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The effect of Climate Change on Food Security in Morocco: An ARDL Econometric Analysis of Population Food Accessibility

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Abstract

Currently, the agricultural sector is becoming increasingly vulnerable to climate hazards, and this vulnerability is evident at several levels, such as sufficient access to good quality food at reasonable prices. To this end, they affect the four dimensions of food security, namely availability, accessibility, stability and utilisation. This study aims to demonstrate the effect of climate change on the prevalence of undernourishment, with a view to guiding decision-makers towards the adoption of strategies to reduce this indicator. The methodology adopted in this article is based on an econometric study using an ARDL model and national data comprising 30 observations. The results of the model show a negative long-term and short-term relationship between the endogenous variable (undernourishment) and the exogenous variable (cereal production). In the short term, the average temperature of the previous period has a positive influence on the prevalence of undernourishment. This suggests that a one-unit increase in the average temperature of the previous year will lead to a 0.201 increase in the level of undernourishment and food insecurity. In conclusion, the negative relationship between cereal production, which is highly dependent on climatic conditions, and the important role of cereals in reducing undernourishment must be taken into account when suggesting that the country should establish an agri-food system capable of adapting to these conditions.

Keywords: climate change, Accessibility, food security, Prevalence of undernourishment, ARDL.
JEL classification: Q18, Q54, C01, Q01
Paper type: Empirical research

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1. Introduction

Recently, several climate-related phenomena have become increasingly evident and intense, such as droughts, species extinction, cyclones and floods, rising sea levels, reduced crop potential, and diminishing water resources. The Intergovernmental Panel on Climate Change (IPCC) asserts that variations in weather conditions and erratic weather patterns, manifesting as rising temperatures and alterations in precipitation patterns, are attributable to the repercussions of greenhouse gas emissions, predominantly attributable to anthropogenic activities. The environmental Kuznets curve theory posits that a nation can prioritize economic growth over environmental preservation. It is postulated that an increase in income is concomitant with an escalation in pollution; nevertheless, this long-term economic growth may ultimately prove beneficial in terms of mitigating environmental degradation (Grossman & Krueger, 1995; Mason, 2003). Faced with this situation, the economies of African countries are becoming increasingly vulnerable, as their development and wealth are heavily dependent on the agricultural sector, which constitutes a significant proportion of their economies and is a contributing factor to their development and wealth (Dercon & Gollin, 2014; Senbet & Simbanegavi, 2017). The repercussions of climate change extend beyond agricultural production and also affect the international market for agricultural products. Consequently, these countries face the enormous task of ensuring food security for their populations(El-Nasser & Ibrahim, 2024).

Like many other countries on the African continent, Morocco's economy depends on the agricultural sector, greatly increasing its vulnerability to climate change. According to the High Commission for Planning, the agricultural sector accounts for between 11% and 18% of GDP. It follows that the above-mentioned climatic conditions pose a significant threat to Morocco's agricultural productivity and food security, particularly with regard to cereal and citrus crops (Abdelmajid et al., 2021; Mohamed Belmahi et al., 2023). The distribution of agricultural areas in Morocco is principally concentrated in the northern part of the country, along the Atlantic coast, the Rif region, and certain inland areas of the Atlas region. Northern Morocco is characterized by a Mediterranean climate, with mild, wet winters and hot, dry summers, which are conducive to agricultural activities. Nonetheless, farmland is less prevalent in the southern and interior regions, where climatic conditions are more arid and less conducive to agricultural activities(Belattar et al., 2023; Daoud et al., 2014; Salhi et al., 2019). The agricultural performance of Morocco is closely associated with its precipitation patterns, about 80% of the cultivated areas are rain-fed, which contributes to over 40% of the agricultural value added during average years(Mengoub et al., 2021). According to data from the Food and Agriculture Organization (FAO) of the United Nations, cereals, with wheat being of particular significance, play a pivotal role in ensuring food security. Morocco's diet is predominantly cereal-based, with wheat accounting for around 255 kilograms of the total amount of cereal consumed per person per year. From 2000 to 2020, the coefficient of variation of wheat yield in Morocco was recorded at 0.34, in comparison to 0.23 in Tunisia, 0.18 in Algeria and Spain, 0.11 in France, and 0.06 in Turkey. In consideration of the prevailing consumption patterns, the repercussions of protracted droughts are rendering the nation increasingly reliant on imports of these products, thereby subjecting it to the vicissitudes of global markets(Mohamed Belmahi et al., 2023). The conceptualization of food security in Morocco can be approached through the lens of the undernourishment situation of individuals. This assertion is substantiated by data provided by the Food and Agriculture Organization (FAO) in 2024. According to the High Commission for Planning, the total population of Morocco in 2022 was 36,310,591 inhabitants, of which 6.9%, equivalent to approximately 2,505,430 individuals, were affected by undernourishment. Morocco experienced a downward trend in hunger from 2000-2002 to 2016-2018, indicating an improvement in the food situation for the population. Conversely, at the inception of the

2017-2019 period, the prevalence of undernourishment escalated, surpassing the average levels recorded since the year 2000.
The primary objective of ensuring food security can be linked to the efficiency of the nation's agricultural sector. This is achieved by ensuring its proper functioning for the availability and quality of food products. However, beyond this consideration lies the issue of economic access to food, particularly for individuals in fragile social circumstances who are unable to meet their dietary requirements. Evidently, low-income households are the most vulnerable to fluctuations in food prices and lack the financial means to procure these products(Benjelloun, 2004; Capone et al., 2013, 2014; Ramadan, 2019). The objective of this study is to analyze the impact of climate variations, income and cereal production on the Moroccan population's access to food, as summarized by undernourishment, one of the food security indicators used by the Food and Agriculture Organization of the United Nations. This study will use an ARDL model methodology to determine whether there is a long-term relationship between undernourishment and climate variables, particularly temperature and rainfall, for the period 1992-2021.

2. Literature review

Since the 1970s, at the time of the world food crisis, the issue of food security has evolved and is now a widely debated concept. The concept of food security has been defined in a variety of ways. The United Nations (1975) define it as the capacity to supply the world with basic food products in order to sustain growth in food consumption, whilst controlling fluctuations and prices. The Food and Agriculture Organization of the United Nations (1996) define it as ensuring physical and economic access to the food people need at all times. Based on these definitions, the Food and Agriculture Organization of the United Nations has introduced four dimensions: food availability; economic and physical accessibility to food; utilisation; and stability of food over time. The measurement indicators for each factor are presented in the following table:

❖ ***Availability:*** The present dimension is concerned with the issue of inequality (i.e., poverty and income disparities), and it emphasizes all aspects related to people's social, physical, and economic access to available food(Ashley, 2016; Reig, 2012);

❖ ***Accessibility*:** This dimension focuses on the problem of inequality (poverty, income disparities), and emphasizes all aspects related to people's social, physical and economic access to available food. (Ashley, 2016);

❖ ***Food stability*:** At national level, food stability is achieved when the entire population is guaranteed consistent access to sufficient nutrition, thereby enabling them to maintain optimal levels of health and well-being. The issue pertains to the long-term stability and sustainability of the food supply(Aurino, 2014, Ashley, 2016).

❖ ***Utilization:*** Refers to the manner in which individuals can utilise food availability based on its nutritional value(Ashley, 2016).

Ensuring food security for the population has become a necessity for many economies, particularly for developing countries. However, structural and cyclical challenges are hampering this process. The recent emergence of COVID-19 has had a considerable impact on the food system, disrupting the global food supply and transport chain.This has resulted in a marked increase in the prevalence of undernourishment on a global scale labor shortages due to health concerns and transportation and delivery issues of food products, primarily attributable to travel restrictions. The world has also witnessed heightened demand and instances of panic buying, attributable to the prevailing uncertainty surrounding the pandemic(Chari et al., 2022; Tonnang et al., 2023; Alabi & Ngwenyama, 2023). According to estimates by the Food and Agriculture Organization of the United Nations (FAO), Africa is the continent most affected by undernourishment, with 20.4% of the world's population affected. This figure has been rising steadily since 2015. Asia has 384.5 million undernourished people, or 8.1% of the world's

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population, followed by Latin America and the Caribbean (6.2%) and Oceania (7.3%). As mentioned above, the African continent accounts for a significant proportion of the global prevalence of undernourishment. Five regions of the African continent have a high prevalence of undernourishment, particularly in the Middle East and West Africa, while Southern Africa and North Africa, including Morocco, have low levels of undernourishment(FAO, 2024).

Table 1. dimensions and Indicators of food security.

Dimensions	*Food security indicators*
Physical availability to food	Average dietary energy supply adequacy
	Average value of food production
	Share of dietary energy supply derived from cereals, roots and tubers
	Average protein supply
	Average supply of protein of animal origin
economic and physical access to food	Percentage of paved roads over total roads
	Road's density
	Rail lines density
	Gross domestic products (in purchasing power parity)
	Domestic food price index
	Prevalence of undernourishment
	Share of food expenditure of the poor
	Depth of the food deficit
	Prevalence of food inadequacy
stability over time	Cereal import dependency ratio
	Percent of arable land equipped for irrigation
	Value of food imports over total merchandise exports
	Political stability and absence of violence/terrorism
	Domestic food price volatility
	Per capita food production variability
	Per capita food supply variability
Utilization	Access to improved water sources
	Access to improved sanitation facilities
	Percentage of children under 5 years of age affected by wasting
	Percentage of children under 5 years of age who are stunted
	Percentage of children under 5 years of age who are underweight
	Percentage of adults who are underweight
	Prevalence of anemia among pregnant women
	Prevalence of anemia among children under 5 years of age
	Prevalence of vitamin A deficiency in the population
	Prevalence of iodine deficiency in the population

Source: FAO. 2015.

In order to comprehend the relationship between climate change and food security, a number of researchers are endeavoring to address this relationship through empirical testing, with a view to quantifying the effect of climate hazards on agricultural production and its implications for food security. It is well established that greenhouse gases (GHGs), like CO_2, CH_4 and N_2O, are the primary cause of the disruption to meteorological conditions observed in recent decades. This is largely due to human activities originating from energy, industrial, transport and agricultural sources. In the face of these changing climatic hazards, there is an urgent need for cooperative strategies to be implemented in order to preserve the planet and guarantee the sustainability of natural resources(Filonchyk et al., 2024). The impact of greenhouse gas emissions on food security has been demonstrated by a negative correlation between these emissions and food security. Specifically, an increase in greenhouse gas emissions has the potential to result in an increase in the prevalence of malnutrition. A Study using a NARDL model, the asymmetric effects of climate on the Food Production Index (FPI), carried out by Soumbara & El Ghini, 2024, the results showed that rainfall and temperature have a long-term effect on agricultural productivity, and that the relationship shows that an increase in rainfall and temperature will lead to an improvement in food production, in addition and concerning the asymmetry of the effect of temperature and precipitation on the index of food production in Morocco, precipitation presents an asymmetric effect meaning that Moroccan agricultural production reacts more strongly to increases in rainfall than to decreases, on the other hand temperature does not present this asymmetry. Also (Ani et al., 2022) demonstrated that variations in rainfall and temperature levels have a significant impact on food security, exacerbating the situation of malnutrition in Nigeria. In addition. for Ringler, 2010 and Molotoks et al., 2020 highlighted the detrimental consequences of global warming on agricultural yields, altering global food prices and impeding the capacity of developing countries to ensure food security and complicating the resilience of the agricultural sector. To this end, the implementation of adaptation strategies based on the use of plant growth-promoting microorganisms (PGPM) may be a solution that offers considerable potential for improving agricultural performance, even under adverse climatic conditions(Zellou et al., 2025). In addition, renewable energy and agricultural credit in South Asia, modelled using the dynamic common correlation effect estimation method (DCCE) developed by (Chudik & Pesaran, 2015), have a significant effect: the use of renewable energy improves food security in the short term, even if its impact on long-term security is less significant. Nevertheless, access to agricultural credit has been identified as an essential factor in improving long-term food security, enabling farmers to invest in productive inputsRehman et al., 2024. With pessimistic projections for Morocco's future climate indicate that by 2050, the country will have experienced an increase of 1.3°C and a fall in average annual rainfall of 11%. (Balaghi, R., Dahan, R., ., 2015; Brouziyne et al., 2018), This will put considerable pressure on the agricultural sector, slowing down the country's economic and sustainable development. The issue of people's purchasing power is also a major concern, given its significant negative impact on food security. As (Mahrous, 2019) demonstrates, an increase in food prices leads to a reduction in consumers' purchasing power and their ability to access nutritious food. Conversely, it has been shown that income (measured by GDP per capita), accompanied by food supply, has a significant positive effect on food security: an increase in income is associated with an improvement in food security.Also population growth according to an integrated framework of a computable general equilibrium model has a significant long-term impact in aggravating the risk of food deficit, also for the mode of consumption follows a change from one year to another, for example between 1995 and 2007 there was an increase in the demand for primary production net of food (Amiri et al., 2021; Rochdane et al., 2014). Given this change in consumption patterns, cereal production may no longer be sufficient to meet the food needs of the population by 2034, as shown by the simulations of (Amiri et al., 2021). These simulations predict a decline in per capita cereal availability unless there is a significant reduction in consumption or an increase in productivity.

In the context of a persistent drought and declining water resources, the implementation of national strategies, such as the Green Morocco Plan, has exerted a significant influence. This strategy has promoted the development of export-oriented, intensive agriculture, which has resulted in substantial exploitation of water resources, particularly impacting food crops and family farming systems. The overexploitation of groundwater, a phenomenon that is particularly evident in the Souss-Massa region, has compelled agricultural producers to seek alternative grazing grounds, leading to the migration of these producers to more arid regions, such as Zagora(Abdelmajid et al., 2021).

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Improving food security today cannot be achieved without a fundamental overhaul of governance structures, with the participation of all stakeholders. This requires combining non-sectoral policies and strategies with the implementation of effective impact assessment mechanisms. It is therefore imperative that agricultural, social, environmental and economic policies be coordinated and interconnected within a unified strategy for food sovereignty Zahour, 2021. The interconnection of all actors through the implementation of government policies that promote local production, short food supply chains and diversified subsistence systems, while ensuring the equitable redistribution of productive resources such as land, water and finance, as well as the promotion of traditional and agroecological knowledge, is essential in this regard. Integrating climate justice into Moroccan agricultural policies requires the establishment of insurance mechanisms, targeted social safety nets and participatory decision-making platforms. The aim is not only to adapt agriculture to climate change, but also to fundamentally transform the food system to make it resilient, inclusive and sustainable. Morocco, which is a regional leader on climate issues, has the opportunity to become a model for integrated agroecological transition by combining local knowledge, scientific innovation and community engagement.

Based on the studies presented above, the following hypotheses can be formulated:

Hypothesis 1*: The temperature variable has a positive effect by increasing the prevalence of undernourishment in Morocco;*

Hypothesis 2*: the precipitation variable has a negative effect by reducing the prevalence of undernourishment in Morocco;*

Hypothesis 3*: Since cereal production is highly dependent on rainfall, this variable has a negative effect on the prevalence of undernourishment by improving food security in Morocco;*

Hypothesis 4*: Per capita income has a negative effect on the prevalence of undernourishment by improving the standard of living and accessibility of food for the Moroccan population.*

3. Data and methodology

The objective of this econometric study is to assess the impact of climate variability on food security. The study uses an ARDL model to analyse the long-term and/or short-term relationship between these variables. If the objective is to explain the dependence of an endogenous variable on its own past values and the past values of exogenous variables, and if the order of integration is I(0) or I(1), it is necessary to use the autoregressive distributed lag (ARDL) models developed by Pesaran et al. 2001, the bounds test approach was used to test for the existence of a long-term relationship between variables. Before using a given model, it is necessary to perform a unique analysis of the series of variables used, supplemented by rigorous testing procedures, in order to ensure the optimal selection of an econometric model.

3.1. definition and data sources

The variables used in this analysis cover the period from 1992 to 2021 and are as follows: average annual temperature (°C), average annual rainfall (mm), cereal production (metric tonnes), adjusted net national income per capita (annual growth in %) and prevalence of undernourishment (percentage of the population).

Due to the unavailability of a large number of observations for these variables, we limited our analysis to 30 observations, which influenced the choice of the number of variables.

Table 2: variables and sources

Variable	Temperature	rainfall	cereal production	income per capita	prevalence of undernourishment
Source	Global Climate Monitor		world bank		FAO

Source: Authors.

3.2. The correlation matrix and descriptive statistics

Before modelling the interaction between climate parameters and the food security variable, represented by one of the indicators provided by the Food and Agriculture Organisation of the United Nations (FAO), namely the prevalence of undernourishment, a correlation matrix will be used to describe the relationship between the variables. The present analysis shows a weak positive correlation between the prevalence of undernourishment and average annual rainfall, as well as adjusted per capita national income. Conversely, a negative correlation was observed between the prevalence of undernourishment and average temperature and cereal production. For the variable cereal production shows a positive correlation with rainfall (0.23), indicating that rainy years favor production. Conversely, the negative correlation with the prevalence of undernourishment (-0.28) highlights the undeniable central role of cereals in national food security: a good harvest increases the availability of staple foods and reduces reliance on imports. Conversely, years of low production, often due to drought, increase the food vulnerability of populations. Also, these results therefore confirm the strong dependence of cereal yields on climatic conditions, particularly water availability, which is the main constraint on rain-fed agriculture in Morocco.

Table 3: The correlation matrix

Variables	prevalence of undernourishment	Temperature	Rainfall	income per capita	cereal production
prevalence of undernourishment	1	-0,314	0,099	0,013	-0,280
Temperature	-0,314	1	-0,219	0,065	0,191
Rainfall	0,099	-0,219	1	0,187	0,232
income per capita	0,013	0,065	0,187	1	0,692
cereal production	-0,280	0,191	0,232	0,692	1

Source: Authors' estimations.

Table 4: descriptive statistics

Variable	Observations	Minimum	Maximum	Mean	SD
prevalence of undernourishment	30	3,500	8,000	5,320	1,293
Temperature	30	18,637	20,517	19,798	0,455
Rainfall	30	122,241	374,771	219,238	57,111
income per capita	30	-7,162	10,231	2,133	3,811
cereal production	30	1783230,000	11687921,960	6509337,280	3048163,476

Source: Authors' estimations.

After Granger's causality test, two significant results were obtained, summarised in the following table. With both p-values below 5%, we can reject both null hypotheses, namely that temperature does not cause undernourishment and that per capita income does not cause undernourishment. In other words, there is a unidirectional relationship from temperature to undernourishment and from per capita income to undernourishment.

Table 5: Granger Causality

Null Hypothesis	F-Statistic	Prob
average temperature does not Granger Cause prevalence of undernourishment	3.88	0.035
income per capita does not Granger Cause prevalence of undernourishment	4.32	0.025

Source: Authors' estimations.

3.3. Estimating the model

As a preliminary step, we will then have the model represented by the following linear function:

$$Pre^{Und} = \beta_0 + \beta_1 * Prod^C + \beta_2 * TEM^m + \beta_3 * PRECP^m + \beta_4 * Inc^C + \mu.$$

where the variables are defined as follows:

- Pre^{Und} : Prevalence of undernourishment (%);

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- Prod^C : Cereal production (metric tonnes);
- TEM^m : Average annual temperature(°C);
- PRECP^m : Average annual rainfall (mm);
- Inc^C : income per capita (annual growth in %);
- β_0 : the constant;
- $\beta_1, \beta_2, \beta_3, \beta_4$: model coefficients;
- μ : the error.

To analyze the short- and long-term effects of the explanatory variables on GDP per capita in Morocco, the ARDL model will be represented as follows:

$$\Delta Pre^{Und} = a_0 + \sum_1^q a_{1i}\, \Delta Pre^{Und}{}_{-1} + \sum_1^q a_{2i}\, \Delta TEM^m{}_{-1} + \sum_1^q a_{3i}\, \Delta PRECP^m{}_{-1} + \sum_1^q a_{4i}\, \Delta \text{Prod}^C{}_{-1} + \sum_1^q a_{5i}\, \Delta \text{Inc}^C{}_{-1} + b_1 TEM^m{}_{-1} + b_2 PRECP^m{}_{-1} + b_3 \text{Prod}^C{}_{-1} + b_4 \text{Inc}^C{}_{-1} + + b_5 Pre^{Und}{}_{-1} + e_t$$

The elements of this function are defined as follows:

- Δ : First difference operator
- a_0 : the constant;
- a_1, a_2, a_3, a_4, a_5 : Short-term effects;
- b_1, b_2, b_3, b_4, b_5: Long-term dynamics of the model;
- e_t: Error term.

After a descriptive analysis of our variables and modelling of the ARDL model, we will first check stationarity, then the optimal lag in order to find the best model after its validation. The second phase will focus on the bound test, through which we will obtain the long-term and short-term relationships between our variables. Finally, we will discuss the results.

3.4. Result of unit root test

The first step in this empirical study is to determine whether these variables are stationary, at what level (differentiation, confidence) and the type of model:

Table 6: Dicky-fuller stationarity test (stationarity of variables)

Série	Level of differentiation	Type of model	Confidence level	T-Stat	P-value	Obs
prevalence of undernourishment	1	None	1%	-2,6663	0.0096	Stationary
Temperature	0	Trend and intercept	1%	-4,9301	0.0015	Stationary
Rainfall	0	Constant	1%	-3,6676	0.0085	Stationary
income per capita	0	Constant	1%	-9.7711	0.0000	Stationary
cereal production	0	Constant	1%	-6,4876	0.0000	Stationary

Source: Authors' estimations.

The key conclusion to be drawn from this table is the determination of whether these variables are stationary and, if so, at what level of differentiation. At this stage, and in accordance with the data presented in Table 5, it is clear that all variables remain stationary, without having undergone differentiation, except for the prevalence of undernourishment, which is stationary at the first level of differentiation. Consequently, the utilisation of the cointegration test is recommended for the purpose of verifying the existence of a long-term relationship. As stated in the econometric literature on the treatment of time series, the transition occurs from Engle and Granger's approach, which is based on the treatment of series with an integration order of 1, to the Johansen test. The latter assumes that all series are integrated to the same order. In this case, it is preferable to use the bounds cointegration test proposed by (Pesaran et al., 2001). The ARDL (Auto Regressive Distributed Lag) model is utilised for the purpose of analysing both short-term dynamics and long-term relationships between series. The model is predicated on two steps: determining the optimal lag and testing for cointegration between series using the Fisher test.

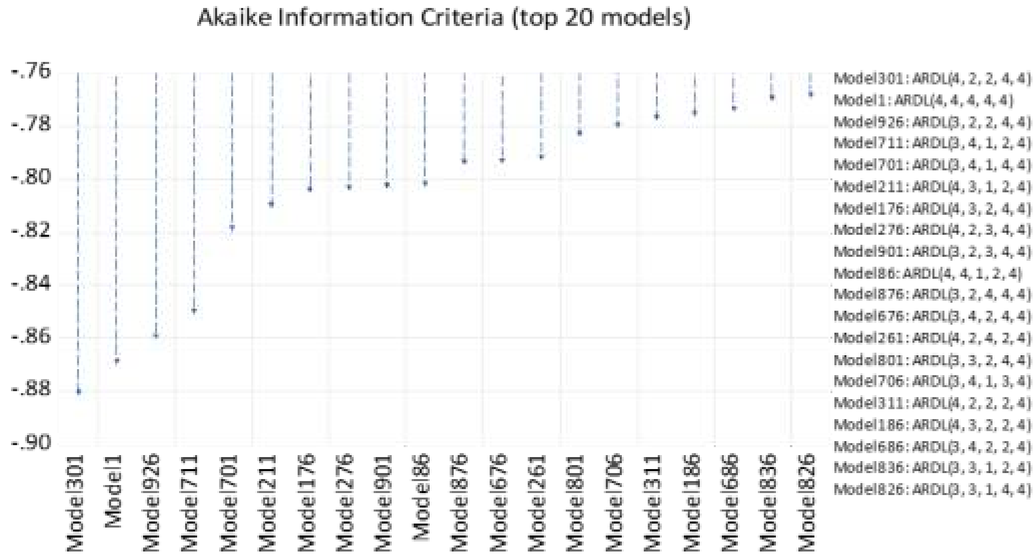
The employment of information criteria, with particular reference to the Akaike Information Criterion (AIC), facilitates the determination of the optimal lags of the ARDL model. An excessive number of lags can result in alterations to the model, particularly with regard to the autocorrelations between variables and the subsequent reduction in degrees of freedom. In order to achieve this objective, it is imperative to select an optimal number of lags, employing selection criteria such as the Akaike Information Criterion (AIC). As demonstrated in Figure 2, the application of the **ARDL model (4.2.2.4.4)** is indicated as the most appropriate, with a determination of the optimal number of lags to be 4.

Table 7: Order of delay according to selection criterion

Lag	Log L	LR	FPE	AIC	SC	HQ
0	-670.017	NA	2.44e+16	51.92442	52.16636	51.99409
1	-615.842	83.34626*	2.70e+15	49.68018	51.13183	50.09820
2	-591.389	28.21531	3.59e+15	49.72224	52.38360	50.48861
3	-555.933	27.27370	3.36e+15	48.91794	52.78901	50.03267
4	-474.062	31.48893	3.47e+14*	44.54323*	49.62401*	46.00631*

Source : Authors' estimations.

Figure 1: the 20 possible AIC models



Source : Estimates by the authors

After the estimation of the model (ARDL **4.2.2.4.4**), it is imperative to ascertain the validity and robustness of the model in order to obtain reliable statistical results.

First, we will begin with a multicollinearity test for the explanatory variables. The following table shows that there is no multicollinearity between our explanatory variables, meaning that each one provides its own independent information in explaining the dependent variable: the prevalence of undernourishment.

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Table 8 : test for collinearit

Variables	Centered VIF	Obs
Temp-m	3.22	The explanatory variables do not pose a problem of collinearity. VIF > 10 → high multicollinearity. VIF between 5 and 10 → moderate. VIF < 5 → acceptable.
Temp-m (-1)	2.34	
Temp-m (-2)	3.92	
$Prod^{C}$)	4.39	
$Prod^{C}$ (-1)	3.77	
$Prod^{C}$ (-2)	3.59	
$Prod^{C}$ (-3)	5.51	
$Prod^{C}$ (-4)	4.91	
Precep-m	4.15	
Precep-m (-1)	4.54	
Precep-m (-2)	2.42	
Inc	5.38	
Inc^{c} (-1)	4.29	
Inc^{c}(-2)	7.91	
Inc^{c}(-3)	6.76	
Inc^{c}(-4)	6.21	

Source: Authors' estimations.

The subsequent table provides a synopsis and presentation of the test for normality of the residuals, autocorrelation, and the homoscedasticity of the errors. The coefficient of determination of 0.996 indicates that the explanatory variables collectively account for approximately 99% of prevalence of undernourishment, a finding that is further substantiated by the adjusted R^2 of 0.980. In order to ascertain the normality of the errors, a p-value of 0.39 was determined, in conjunction with a Jarque-Bera statistic of 1.85. This evidence supports the null hypothesis that the errors are normally distributed. The Breusch-Godfrey test revealed that there was no autocorrelation between the errors, and the Breusch-Pagan-Godfrey test indicated that there was no heteroscedasticity. In light of the aforementioned effects, it can be concluded that the model under scrutiny is robust.

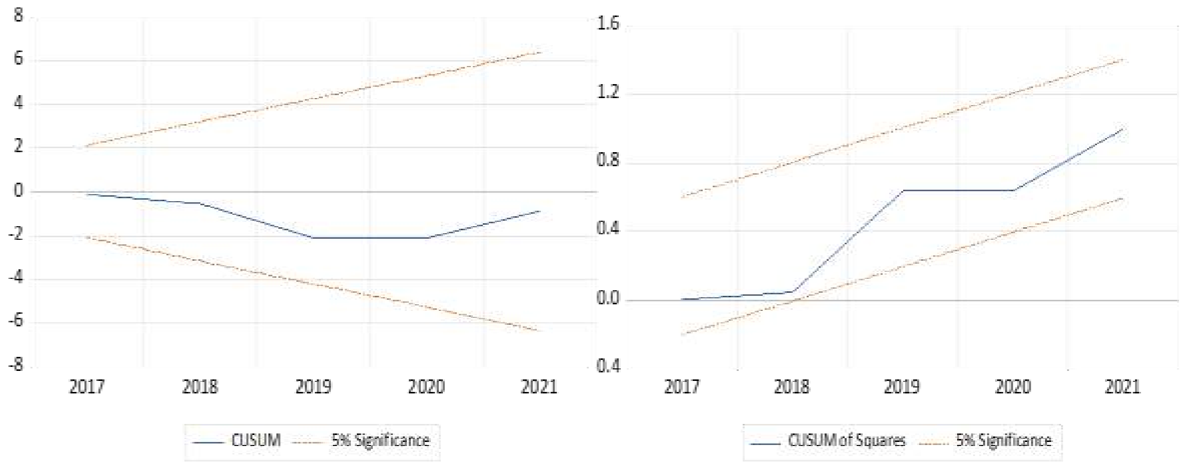
Table 9: model validity test

Test	Null hypothesis	J.B/ F-stat/T	P-value	Obs
Jarque-Bera	The residues are normally distributed.	1.85	0.39	The residuals of the model are normally distributed.
Breusch-Godfrey	The absence of autocorrelation	0.49	0.65	The residuals are uncorrelated.
Breusch-Pegan-Godfrey	Homoskedasticity	0.35	0.95	The variance is constant.
R^2	0.996			
R^2 adjusted	0.980			

Source: Authors' estimations.

By testing the stability of the cumulative sum (CUSUM) and the cumulative sum of squares (CUSUMQ), we can verify the short- and long-term stability of the model's coefficients, as shown in the following figure.

Figure 2: CUSUM AND CUSUMQ2 stability test



Source: Authors' estimations.

From the figure above, the CUSUM and CUSUMQ2 values of the recursive residuals remain within the critical limits, indicating that the coefficients are stable throughout the sampling period.

3.5. Test of cointegration at the bounds.

As previously mentioned, we have carried out a residual diagnosis to check the robustness of the model. We also tested the stability of the model throughout our period. Now, we will test the existence of the long-term relationship using the cointegration test proposed by (Pesaran et al., 2001).

Table 10: Test of cointegration at the bounds

F.Stat	**7.33**	
K	**4**	
Risk	**I (0)**	**I (1)**
1%	**3.29**	**4.37**
2.5%	**2.88**	**3.87**
5%	**2.56**	**3.49**
10%	**2.2**	**3.09**

Source: Authors' estimations.

According to the table above, the F-statistic value is 7.33, which exceeds all the upper bound values. This implies that the null hypothesis of non-cointegration is rejected at 99% of the confidence interval, concluding that there is a long-term relationship.

4. Results

After verifying the existence of a long-term relationship between the variables, as presented and verified by the statistical value F, which is 7.33, exceeding all upper limit values, we will now evaluate the degrees of this relationship between these variables in the long and short term. The following tables demonstrate these relationships.

4.1. Long–run and short–run results

As demonstrated in the table 11, the estimated long-term model signifies a predominantly significant relationship between the endogenous variable (Prevalence of undernourishment) and the exogenous variable (Cereal production). This variable is found to be significant at the 1% level with a p-value equal to 0.0045, thereby indicating the presence of a negative long-term relationship with a coefficient equal to -5.34e-07 between these two variables. For the remaining variables, it is observed that these are non-significant, thus indicating the absence of a long-term relationship.

Table 11: Long-term dynamics.

Dependent variable: Pre^{Und}				
Variables	**Coefficient**	**SD**	**T-statistics**	**P-value**
Temp-m	**-0.492**	**0.91**	**-0.540**	**0.611**
Prod^{C}	**-5.34E-07**	**1.09E-07**	**-4.902**	**0.0045**
Precep-m	**0.010**	**0.0065**	**1.647**	**0.160**
INC	**-0.333**	**0.213**	**-1.563**	**0.1786**
Constant	**16.463**	**18.407**	**0.894**	**0.4121**

Source: Authors' estimations.

The results of this study indicate that cereal production can contribute to ensuring food security and reducing the prevalence of undernourishment. It is also noteworthy that there are no long-term effects of climatic parameters on the prevalence of undernourishment. Several studies have been conducted to assess the impact of climate change on agricultural yield variability. The results of these studies confirmed a positive correlation between rainfall and agricultural gross domestic product (GDP), as well as a negative correlation between temperature and agricultural GDP. The relationship between these two variables shows that a one degree Celsius increase can lead to a decline of between 2.07% and 1.26% in agricultural GDP(Benkachchach & El Issaoui, 2024). We can therefore conclude that climate variability has no direct long-term impact on the prevalence of undernourishment, but that cereal production, which is dependent on rainfall, has a negative effect on food insecurity. and contributes to reducing undernourishment in Morocco.

Table 12 : error-correction model

Dependent variable: Pre^{Und}				
Variables	**Coefficient**	**SD**	**T-statistics**	**P-value**
D(Pre$^{Und}(-1)$**)**	0.090	0.095	0.939	0.3906
D(Pre$^{Und}(-2)$**)**	-0.186	0.092	-2.002	0.1016
D(Pre^{Und}**(-3))**	0.119	0.081	1.464	0.2030
D(Temp-m)	0.151	0.074	2.031	0.0980
D(Temp-m (-1))	**0.201**	**0.078**	**2.568**	**0.0501**
D(Prod^{C}**)**	**-8.05E-08**	**1.32E-08**	**-6.094**	**0.0017**
D(Prod^{C} **(-1)**	**3.69E-08**	**1.70E-08**	**2.177**	**0.0814**
D(Prod^{C} **(-2)**	**-4.29E-08**	**1.55E-08**	**-2.761**	**0.0398**
D(Prod^{C} **(-3)**	-2.44E-08	1.37E-08	-1.787	0.1338
D(Precep-m)	0.0007	0.000521	1.410	0.2175
D(Precep-m (-1))	**0.0010**	**0.000491**	**2.206**	**0.0784**
D(Inc)	-0.0137	0.0119	-1.148	0.3029
D(Inc^{c} **(-1))**	-0.0298	0.0183	-1.627	0.1645
D(Inc^{c}**(-2))**	0.0120	0.0167	0.723	0.5020
D(Inc^{c}**(-3))**	**0.0524**	**0.0121**	**4.318**	**0.0076**
ContEq(-1)	-0.3023	0.0322	-9.379	0.0002

Source : Authors' estimations.

The results presented in the table above show that in the short term and at the 10% level, the average temperature of the previous period has a positive influence on the prevalence of undernourishment. This suggests that a one-unit change in the average temperature of the previous year will lead to a 0.201 increase in the level of undernourishment. With regard to rainfall, it can be seen that the previous year's rainfall has a positive impact on the level of undernourishment, which may be explained by the fact that the effect of rainfall varies according to its temporal and spatial distribution. A national average may mask disparities, with some regions benefiting from rainfall while others suffer from it. For the cereal production variable, it was determined that the variables for the same period and the two-year lag period were significant, leading to a negative effect and thus improving the food security situation. With regard to national per capita income (-03), which is significant at a 5% threshold and has a positive effect, this shows that an improvement in national per capita income does not improve the food security situation. This highlights the fact that this variable does not reflect the exact purchasing power of the population, as it ignores the dimension of social inequalities and disparities. These results indicate that the establishment of effective agricultural activity has a positive impact on individuals' nutritional levels. Given the strong correlation between the agricultural sector and climatic factors, such as high rainfall and normal temperatures, we can expect an improvement in the sector's performance, which will translate into increased agricultural value added and improved food availability.

For the interpretation of the ContEq(-1) error correction term, which has a negative and significant coefficient, then indicating a low adjustment mechanism towards long-term equilibrium, meaning that any deviation from the long-term relationship is corrected by around 30% following any shock from exogenous variables.

4.2. Discussion of Results

The results obtained from the ARDL econometric model indicate that climate variables, particularly temperature, have a short-term amplifying effect on the situation of undernourishment in Morocco. In other words, high temperatures this year may impact and reduce the country's food security. Precipitation has been shown to have a positive effect on undernourishment. This result can be explained by the absence of a direct link between these two variables. However, several other variables may come into play, such as food production levels and food imports, even in the event of low rainfall. If rainfall is abundant, its effect varies according to its temporal and spatial distribution. The national average may conceal disparities, with some regions benefiting from the rain while others suffer. The national income Per capita has a positive short-term effect on undernourishment, which is paradoxical and can be explained by several factors. First, this income is national and does not reflect income disparities and inequalities, meaning that vulnerable households do not benefit from improvements in this indicator. Second, national income may be driven by other non-agricultural sectors that do not benefit poor rural areas. Short- and long-term relationships have been identified between cereal production and the prevalence of undernourishment. This relationship appeared to be negative for all periods of the cereal production variable, except for production in the previous year, which showed a positive relationship with the level of undernourishment. This indicates that cereals play an important role in reducing undernourishment among the population. As mentioned above, the Moroccan diet is mainly based on cereals, with wheat accounting for the majority, and an annual per capita consumption of around 255 kilograms.Despite these results, our study has limitations and cannot be generalized to other contexts. Among these limitations is the choice of variables, which depends on the availability and quality of data. These results may vary depending on the sample, context, time periods, or economic conditions.

It is evident from the findings of numerous studies conducted to ascertain the influence of temperature and precipitation on agricultural yield that there are deleterious effects of temperature and beneficial effects of precipitation on agricultural yield(Salahddine et al., 2017; Amiri et al., 2021; Ani et al., 2022; Soumbara & El Ghini, 2024; Zellou et al., 2025). In addition, non-climatic factors play a central role in agricultural yield. For example, the amount of arable land has a decisive influence on overall agricultural yield. However, arable land is under threat from increased construction and factory expansion, which is having a negative impact on overall agricultural yield(Gerbens-Leenes et al., 2002).As illustrated by (Otekunrin, 2022), household food insecurity in Nigeria is affected not only by climatic hazards, but also by demographic and economic factors. All these factors affect the agricultural sector in one way or another, compromising countries' food availability. However, a country whose agricultural sector contributes little to GDP can compensate for its population's level of food insecurity by importing food products.In the face of challenges that hinder food resilience and sustainability, it is essential to find innovative solutions to address current and future issues.Modernising agriculture requires promoting the adoption of new Industry 4.0 technologies to optimise the use of natural resources in this sector and make it more efficient. Taking the quality of infrastructure and road networks into account is also essential to make these technologies more effective throughout the food supply chain. Alongside these transformations, decision-makers and politicians must ensure that the social dimension is integrated into the policies and strategies implemented to guarantee citizens' access to healthy food.

5. Conclusion

The objective of this study was to analyze the impact of climate change on the prevalence of undernourishment in Morocco, highlighting the nature and extent of the short- and long-term effects of climate variables on food security. As part of this study, we opted to use the autoregressive distributed lag (ARDL) model, designed by (Pesaran et al., 2001). This methodological approach enabled us to capture the adjustment dynamics between climate fluctuations and the food security index. The empirical results obtained confirm the existence of a significant relationship between the average temperature of the previous period and the prevalence of short-term food insecurity, with a significance threshold of 10%. This observation suggests that a one-unit increase in the average temperature of the previous year leads to a 20,1% increase in the rate of undernourishment. For Cereal production, which depends on rainfall, has short- and long-term negative impacts on the prevalence of undernourishment, thereby improving the country's food security. To this end, high temperatures pose a challenge by exacerbating the country's food sovereignty situation. Cereal production, which is a staple food source, helps reduce undernourishment. The country is therefore obliged to implement a coherent and sustainable response through integrated public policies aimed at strengthening the resilience of the agricultural sector and promoting rational water resource management in order to further improve cereal production. Initiatives such as the Green Morocco Plan and the Generation Green Strategy 2020-2030 are part of this approach. However, their effectiveness will depend on the ability of institutions to articulate the environmental, economic, and social dimensions of development. On the one hand, the country has adopted strategies that promote the reduction of greenhouse gases (GHGs) by facilitating the use of renewable energies. On the other hand, it has fought against water scarcity by implementing innovative irrigation strategies and constructing dams and desalination plants. Conversely, there is a growing recognition of the necessity to provide access to contemporary mechanisms, with the aim of implementing support policies and strategies for smallholders. This is due to their heightened vulnerability to the consequences of climate change. Consequently, it is imperative to guarantee the diversification and resilience of this pivotal sector, in addition to the enhancement of living standards. (Doukkali, 2006; Sraïri, 2017) .As stated in the report by the Moroccan Ministry of Agriculture, Generation Green (2020-2030) is a programme based on two pillars: human priority and sustainability in agriculture. The human priority pillar includes the following measures: improving farmers' incomes, generalizing agricultural insurance, setting up a specific social protection framework, promoting rural entrepreneurship and strengthening agricultural

organizations. The sustainability in agriculture pillar includes the following measures: doubling agricultural GDP and exports, improving distribution chains and promoting environmentally-friendly agriculture by improving soil conservation techniques, supporting farmers in the transition to renewable energies and strengthening product health controls.)(El Bilali et al., 2021).
The objective of ensuring food security can be primarily linked to the efficiency of the nation's agricultural sector by ensuring its proper functioning through the availability and quality of food products against the effect of climate change. However, beyond this consideration lies the issue of economic access to food, particularly for individuals in fragile social circumstances who are unable to meet their dietary requirements. It is evident that low-income households are the most vulnerable to fluctuations in food prices and lack the financial means to procure these products.(Benjelloun, 2004; Capone et al., 2013, 2014; Ramadan, 2019). Confronted with these social challenges, and in accordance with Morocco's commitment to the Sustainable Development Goals, the nation is undertaking initiatives aimed at reducing health inequalities and enhancing equitable access to nutritious food for all segments of society.(Boutayeb, 2022; Bouhoudan et al., 2024). Morocco's capacity to respond to current challenges, and to build a more sustainable and resilient agricultural future, is contingent on the integration of the social and institutional dimensions, and on the combination of adaptation and mitigation strategies, with the strengthening of cooperation between the various stakeholders involved. The success of these efforts will depend on the country's ability to mobilize the necessary resources, encourage innovation and adopt a holistic approach that recognizes the interconnections between the environment, the economy and society.

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