The Interplay of Food Security, Climate Change, and the Impact of 15th April 2023 War in Sudan: A Comprehensive Analysis

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Abstract

Sudan faces deep challenges of the interrelation between food security, climate change, and the impact of the 15th April 2023 war in Sudan. This study investigates the complex relationships among these factors using the Autoregressive Distributed Lag (ARDL) model over two periods: 1961–2022 and 1961–2024, capturing pre- and post-conflict dynamics. Key variables analyzed include cereal production, population growth, annual mean precipitation, average temperature, and 15th April 2023 war-induced displacement. The results reveal significant long-run equilibrium relationships among these variables, highlighting the severe impacts of climate change and conflict on agricultural productivity and food security. Findings demonstrate that a 1% increase in cereal production land correlates with a 1.18% rise in food security before the war, but this effect diminishes post-conflict due to displacement and land loss. Population growth, while a positive contributor in stable periods, becomes non-significant under conflict conditions. Climatic variables show substantial influence, with altered precipitation patterns and rising temperatures exacerbating food insecurity. The study concludes that food security in Sudan is deeply intertwined with its social, political and environmental context. Policy recommendations include promoting climate-resilient agricultural practices, rebuilding agricultural infrastructure, and adopting integrated strategies to address the combined impacts of climate change and conflict on food security.

Keywords: ARDL model, Climate Change, Food security, 15th April War in Sudan

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Introduction

Sudan is one of sub-Saharan country, located in northeastern Africa, facing significant challenges to achieving sustainable development due to the interconnected issues of food security and climate change. These challenges have been further exacerbated by the shocking impacts of the 15th April War in 2023. This War disrupted agricultural production and damaged critical infrastructure across Sudan.

Climate projections for Sudan show increased temperatures and changing rainfall patterns (IPCC, 2019). These changes directly affect agricultural productivity, water availability, and the frequency of extreme weather events such as droughts and floods, such climatic variations are major challenges concerning food security in Sudan, which worsen existing problems related to poverty levels; malnutrition; and hunger. The influences of climate change on agriculture and food systems, additionally the reality of the ongoing 15th April War, have further compounded this situation. Changes in rainfall patterns can disrupt planting and harvesting seasons, leading to decreased crop yields and earnings losses for farmers. Additionally, extreme weather events can destroy infrastructure, damage crops, and displace communities, exacerbating food insecurity. The combination of conflict, and climate change has created a perfect storm of food insecurity in Sudan.

A study by the International Food Policy Research Institute (IFPRI, 2021) found that Sudan's agricultural productivity has remained low, with cereal yields around 30% below the regional average. This is due to factors such as limited use of improved inputs, inadequate irrigation infrastructure, and the impacts of climate change.

Understanding the complicated relationships between climate change, and food security within the conflict is vital for formulating effective policies and strategies that address these challenges in Sudan. To investigate these relationships, the study will use The ARDL approach to analyze the interdependencies among these variables, it is allowing investigation the long-term equilibrium relationships, incorporating potential short-term dynamics.

Despite the number of studies on food security, climate change, and conflict, there are still significant gaps in understanding the specific relationships between these factors in the Sudanese context. Most studies focus on isolated aspects, such as the effects of climate change on agricultural productivity or the impact of conflict on food access. Integrated analyses that consider the simultaneous effects of climate change and conflict on food security in Sudan are limited. This study aims to fill this gap by employing the Autoregressive Distributed Lag (ARDL) approach to explore the complex interdependencies among these variables, providing a more nuanced understanding of their interactions.

Objectives

The main objective of this study is to comprehensively analyze the interplay between food security, climate change, and 15th April war in Sudan through:

1. Analyze the trends of food security indicators, climate change, and political stability
2. Investigate the relationship between climate change, conflict, and their impact on food security in Sudan.
3. To provide evidence-based policy recommendations to address the challenges of food security in Sudan, climate change adaptation, and conflict mitigation strategies.

Hypotheses

H1: Climate change has a significant negative impact on food security in Sudan.

H2: The 15th April 2023 War in Sudan has a significant negative impact on food security in Sudan.

H3: There is a significant long-run equilibrium relationship between climate change, the impact of the 15th April 2023 War, and food security in Sudan.

Methodology

Data Collection: The food security data can be expressed by total cereal production in metric tons (Byrnes & Bumb, 1998; Smith & Haddad, 2001; Bezuneh & Yiheyis, 2014; Becker & Elliot, 2022), cereal land, and population growth collected from the World Development Indicators (WDI) database. Climate data includes annual mean precipitation (mm) and annual average mean temperature (°C) collected from Food and Agriculture Organization of the United Nations FAOSTAT. The data will cover the period from 1961 to 2022, this expresses to the first period of the study data. The data for 2023 and 2024 collected from the International Organization for Migration (IOM, 2024), which adjusted to estimates the displacement, cereal production land, and cereal production, these data were covered until September 10, 2024, which expresses the second period. The data of Hunger and food insecurity, food supply, and political stability and absence of violence/terrorism (index) collected from the Food and Agriculture Organization of the United Nations FAOSTAT from 2000-2023.

Methods: To evaluate the impact of climate change (annual mean precipitation and annual average mean temperature) and the 15th April War (displacement and loss of cereal production land) on food security in Sudan, the following model is specified, by utilizing the previous studies of (Ujunwa et al., 2019; Becker & Elliot, 2022; Warsame et al., 2024), which forms the theoretical basis for studying how to guide climate change, conflict, and their influence on food security as derived below.

$$\ln FS_t = \beta_0 + \beta_1 \ln PG_t + \beta_2 \ln LAND_t + \beta_3 \ln R_t + \beta_4 \ln T_t + \varepsilon t$$

where $\ln FS_t$, $\ln PG_t$, $\ln LAND_t$ $\ln R_t$ and $\ln T_t$, represent food security, population growth, cereal production land, annual mean precipitation, and annual average mean temperature, respectively whereas εt is the disturbance term.

To discover the short-run and long-run relationship between the 15th April War, climate change, and food security the study will adopt the autoregressive distributed lag (ARDL) method (Pesaran et al., 2001).

The Role of Agriculture in Sudan's Economy

Agriculture is an important component of Sudan's economy, contributing significantly to employment, GDP, and food security. Approximately 58% of the workforce is occupied in agricultural activities, providing a source of income to many Sudanese households (World Bank, 2021). The sector also contributes around 26.2% of the country’s GDP underscoring its importance in economic development (FAO, 2020).

Sudan's diverse agro-ecological zones allow for the cultivation of various crops, such as sorghum, millet, wheat, and oilseeds. The country is particularly known for its production of Arabic gum, which is a major export commodity. Furthermore, livestock is integral to the agricultural landscape, contributing to domestic consumption and export revenues (International Fund for Agricultural Development, 2019).

Despite its potential, the agricultural sector faces many challenges, including climate change, limited access to modern farming technologies, and inadequate infrastructure. These factors affect productivity and threaten food security. Addressing these challenges through investment in infrastructure, research, and sustainable practices is critical for enhancing the sector's contribution to Sudan's economy.

Food Security in Sudan

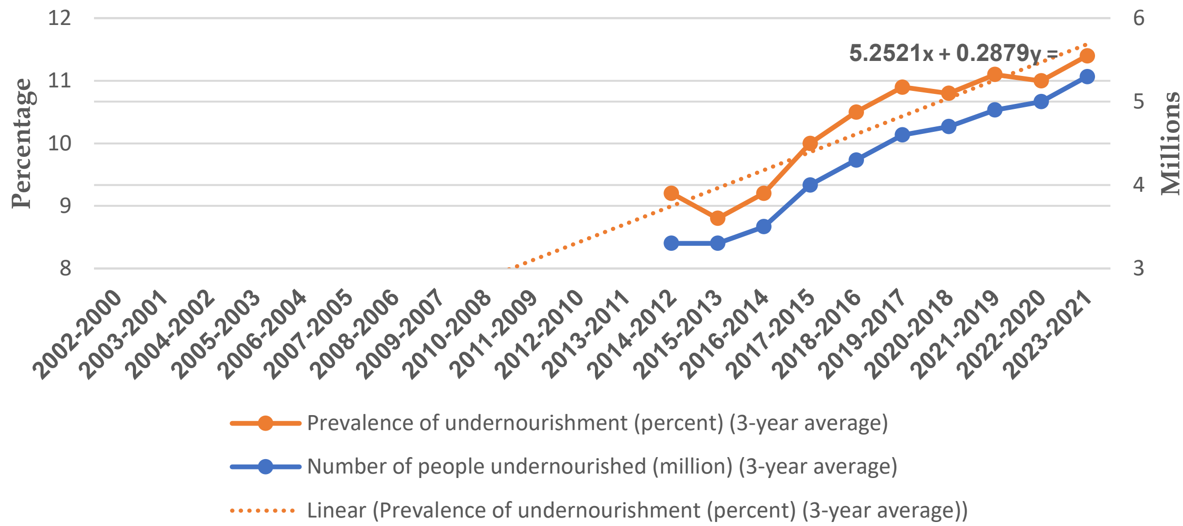
Food security in Sudan is one of the most critical issues facing Sudan’s country, as it is closely linked to the socio-economic structure. As described in the Global Hunger Index (2023), Sudan is classified among the countries that suffer from very high levels of hunger, where food insecurity affects roughly 27% of the population. The Food and Agriculture Organization (FAO, 2020) observes that the agricultural sector is pertinent for food production and the economic base, as much as it contributes about 26.2% to the Gross Domestic Product (GDP) and employs approximately 58% of the population

However, the sector faces challenges, including inadequate infrastructure, reliance on rain-fed agriculture, and limited access to modern farming techniques. According to the International Food Policy Research Institute (IFPRI, 2021), Sudan’s cereal yields are approximately 30% lower than the regional average due to outdated practices and insufficient investment in agricultural technology. Some indicators point to the food situation in Sudan, including:

Hunger and food insecurity

Sudan's hunger increased significantly from 9.2% in 2012-2014 to 11.4% in 2021-2023, However, undernourishment in Sudan is a growing trend, figure (1) shows that the prevalence of undernourishment is 11.4% in 2021-2023, it remained well above the world average which equals 9.2%. It is noted that there is a continuous annual increase in hunger among Sudanese people which increases annually by 28% this is considered a major threat to the issue of food security in Sudan. On the other hand, the number of Sudanese people exposed to hunger is increasing, as 3.3 million people in the year 2012-2014 and reaching around 5.3 million in the year 2021-2023. The major factors affecting Sudan's food security include climate change, economic slowdowns, and in addition to the impact of the ongoing war in Sudan.

Figure (1) Prevalence of undernourishment and the number of undernourished (3-year average) in Sudan



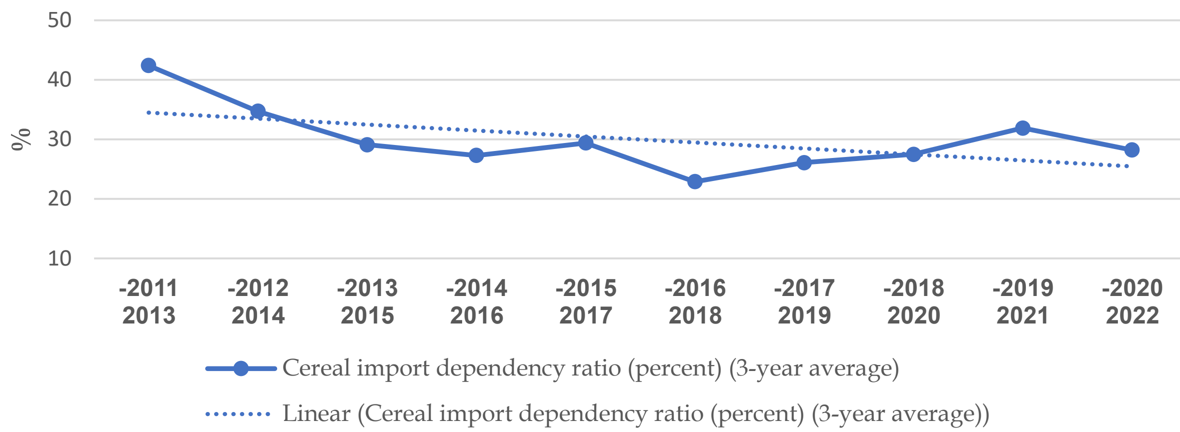
Source: FAOSTAT, 2024

Food Supply

An important indicator of food supply is the cereal import dependency ratio, which provides of how much of the available domestic food supply of cereals has been imported and how much originates in the country's production. Given the importance of cereals as staple foods and the discrepancy between consumption and production in the countries, a measure of food security is the cereal imports dependency ratio, defined as the net trade of cereals (imports minus exports) divided by the total cereals supply in a country (the country's production plus the imports minus the exports). supply in a country (the country's own production plus the imports minus the exports).

Figure (2) show the Cereal import dependency ratio in Sudan, which reported the period 2011-2013 is the highest dependence on cereals imports in Sudan with an import dependency ratio above 42%; and the lowest dependence on cereals imports during the period 2016-2018 with an import dependency ratio equal to 22.9%. In general, the trend of the cereal import dependency ratio in Sudan is declining, which is beneficial for the food supply in Sudan. This reliance on imports makes the country vulnerable to global market fluctuations, necessitating efforts to bolster local production and food selfsufficiency, considered high compared to Sudan's status as an agricultural country

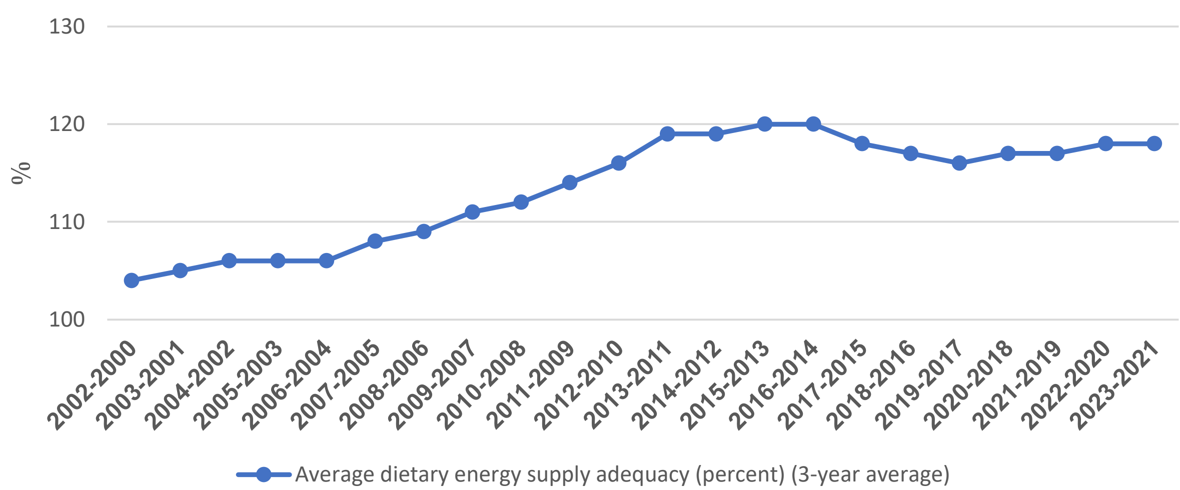
Figure (2) Cereal import dependency ratio (percent) (3-year average)



Source: FAOSTAT, 2024

Regarding to food supply in Sudan the study was measured the average dietary energy supply (DES), which calculated the calories per capita per day. Figure (3) shows the increases in the percentages of the average dietary energy supply in Sudan from 104 to 118 during the period from 2000-2002 to 2021-2023 respectively. In comparison to some countries in the region, such as Chat, Ethiopia, and Egypt the percent of average dietary energy supply is around 77, 77.6, and 133 respectively.

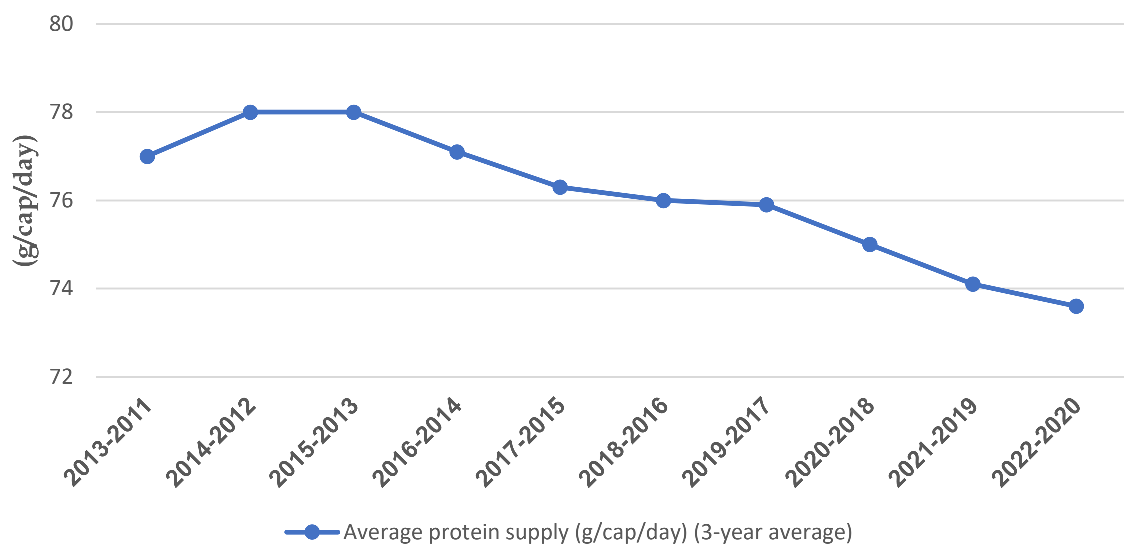
Figure (3) Average dietary energy supply adequacy (percent) (3-year average) in Sudan



Source: FAOSTAT, 2024

The average protein supply (g/cap/day) represents the estimates of per capita food supplies available for human consumption in terms of food availability. In Sudan, the average food supply (g/cap/day) had a negative growth from 77 during the period 2011-2013 to 73.6 during the period 2020-2022 Figure (4).

Figure (4) Average protein supply (g/cap/day) (3-year average) in Sudan



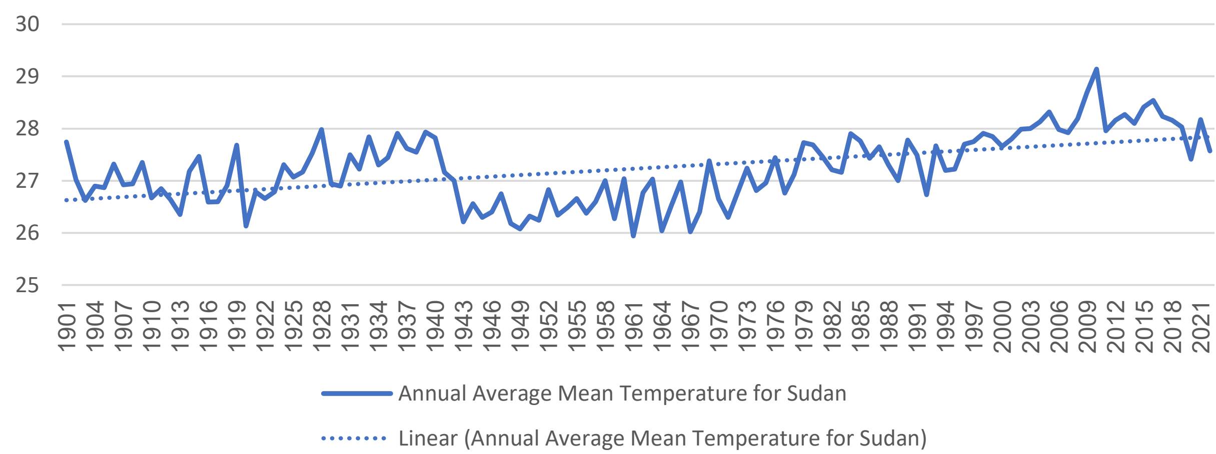
Source: FAOSTAT, 2024

Impact of Climate Change on Agriculture

Climate change has had a major impact on Sudan's agriculture. According to the Intergovernmental Panel on Climate Change (IPCC, 2019), severe temperature increases and changing precipitation patterns will harm crop yields and food security. A study by the United Nations Environment Programme (UNEP, 2020) indicates that Sudan is particularly vulnerable to climate-related shocks, with increased frequency and intensity of extreme weather events, such as droughts and floods. These climatic changes threaten not just agricultural productivity but also water supplies, complicating the food security situation. The World Bank (2020) warns that climate change may exacerbate existing inequalities, disproportionately affecting communities that depend on agriculture for their livelihoods.

Figure (5) shows the annual average mean temperature for Sudan from 1901 to 2022, illustrating the temperature trends throughout time. The figure shows a gradual increase in average temperatures over the years, this trend affects global warming, which poses significant challenges for agriculture and natural ecosystems in Sudan. Different regions within Sudan may exhibit varying temperature patterns. Northern states may suffer higher temperatures than southern states, which could influence agricultural productivity and crop selection. Rising temperatures can lead to heat stress in crops, reduced yields, and increased water demand. This could exacerbate existing issues related to food security, particularly in Sudan where agriculture is a primary livelihood. This figure is crucial for understanding how climate change impacts, particularly concerning agricultural practices and food security.

Figure (5) Annual Average Mean Temperature for Sudan

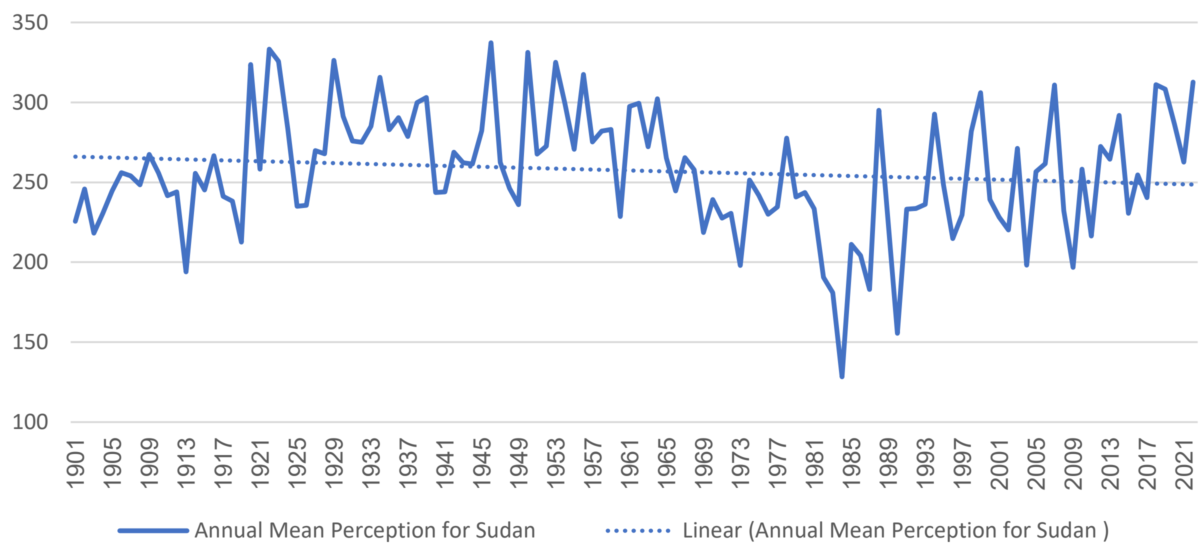


Source: FAOSTAT, 2024

Figure (6) illustrates the annual mean precipitation in Sudan, providing insights into the country's rainfall patterns over a specified period. Understanding this data is critical for evaluating the implications for agriculture, water resources, and overall environmental stability, the figure shows average rainfall, highlighting trends over the years. The trend is decreasing with large fluctuations in rainfall from year to year, indicating variability in rainfall that can impact agricultural planning and water resource management, considering the rain-fed sector accounts for about 60-70% of total agricultural production in Sudan (FAO, 2015).

Changes in rainfall directly impact crop yields. Adequate rainfall is essential for successful agriculture, and changes in patterns can lead to droughts or floods, impacting food security. Variability in rainfall can pose a challenge to water management strategies, necessitating improvements in irrigation and water conservation techniques to ensure reliable water supplies for agriculture.

Figure (6) Annual Mean Precipitation for Sudan



Source: FAOSTAT, 2024

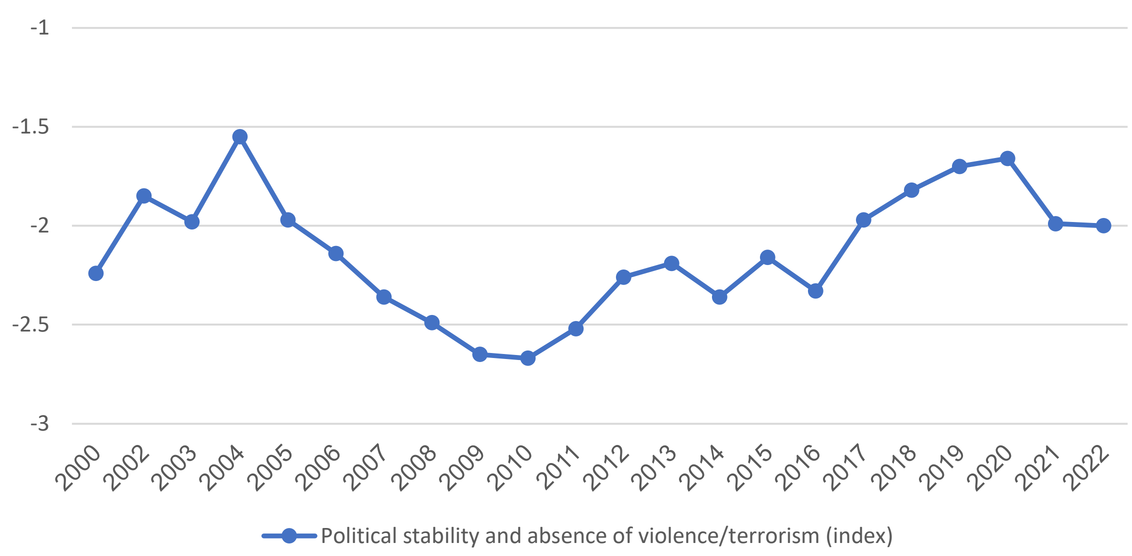
Conflict and Food Security

There is a strong relationship between conflict and food security, armed conflicts disrupt agricultural production, displace populations, and damage critical infrastructure. According to Ogunwa et al. (2019), they show how conflicts lead to significant food shortages by hindering access to markets and agricultural inputs. The ongoing conflict in Sudan, particularly the 15th April 2023 war, has intensified food insecurity by displacing millions of people and damaging agricultural land. According to International Organization for Migration (IOM, 2024), the conflict has displaced an estimated

10,756,408 people, further straining an already fragile food situation. The loss of livelihoods due to conflict increases reliance on humanitarian assistance, which is often insufficient to meet the needs of affected populations.

Figure (7) displays an index that assesses political stability and the absence of violence or terrorism in Sudan. This figure is crucial for understanding the relationship between political conditions and food security in Sudan. which illustrates fluctuations in the political stability index across time, suggesting periods of relative stability or rising conflict. Understanding these trends is essential for understanding how political dynamics influence food security. There may be a clear link between declining political stability and deteriorating food security. Areas with greater levels of violence or instability frequently experience disruptions in agricultural production and distribution systems. Regions with ongoing conflict may show lower stability scores, and affect local agricultural practices and access to markets. The figure may illustrate how violence and instability can lead to displacement of farming communities, loss of livelihoods, and reduced agricultural output, further exacerbating food insecurity.

Figure (7) Political stability and absence of violence/terrorism (index) in Sudan



Source: FAOSTAT, 2024

Interconnections Between Climate Change, Conflict, and Food Security

The relationship between climate change, conflict, and food security is complex. Studies indicate that climate change can exacerbate resource scarcity, leading to increased competition over water and arable land, thereby fueling violence (Warsame et al., 2024. The United Nations Environment Programme (UNEP) (2020) highlights that without addressing these interconnected challenges, efforts to improve food security will be ineffective. Research by Becker and Elliot (2022) reveals that climate change impacts agricultural productivity and affects social stability, as communities struggle to cope with the combined stresses of rising temperatures and changing precipitation patterns. In Sudan the complex relationship between climate change, ongoing conflict, and food security necessitates a holistic approach. Addressing these interconnected issues is crucial requires in-depth analysis using ARDL approach. The study relied on food security data as a dependent variable and climate factors (annual mean precipitation and annual average mean temperature), population growth, and cereal production land as independent variables for the period from 1961-2022 for the first period, while the second period is from 1961-2024, to assess the impact of the 15th April war 2023.

ARDL Model Diagnosis

Unit root tests

Table (1) shows the unit root test utilizing the augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests for first and second periods, which shows that the annual mean precipitation is stationary at level I(0) and the first difference I(1) for both periods. Food security, cereal production land, population growth and annual average mean temperature are stationary at I(0) for both periods.

Table (1) Unit root tests

Variable	1st Period		2nd Period	
	ADF	PP	ADF	PP
lnFS	1.673	1.538	-1.950	-1.835
1st difference lnFS	-10.624***	-27.661***	-10.750***	-27.352***
lnLAND	-1.875	-2.160	-2.084	-2.340
1st difference LAND	-11.220***	-16.587***	-8.294***	-13.366***
lnPG	-2.834	-2.819	-0.061	-2.433
1st difference lnPG	-7.764***	-8.591***	-3.550**	-9.957***
lnR	-5.059***	-5.233***	-4.951***	-4.964***
1st difference lnR	-5.670***	19.427***	-8.956***	-18.331***
lnT	-1.561	-2.814	-1.678	-2.211
1st difference lnT	-13.737***	-16.938***	-13.546***	-15.150***

***** and ** represent significance level at 1%, and 5% respectively. 1st difference and 2nd difference stand for the first difference and second difference level with natural logarithm.**

Long-run cointegration

To estimate long run cointegration using the bounds test in Table (2), where the F-bound test statistics is equal (5.773 and 4.975) for first and second periods respectively, which are greater than upper bound critical value (4.956 and 4.940), respectively at a p value < 0.01. This results from both periods suggest that the relationships among the variables have remained stable and significant over time, indicating that factors influencing food security, such as land use and population dynamics, continue to interact. Although both periods show significant cointegration, the F-statistic for the first period (5.773) is higher than that of the second period (4.975). This could suggest that while the relationships are still meaningful post-conflict, their strength may have slightly diminished, potentially due to disruptions caused by the 15th April war in Sudan.

Table (2) The F-bounds test

First Period				Second Period			
***F*-statistic**	**Significance (%)**	**K4**		***F*-statistic**	**Significance (%)**	**K4**	
		I (0)	I (1)			I (0)	I (1)
5.773	1	3.710	4.965	4.975	1	3.725	4.940
	5	2.743	3.792		5	2.750	3.755
	10	2.323	3.273		10	2.335	3.252

Table (3) summarizes the long-run coefficients and t-statistics for the explanatory variables in both periods. Regarding to the cereal production land in the first period the coefficient of 1.176806 with a t-statistic of 10.452 indicates a strong positive influence of cereal production land on food security. Each 1% increase in cereal land is associated with a 1.18% increase in food security, and the relationship is highly significant ($p < 0.01$), this result is in line with study of Becker & Elliot (2022) which applied in 15 African countries, 14 out of 15 countries find that the cereal production land has a positive significant with food security. For the second period, the coefficient drops to 0.321183 with a t-statistic of 2.081295. Although this remains a positive relationship, the effect is significantly weaker, indicating that the contribution of cereal production land to food security has diminished in second period. This change may be due to disruptions in agricultural activities and access to land caused by the conflict. For the population growth in the first period, the coefficient of 0.061514 and t-statistic of 2.498919 suggests that population growth positively impacts food security, with a 1% increase in population resulting in a 0.06% increase in food security. This relationship is statistically significant at the 5% level, this result is consistent with (Becker & Elliot, 2022). Concerning to second period, the coefficient becomes positive (0.011540) with a t-statistic of -1.360420, indicating that population growth is not statistically significant to food security for the second period. This may indicate that the population growth in second period has not translated into improved food security, possibly due to resource constraints or instability, this result is somewhat similar to the results of studies. (Faisal & Parveen, 2004; Yang & Hanson, 2009). As for annual mean precipitation in the first period, the coefficient of 1.315153 with a t-statistic of 5.193346 indicates a strong positive relationship between annual mean precipitation and food security. A 1% increase in positive precipitation is linked to a 1.32% increase in food security, with strong statistical significance ($p < 0.01$). For the second period, the coefficient decreases to 0.561181 with a t-statistic of 3.207251. While still significant, this reduction suggests that perceptions of food security have been affected by the conflict, leading to less confidence in food availability despite the positive relationship remaining intact, this result of the positive effects of rainfall on food security agree with previous studies such as (Kinda and Badolo, 2019; Mahrous, 2019; warsame et al., 2024). On the other hand, the average mean temperature for the first period, the coefficient of 0.640197 with a t-statistic of 0.124069 indicates a non-significant relationship between average mean temperature and food security, suggesting that temperature did not have a meaningful impact during this period. As for the second period, the coefficient increases to 3.039143 with a t-statistic of 1.077478, but it remains non-significant. This change may indicate that climate factors are becoming more relevant comparing to second period. Generally, the impacts of 15th April war in Sudan on food security is going harmony with previous studies (see Souza & Jolliffe, 2013; Dabalen & Paul, 2014; Ujunwa et al., 2019).

Table (3) Long-run coefficient

Explanatory variable	**1st Period**		**2nd Period**	
	Coefficient	**t-Statistic**	**Coefficient**	**t-Statistic**
Cereal production Land	1.176806	10.452***	0.321183	2.081295**
Population Growth	0.061514	2.498919**	0.011540	-1.360420
Annual Mean Precipitation	1.315153	5.193346***	0.561181	3.207251***
Average Mean Temperature	0.640197	0.124069	3.039143	1.077478
*** and ** exhibit significance levels at 1% and 5% significance levels respectively.				

To confirm the findings from the ARDL bounds test, the Johansen and Juselius (J&J) cointegration method was applied to investigate the long-term relationships between food security and relevant explanatory variables. The results are summarized in Table (4). For the first period the Trace test shows a test statistic of 79.52893, which is greater than the critical value of 69.81889, with a p-value of 0.0069. This indicates strong evidence of at least one cointegrating relationship among the variables, confirming that food security is significantly linked to cereal production land, population growth, annual mean precipitation, and average mean temperature. The Maximum Eigenvalue test also supports this, with a statistic of 36.89394 exceeding the critical value of 33.87687 and a p-value of 0.0211, indicating a significant cointegrating relationship. Regarding to the second period, the Trace test statistic of 67.84640 is lower than the critical value of 69.81889, leading to a p-value of 0.0711. While this does not provide strong evidence at the 5% level, it suggests a marginal relationship that may still be of interest for further exploration. In contrast, the Maximum Eigenvalue test for the second period shows a statistic of 34.07578, which exceeds the critical value of 33.87687, with a p-value of 0.0473. This indicates significant evidence of a long-run relationship, the overall strength may be weaker compared to the first period. To comparative analysis of periods, the results for the first period demonstrate strong evidence of cointegration, suggesting stable relationships among variables that influence food security. In the second period, while the cointegrating relationship persists, the differences in the statistical significance between the two tests imply that the dynamics affecting food security may have changed, potentially due to external factors such as conflict.

Table (4) Johansen cointegration test.

	1st Period			**2nd Period**		
Hypothesis	**Test statistic**	**5% Critical value**	**p Value**	**Test statistic**	**5% Critical value**	**p Value**
Trace test						
None*	79.52893	69.81889	0.0069***	67.84640	69.81889	0.0711
At most 1	42.63499	47.85613	0.1417	33.77062	47.85613	0.5144
At most 2	22.87714	29.79707	0.2522	18.33526	29.79707	0.5414
At most 3	10.31730	15.49471	0.2571	7.771079	15.49471	0.4902
At most 4	1.963566	3.841465	0.1611	1.155377	3.841465	0.2824
Maximum Eigenvalue						
None	36.89394	33.87687	0.0211**	34.07578	33.87687	0.0473**
At most 1	19.75785	27.58434	0.3581	15.43536	27.58434	0.7131
At most 2	12.55985	21.13162	0.4935	10.56418	21.13162	0.6905
At most 3	8.353729	14.26460	0.3439	6.615702	14.26460	0.5355
At most 4	1.963566	3.841465	0.1611	1.155377	3.841465	0.2824
** and * signify significance levels at 5% and 10% levels, respectively						

Short-run effect

Table (5) and (6) show the following analysis compares the short-run results from two ARDL models estimating the relationship between food security and various explanatory variables across two distinct periods. Regarding to cointegrating coefficient for the first period, notice that the cointegrating coefficient of -1.006302 is significant (p = 0.0000), indicating a strong long-run relationship between the variables. This suggests that deviations from long-run equilibrium are corrected over time, supporting the stability of the relationship. For the second period, the coefficient decreases slightly to -0.900884 but remains significant (p = 0.0000), indicating that the long-run relationship persists, albeit with a slightly weaker adjustment mechanism. Regarding to the short-run regressors the change in cereal production land D(LNLAND), the coefficient of 1.072764 (t-statistic = 14.04211, p = 0.0000) indicates a strong positive impact of changes in cereal production land on food security. This suggests that increasing cereal production land significantly enhances food security in the short run. For second period, the coefficient decreases to 0.968746 (t-statistic = 12.80021, p = 0.0000). Although still positive and significant, this decrease might indicate diminishing returns or increased challenges in maximizing the benefits from cereal land post-conflict. With regards to change in annual average mean temperature D(LNT), notice that the second period, the coefficient of -0.200616 is not statistically significant (p = 0.8957), indicating that changes in temperature do not have a measurable short-run effect on food security during this period. This suggests that while temperature may influence agricultural outcomes, its immediate impact on food security is negligible in the current context.

To fitted the first period model, The R-squared value of 0.896185 indicates that approximately 89.6% of the variability in food security is explained by the model. The high F-statistic (509.3187, p = 0.0000) supports the overall significance of the model. For the second period, the R-squared value slightly decreases to 0.887533, indicating that about 88.8% of the variability is explained. Although still high, the reduction could reflect additional complexities or external factors affecting food security in the later period.

The results from both periods highlight the critical role of cereal production land in enhancing food security, particularly in the short run. The persistence of a significant long-run relationship indicates that policy efforts focusing on increasing cereal land can yield lasting benefits. However, the lack of significant short-run effects from temperature changes in the second period suggests a need for further investigation into other factors influencing food security in the context of climate change and post-conflict recovery.

Table (5) Short-run effect for the first period

Variable	Coefficient	Std. Error	t-Statistic	Prob.*
Cointegrating Equation				
COINTEQ	-1.006302	0.114455	-8.792154	0.0000
Short-run Regressors: Linear (Independent)				
D(LNLAND)	1.072764	0.076396	14.04211	0.0000
Model Fit				
R-squared	0.896185			
F-statistic	509.3187			
Prob(F-statistic)	0.000000			

Table (6) Short-run effect for the second period

Variable	Coefficient	Std. Error	t-Statistic	Prob.*
Cointegrating Equation				
COINTEQ	-0.900884	0.107724	-8.362920	0.0000
Short-run Regressors: Linear (Independent)				
D(LNLAND)	0.968746	0.075682	12.80021	0.0000
D(LNT)	-0.200616	1.523875	-0.131649	0.8957
Model Fit				
R-squared	0.887533			
F-statistic	236.7450			
Prob(F-statistic)	0.000000			

Conclusions

The comprehensive analysis of this study has highlighted the complicated relationships between food security, climate change, and the impact of the 15th April 2023 war in Sudan. The findings indicate a significant deterioration in food security, exacerbated by climate change and conflict-related disruptions. The use of the Autoregressive Distributed Lag (ARDL) model has revealed a long-run equilibrium relationship among the examined variables. Notably, agricultural productivity has been adversely affected by rising temperatures and altered precipitation patterns, while the ongoing conflict has intensified food insecurity through mass displacement and destruction of agricultural infrastructure.

Key insights from the study include:

- A 1% increase in cereal production land correlates with a 1.18% increase in food security in the pre-war period, but this relationship weakened post-conflict.
- Population growth negatively affected food security during the latter period, reflecting the strain on resources amid instability.
- The agricultural sector, which employs a significant portion of the population and contributes substantially to GDP, remains highly vulnerable to climate-related shocks.

Recommendations

To address the challenges of food security in Sudan and foster resilience against climate change and conflict, the following recommendations are proposed:

1. Investment in Sustainable Agricultural Practices

- Promote agroecological methods and climate-smart agriculture to enhance productivity and sustainability.
- Support research and development in agricultural technologies that are resilient to climate change.

2. Enhancement of Agricultural Infrastructure

- Rebuild and strengthen agricultural infrastructure, including irrigation systems, storage facilities, and market access.
- Implement policies that facilitate the rehabilitation of lands damaged by conflict and climate change.

3. Robust Humanitarian Support

- Provide immediate humanitarian assistance to displaced populations and communities affected by the conflict.
- Establish food security programs that target vulnerable groups, ensuring access to adequate nutrition.

4. Development of Comprehensive Policy Frameworks

- Formulate integrated policies that address the interconnections between climate change, conflict, and food security.
- Foster collaboration among governmental, non-governmental, and international organizations to implement holistic strategies.

5. Community Engagement and Education

- Involve local communities in the planning and implementation of agricultural and food security initiatives.
- Conduct awareness campaigns to educate communities about climate change adaptation strategies and sustainable practices.

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