviation of 0.83, indicating a gradual population growth. Minimally varied (0.56°C standard deviation), mean annual temperature is 21.28°C with an average of 293.47 mm precipitation (standard deviation 60.22 mm). On average, under study years, we find that 47.11% of the total land area is agricultural while having a standard deviation of 0.91%, indicating stable land usage. Making a log transformation, the economic performance also varies relatively significantly across years with a mean of 2.09 and standard deviation of 2.00 from -2.97 to 5.82 indicating gaps in GDP per capita per country per year. The vulnerability index averages 0.54 with low variability (standard deviation of 0.02), indicating minimal variability to the processes of risk exposure over time.

Table 5: Descriptive Summary of Variables

Variable	Observations (N)	Mean	Std. Dev.	Min	Max
Cereal Yield (kg/ha)	43	2363.66	589.9014	1544.90	3489.40
Pakistan Hunger Index	43	37.2434	8.372985	22.93469	51.28087
ND Gain Index	43	41.04729	2.312915	38.3299	46.87199
Population (Log)	43	2.590716	0.8301116	1.204056	4.423125
Temperature (°C)	43	21.27605	0.5563193	20.21	22.24
Precipitation (mm)	43	293.467	60.22463	181.50	442.88
Agricultural Land (%)	43	47.10646	0.9097612	45.66988	49.9546
GDP per Capita (Log)	43	2.086736	2.00429	-2.970295	5.818349
Vulnerability Index	43	0.5365442	0.0231054	0.498	0.575

4.1. Model 1: Results and Interpretation

The first dependent variable, Cereal Yield, can be explained in terms of agricultural output in relation to arable land, using kilograms per hectare. The findings of the present study with regard to the impact of the independent variables on cereal yields, based on the estimation of the ARDL model, include both direct and lagged effects; however, some of the obtained results correspond to the hypothesis.

Table 6: Summary Statistics of the ARDL Model, Including Goodness-of-Fit Metrics and Model Diagnostics

Metric	Value
R-squared	0.9602
Adjusted R-squared	0.8365
Prob > F	0.0015

Table 7: ARDL Short-Run Results for Model-1, Showing Significant Lags and Variables

Variable	Coefficient	Std. Error	t-Statistic	Prob.
Cereal_yield_diff1(L1)	-0.74422	0.112615	-6.61	0
ND_Gain(L3)	-67.943	21.86165	-3.11	0.01
ND_Gain(L4)	24.77424	10.37956	2.39	0.04
Population_Growth_Pct	-328.3015	131.1398	-2.5	0.03
Temp	-153.2756	31.33753	-4.89	0
Temp(L4)	-223.3223	65.12601	-3.43	0.01
Precipitation(L1)	1.170612	0.399451	2.93	0.02
Agricultural_land	-131.8838	34.47157	-3.83	0
Agricultural_land(L2)	61.82372	26.78319	2.31	0.05
GDP_Capita(L1)	-39.48381	11.50303	-3.43	0.01
GDP_Capita(L3)	-38.76659	10.41201	-3.72	0.01
_cons	10415.44	2268.757	4.59	0

The results on the ND-Gain index, which measures climate adaptability, indicate overall, positive and negative, impacts across time lags. In the short-run they are insignificant though, the fourth lag post a positive coefficient value (β=24.77, p= 0.041) implying that investment in climate resilience amounts to longer term benefits. This can be in line with the hypothesis that proposed that an increase in the adaptive capacity leads to an improvement in productivity. For instance, long-term implementation of climate-smart technologies such as proper water management systems and on-farm weather applications increases yields (Lipper et al., 2014). On the other hand, the third lag raises negative coefficient (β=-67.94) although significant at 0.013 meaning that past vulnerabilities to climate change affect productivity. The pursues show that efforts to deal past adversities like declined soils and weakened ecosystems, should be optimized if improved improvements are to be realized in the future. Growth of population revealed a negative impact as far as symptom severity is concerned with short term influence

($\beta=-328.30, p=0.034$). This goes with the hypothesis that whenever there is large scale demography it has instantaneous effects on pressures on agricultural production and hence germane food production per unit of area. Still, the absence of statistically significant lagged effects also means that population-driven gains, for example in availability of labor or in policy responses to food demand, may occur out of phase over time (UN, 2017). The findings suggest that there are policy implications in terms of both short-term, resource-demanding capacity and long-term, capacity-building benefits.

Temperature was also significantly negative in the short-term cluster results ($\beta = -153.28, p = 0.001$) and in the fourth lag ($\beta = -223.32, p = 0.008$). These results support previous literature showing that higher temperatures are detrimental to cereal production and increase heat stress effects on yield (Schlenker and Roberts, 2009). The system integrates several negative effects which increase over time, making it necessary to implement heat tolerant crops, and enhanced irrigation systems to reduce heat related stress to crops during delicate developmental stages. Again, similar to temperature, the findings for Precipitation show a positive and statically significant in the first lag estimate ($\beta= 1.17$; $p = 0.017$). The observed result provides credence to the hypothesis that timeous and satisfactory rainfall enhances the yields in the agricultural sector. Although the changes in states were either very slight in the long-term or preceded short-term percentage yield changes, the results indicated that the precipitation impeding crop yield follows and amplifies this variation with a time-lag, highlighting the importance of effective water-supply systems to stabilize production during vulnerable crop developmental phases (Rosenzweig et al., 2014). The effect of Agricultural Land Use was variable. Short-term consequences of improper management of agricultural land were also extremely significant and negative ($\beta=-131.88$,$p=0.004$). This means that when practices are prolonged or some frustrations are carried out in the wrong way, it results to low yields due to low fertility of the soil. However, the second lag had a positive impact ($\beta=61.82$, $p= 0.046$) , which indicates that sustainable land use improves productivity in the long run. By implementing the outcomes illustrated above, it is evident that long-term practices including crop cycling and chemical free production and management, are important or reconstructing and sustaining soils (Tilman et al., 2002). Lastly, GDP per capita growth gave evidence of the short term positive but non-significant relationship ($\beta=13.88; p=0.110$), hence indicating that economic growth might not necessarily result to productivity improvements in the short run. However, negative effects were defined in the initial lag ($\beta=-39.48, p=0.007$) and the third lag ($\beta=-38.77, p=0.005$). Implying these results suggest that there may be negative impacts for agriculture that may be lagged effects of economic development including sprawl, or increased pollution and degradation of land that decreases the carrying capacity for agriculture while disrupting ecosystems (Godfray et al., 2010). Together with the strategies for economic growth, the existence of political measures to support the development of sustainable agriculture should be underlined, such as rural infrastructure development, strengthening the use of organic farming methods.

Table 8: Diagnostic Test Results for Model-1 Indicating Robustness of Residuals

Tests	Statistic	p-value	Interpretation
Breusch-Godfrey Test (Serial Correlation)	$Chi^2 = 1.001$	0.32	Passed
Breusch-Pagan Test (Heteroskedasticity)	$Chi^2 = 0.08$	0.78	Passed
Shapiro-Wilk Test (Normality)	W = 0.94434	0.05	Passed
Variance Inflation Factor (VIF)	VIF < 10		Passed

Overall, the findings related to Model 1 emphasize the interactions between climate variability and stability, socioeconomic characteristics, and crop yields. Large lagged responses include the beneficial and significant impacts of the ND-Gain Index, precipitation and agricultural land use pointing to the need for sustainable development. At the same time, the negative impacts of temperature increase and population increase show that urgent issues need to be solved nowadays in order to increase production rates and feed the world's population.

4.2. Model 2: Results and Interpretation

The second dependent variable used here is Hunger Index, measures food insecurity, where a lower value is favorable, indicating better conditions, while a higher value signals worsening food insecurity. The ARDL model results highlight significant relationships between the Hunger Index and its determinants, with both immediate and lagged effects.

Table 9: ARDL Short-Run Results for Model-2, Showing Significant Lags and Variables

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D_Hunger_Index(L1)	0.267965	0.22095	1.21	0.24
D_Hunger_Index(L2)	-0.1842678	0.226243	-0.81	0.425
D_Vulnerability(L3)	182.6521	75.65623	2.41	0.026
Population_Growth_Pct	-2.477567	1.253493	-1.98	0.063
Population_Growth_Pct(L1)	4.618525	2.042124	2.26	0.036
Population_Growth_Pct(L2)	-3.843893	1.98392	-1.94	0.068
Agricultural_land	-0.4801813	0.373414	-1.29	0.214
Agricultural_land(L1)	0.7082271	0.41437	1.71	0.104
GDP_Capita	-0.0432322	0.127725	-0.34	0.739
_cons	-5.59756	12.35492	-0.45	0.656

The susceptibility to climate change captured by the Vulnerability variable has a positive and significant coefficient at lag three (β=182.65,p=0.026). This shows that greater exposure to the effects of climatic shocks leads to persistent food insecurity. As analysis reveals that climate risk exposure negatively affects hunger in the long run. This has some support for the hypothesis that those places that do not have the necessary adaptive capacity are the ones that experience long-term impacts on the food insecure end of things (Schlenker & Lobell, 2010). The outcomes call for strengthening of capacity by investing in structures like the improvement of the agricultural base and transformation of food systems (FAO, 2016). Population Growth responded positively in analysis. In the short term, it had near-significant negative coefficients with the Hunger Index (β=-2.48, p=.06, nearly significant) this shows that population increase put a lot pressure on the available resources and leads to a short-term hunger. However, the first lag provided a significant positive impact (β=4.62, p = 0.036), meaning that policies or demographic change over time might reverse the pressure. For instance, high population pressure may lead to Lagos development of technologies or advocacy of labor demanding techniques of crop growing that enhance food yields (Godfray et al., 2010). The study facts drawn collectively indicate that population growth is both an advantage and a disadvantage that needs to be harnessed optimally and at the same time not exert pressure on available resources in the short run.

In the case of Agricultural land use, all the Impact measures were found to have no statistically significant difference in the short term, nor across lag. Nonetheless, the first lag demonstrated positive coefficient but nearly significant (β=0.71, p = 0.104), which presupposes that enhance of land management practices can play a role in combating hunger. This also highlight that increasing agricultural area might not help to reduce hunger but more efficient farming practices are needed. While these effects were not substantial, they corroborate the findings of other scholars that have posited that sustainable land use promotes the achievement of food security (Tilman et al., 2002). As the fourth dependent variable, there was no statistical significance between GDP Per Capita Growth and the Hunger Index in the short run and for any previous years. The insignificance of the coefficients across all lags also supports this conclusion, which is p>0.05, indicative of the possibility that economic growth may not necessarily eliminate food insecurity because wealth may not be evenly distributed or because investment in agriculture may not receive adequate attention. This is in accordance with the assertion that economic growth has to be structural and must be supported by interventions on the structure of food systems (FAO, 2016).

Table 10: Diagnostic Test Results for Model-2 Indicating Robustness of Residuals

Tests	Statistic	p-value	Interpretation
Breusch-Godfrey Test (Serial Correlation)	$Chi^2 = 0.971$	0.3245	Passed
Breusch-Pagan Test (Heteroskedasticity)	$Chi^2 = 2.74$	0.0978	Passed
Shapiro-Wilk Test (Normality)	W = 0.98714	0.9282	Passed
Ramsey RESET Test (Omitted Variables)	F = 1.71	0.2057	Passed
Variance Inflation Factor (VIF)	Mean VIF = 5.07	NA	Passed

In sum, the findings for Model 2 show that it is complex to explain food insecurity only in the context of climate change and sociodemographic characteristics. Lagged effects are also substantial, for example, indicating that vulnerability improves the Hunger Index, and therefore, there is a need to prioritize long-term climate risk management plans. Also, the two fold nature of population means that while policies must respond to present pressures for resource availability, there may be long term gain to increased population in terms of labor supply and innovation.

5. Discussion

The presented results of the current research are consistent with and enhance the knowledge base concerning climatic cycles, socioeconomic indicators, and food security. The striking and positive lagged impact of vulnerability on the Hunger Index corresponds with findings on chronic effects of climate variability on yield and food shortage on the part of (Schlenker & Lobell, 2010). However, the lack of immediate significance contrasts with studies that emphasize the direct effects of climate variability on food systems. This could be due to the moderating effect of external funds which Pakistan received during the epoch of the War on Terror, which provided some protections during climatic shocks up to a point (Liu, Iqtidar, & Jaffar, 2019). Likewise, the dual outcome of population rise and its consequences similarly explain the positive impact of demography attested by (Godfray et al., 2010) saying that though sometimes population growth become a burden on the available resources , but on the other hand it stimulates productivity with the view of increased working force and innovation. Interestingly, the non-significant effects of GDP per capita growth on the Hunger Index challenge the conventional wisdom that economic growth automatically improves food security. This is consistent with debates presaging the growth-oriented architectures that do not anticipate sustainable socioeconomic divergence and geographical disparities in the distribution of resources (FAO, 2016). Applying the same to agricultural land use yielded no direct impacts, a situation concurred with by issues noted by (Tilman et al., 2002) by noting that there is significant potential for beneficial land management in agricultural land. Combined, these observations support the need to anchor mainstream global theorization in region and geopolitical context.

6. Conclusion

This paper offers important recommendations of climate change, social and economic status, and food insecurity, particularly cereal production and a new Hunger Index for Pakistan. Comparing short and lagged effects, it is also suggested to examine the relationships as dynamic and complex, by using more complex econometric methods like ARDL model. The results dovetail with global research, which has established the negative effect of higher temperatures and climate risk on yields and food security (Lobell, Schlenker, & Costa-Roberts, 2011; Schlenker & Lobell, 2010). However, this study also states certain regional characteristics, like the role of population as both an emerging pressure on the resources in the short-term and a source of development in the long-term with population support for innovation in the agricultural industry. Hence the positive lagged effects of precipitation and sustainable agricultural land use call for increased investment in climate-smart agriculture, irrigation, efficient farming practices and water management systems (Rosenzweig et al., 2014). On the other hand, the weak relationship between the results and GDP per capita growth, as well as the nonsignificant direct effects of the agricultural land use, points to the fact that policy efforts beyond mere economic growth are required, but besides this equitable resource distribution and sustainable practices are called for (FAO, 2016). The constructed Hunger Index offers a far more localized and accurate depiction of food insecurity for a given region due to problems with Indices such as the GHI. This policy innovation demonstrates the need to develop and apply analytical instruments that meet the socio-climatic conditions of developing nations such as Pakistan. The conclusions also help to understand weak and strong connections between climatic and socio-economic conditions and give important recommendations for practical actions to practitioners and policy makers. It must also be noted that the phenomena analyzed in the study hold potential for understanding the experiences of other climate vulnerable countries as well. The above findings indicate that several variables have significant lagged effects and hence require forward looking as policies that capture long term impacts of current actions. Hence, the results point towards a more proactive that centers on climate change adaptation measures, socioeconomic uplift through development and, most importantly, investment on the resilience of agriculture. Lastly, this study fills several gaps within the existing literature which offers a comprehensive approach to tackle the challenges posed by climate change to food security solutions. Despite these weaknesses, there are many significant implications that arise from the study for climate science, agricultural economics, and policy literature. To that end, in the future studies further work must be made based on these findings adding regional perspectives, non-linear ways and dynamic approaches to improve the concept of food security concerning the current global evolutions. Findings from this study have important policy recommendations for dealing with food insecurity in Pakistan. This suggests that the positive influence of climate vulnerability comes with a one-year lag and emphasizes the importance of long-term investments in climate change adaptation including transport and storage infrastructure improvements, adoption of climate smart crops and development of early warning systems for extreme weather (Lipper et al., 2014). The mixed effects of population growth suggest adopting a dual approach: meeting short term raw material shortages while catalyzing labor force growth through additional education, skill development and better Farming techniques.

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