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Article

Assessing the impact of climatic factors on the trade performance of South African maize commodity

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Abstract: The maize commodity is of strategic significance to the South African economy as it is a stable commodity and therefore a key factor for food security. In recent times climate change has impacted on the productivity of this commodity and this has impacted trade negatively. This paper explores the intricate relationship between climatic factors and trade performance for the South African maize. Secondary annual time series data spanning 2001 to 2023, was sourced from an abstract from Department of Agriculture, Land Reform and Rural Development (DALRRD) and World Bank's Climate Change Knowledge Portal. Autoregressive Distributed Lag (ARDL) cointegration technique was used as an empirical model to assess the long-term and short-term relationships between explanatory variables and the dependent variable. Results of the ARDL model show that, average annual rainfall (β = 2.184, p = 0.056), fertilizer consumption (β = 1.919, p = 0.036), gross value of production (β = 1.279 , p = 0.006) and average annual surface temperature (β = −0.650, p = 0.991) and change in temperature for previous years, (β = −0.650, p = 0.991) and the effects towards coefficient change for export volumes, (β = 0.669, p = 0.0007). In overall, as a recommendation, South African policymakers should consider these findings when developing strategies to mitigate the impacts of some of these climatic factors and implementing adaptive strategies for maize producers.

Keywords: ARDL model; maize; bound test; trade performance; South Africa

1. Introduction

Climate change defined by long-term changes in temperature and weather patterns, poses major challenges to worldwide agricultural productivity. Climate change has a particularly profound impact in South Africa, which is heavily reliant on agriculture for both domestic consumption and export performance. Scientific evidence indicates that this issue endangers the health of all living organisms and the ecosystem (Rudolph and Zenda, 2024). South Africa's agricultural sector is affected by climate change, as it depends on rain and faces challenges such as deteriorating infrastructure, limited investments, and institutional incapacity (World Bank, 2021).

There is a surging need for the world, Africa, as well as South Africa to systematically consolidate the risks and opportunities that are related to climate adaptability, particularly in the agriculture sector. The impact of climate-change on the overall economy of South Africa has been relatively low, however, it is anticipated that South Africa will rank among the countries most negatively affected by climate change in the near future, which might affect both economic expansion and energy production (World Bank, 2021). Amongst the various sectors that are likely to feel the impact of climate change, agriculture is the most vulnerable since most industries rely on climate in terms of rainfall patterns, temperature, as well as humidity. More than 860,000 individuals are employed in this industry, and numerous more benefit from the downstream value-chains. The agricultural sector is the backbone of food security and contributes to export revenue. Agricultural trade ensures that countries that have climates which are more conducive for certain agricultural products can export to those countries with less favorable climatic conditions (Mmelesi and Mosikari, 2024). Thus, the changing climatic conditions mean that different countries are affected differently in terms of the agricultural products they tend to export, and this study, focuses on the impact that climate has on the trade performance for maize as a commodity. This paper assesses how these trade patterns for maize are likely to be disrupted due to changing climatic conditions; not only for South Africa as a net-exporter of maize but also for the importers of maize from South Africa (Hedlund et al., 2022).

Moreover, maize is critical to export revenue of South Africa, and it is one of the most valuable staple crops and constitutes almost 46% of the total area planted in the year of 2020 (Bradshaw et al., 2022). South Africa is the highest producer of maize in the African continent, however, it also has recently faced heatwaves that were characterized by prolonged period of high temperatures, as suggested by (Simanjuntak et al., 2023), which impedes the development of maize and affects the viability of pollen, fertilization, as well as grain maturity. Considering that South Africa exports to neighboring countries, particularly those in the Southern African Development Community (SADC) region, a significant decline in maize production poses a threat to food security in the region (Simanjuntak et al., 2023).

2. Literature review

This branch of the study presents the preliminary literature review that has shaped the critical discourses surrounding the impact of climate change on the trade performance of maize commodity in South Africa. Extraordinary efforts are made to learn from previous studies that pinpointed rigid attention towards the assessment of the relationship that exists between climate change and South African maize trade performance. Lessons on the impact of climate change on trade are drawn from various sectors, industries, from internationally, regionally, and national scenarios. This ensures that the study enables a rich and argumentative dissertation of the impact of agricultural trade on maize specifically using South Africa as a point of reference.

2.1. Overview of climate change in South Africa

The fundamental indicators of climate change according to the World Bank (2021) can be observed through changes in temperatures, precipitation, as well as natural disasters. Temperature increases in South Africa are forecast to continue increasing with the average monthly temperature pondered to rise by 2.0 °C (Degree Celsius) in 2050, and 4.0 °C (Degree Celsius) in 2090 under a high emission scenario (RCP8.5) as suggested by the World Bank Group on the South Africa risk country profile (World Bank, 2021).

Further studies on the South African risk country profile suggest that these temperature increases will be more severe between November and March, which will have a negative impact on the South African maize production calender. This becomes more serious since rising temperatures are followed by long spells of heatwave as already experienced in 2023/2024 maize season. In 2023 (Simanjuntak et al., 2023) further emphasized that heatwaves reduce maize yields by almost 80% since heat stress tends to damage pollen. Heatwaves contribute to soil moisture deficit and lower water flux, which overtime leads to poor soil fertility as well as prepares the path towards severe drought episodes. Higher rates of evapotranspiration coupled with heatwaves and lower precipitation contribute to drought. The Western and Interior regions of South Africa are the most susceptible to extremely warm temperatures. The Northern Cape, North-West, and Limpopo are forecast to reach 20 and 40 days of hotter temperatures “hot days” whereby temperatures will exceed 35 °C (Degrees Celsius) by 2050 (World Bank, 2021).

As for precipitation, South African rainfall patterns have been fluctuating because of climate changes. This affects the production of maize as well as other crops. The South-Western Cape regions of the country normally receive their annual rainfall in the form of frontal rain (during austral winter). The World Bank Group suggests models that indicate a possible decrease in precipitation in the forecast future. Along the east coast the winter rainfall is expected to increase. However, the experience of the USA (United States of America) saw a decrease of 30% in yields because of increasing rainfall above annual average (Simanjuntak et al., 2023). The north-east coast is further forecast to experience drier spells in by 2050, and a drying trend in the western section of the country, with the south-western section at higher risks of droughts at the end of the century (World Bank, 2021). The August to October Spring months are also likely to experience delays in the seasonal summer rains which has severe consequences overall.

South Africa faces significant water challenges, and this has been fuelled by climate change. The average annual rainfall is approximately 490 mm per annum which is almost half that of the global average. With increasingly high evaporation rates, only 9% of rainfall goes to the rivers. As was experienced at the start of the year, the rainfall in South Africa is also unevenly distributed low (north and western regions), and high (east and southern regions), suggesting areas susceptible to droughts and floods respectively (Engelbrecht and Scholes, 2021). With only 8% of the land area being the source of water for 50% of the country’s surface water, there is a strong case to focus on South Africa especially given the importance of water towards agricultural productivity. With water scarcity, climate change can lead to crop failure, reduced yields, changing growing seasons, new pests and diseases that can affect the agribusiness sector.

South Africa is going to continue experiencing the impact of climate change and the agriculture sector will be the most affected. The South African climate is expected to get hotter, drier, and rainfall patterns more variable than before. Furthermore, natural disasters such as droughts, floods, and new pests and diseases are inevitable (Department of Environmental Affairs, 2018).

2.2. South African maize trade performance analysis

The export earnings generated by the South African maize commodity is a major contributor to the country's GDP. Due to its exports of maize to the neighboring nations, South Africa is not only accountable for ensuring food security within its own borders, but for the food security of other nations given the production risks. From a global perspective; Brazil, USA, Ukraine, Argentina, Romania, Poland, and South Africa are the global dominant exporters of maize, and South Africa has a share of almost 2.3% and exported at least 4 million tons in 2023 (ITC, 2024). This has been a steady growth from the 3.7 million tons exported in 2022. The South African maize annual growth in value for the past five years (2019–2023) has been 44%, and the ITAC has suggested that the annual growth in quantity for the exports in the past five years is 33%.

The value of the South African maize exports reached R22.3 million in 2023. Taipei (Chinese), Republic of Korea, Japan, Mexico, Zimbabwe, Mozambique, China, Botswana, Namibia, as well as Vietnam are the major export destinations for South Africa maize (ITC, 2024). Whereas the maize imports value is at almost R4 million. Zambia, Chile, USA, Zimbabwe, and Brazil are some of the major suppliers of maize to South Africa when in needs. However, South Africa is a net-exporter of maize, and the domestic industry is dominant. The import value for maize in the past five years has decreased by 32% and decreased by 16% year over year (2022/2023).

2.3. Maize production, consumption and the South African climate changes

The impact of climate change has been a thorn in the agricultural sector for decades and continues to worsen and as a result the farming conditions have become more and more prevalent causing reduction in the production volumes. There are several studies that have proven that climate change has a direct impact on the production of maize crops both white and yellow maize (Bozzola et al., 2023). This decline in agricultural productivity consequently leads to an increase in hunger, malnutrition as well as food security especially in developing countries where their food security depends solely on the maize commodity.

Major export destinations for South Africa maize are SADC member who rely on maize as a staple food. There are many strategies that researchers suggest can contribute to the mitigation of global warming and climate change in different countries. These strategies include the development of climate smart agricultural practices and food systems, introduction of improved irrigation systems as well as providing farmers with education and training on how to adapt to the changes in climate. The changes in atmospheric carbon dioxide concentration, the temperature and precipitation levels may inform tools for predicting future climate conditions. The phenomenon where these instruments change from their historic original form due to conditions that are beyond human control is referred to as climate change (Rudolph and Zenda, 2024). Studies suggests that an increase in the atmospheric concentration of carbon dioxide can be advantageous or harmful to the production performance of the maize commodity.

Through stimulation process of photosynthesis and growth, the increased levels of carbon dioxide can contribute to high production levels of maize, for an example in China which is the second largest producer and consumers of maize commodity, studies suggested that a 50% increase in the concentration of carbon dioxide has increased the production level of maize by 23%, however there is another view that suggest that the negative impact of atmospheric CO_2 concentration may outweigh the benefits. In Pakistan it was predicted that the increased levels of CO_2 concentration have increased the production yield of maize, but these benefits were significantly reduced by the drought stress. The food supplies of the world are threatened by climate change because it impacts negatively on the entire agricultural production system, therefore it is crucial to understand the how the production of maize in each country is affected by climate change, to make informed decisions when it comes to the trade, international economics as well as political policies. Studies have reported that the maize production in China has been affected by temperature increases from the year 1997 to the year 2016, where the production volumes dropped by 1.7% for every 10C increase in temperature (Bozzola et al., 2023).

In the near future, the South African maize production is set to expand by 4% to 3.1 MHa for 2024/2025 season, and it currently sits at 2.6 MHa (Caldwell and Esterhuizen, 2023). Due to droughts and recent increase in prices, the area planted for maize is also set to continue increasing and this may be a way for the industry to absorb the shocks that are related to climate change. As for the consumption of maize, most South African consume the white maize due to its affordability and this trend is similar to the rest of the neighbouring countries and use the yellow maize mostly as feed. The growing population in South Africa as well as immigration of people from other countries that also rely on maize as a staple diet, have over the past years, seen South Africa maintain an average growth rate of about 2% per annum in the consumption of corn for the past decade (Caldwell and Esterhuizen, 2023). The country’s Gross Domestic Product (GDP) grew by 0.6% in 2023 and the economy is under pressure, hence maize is relatively affordable for most consumers compared to meat or other grains such as rice as suggested in 2023 by (Caldwell and Esterhuizen, 2023).

3. Methodology

3.1. Study design

The study will employ a mixed methods longitudinal study design. This design is very much convenient when investigating the phenomena that changes over a certain period of time, it combines both quantitative and qualitative approaches in order to provide an in-depth understanding of the impact of climate change on the trade performance of maize in the country.

3.2. Selection and description of study area

The study will focus on the Republic of South Africa as the primary study area, specifically targeting the maize belt, which includes key maize-producing regions. South Africa is divided into four regions, and these are the interior plateau, the eastern plateau slopes, the Cape Fold Belt, and the western plateau slope. The maize belt spans parts of the Free State, North-West and Mpumalanga provinces areas known for their fertile soils, favourable climate for maize cultivation, and significant agricultural output. The country is bordered by Namibia, Zimbabwe, Botswana, Lesotho, Eswatini, and Mozambique (World Bank, 2021). Additionally, South Africa has a 3000 km long coastline from the border of Mozambique to Namibia, with the Indian ocean along the eastern coast and the Atlantic Ocean along the western coast, converging renowned Cape Agulhas.

Moreover, the total of the dryland as suggested by the World Bank Group is 1,219,602 km^2. Positioned within what is considered a 'drought belt', South Africa is the fifth most water-scarce country in Sub-Saharan Africa. This geographic, socio-economic, and biodiversity context makes it ideal for this study. South Africa has a stable socio-political environment but faces high levels of unemployment and relies heavily on sectors such as agriculture for employment. There is a growing population that is slight above 59% and it's expected to continue growing, and this creates pressure on the existing food systems.

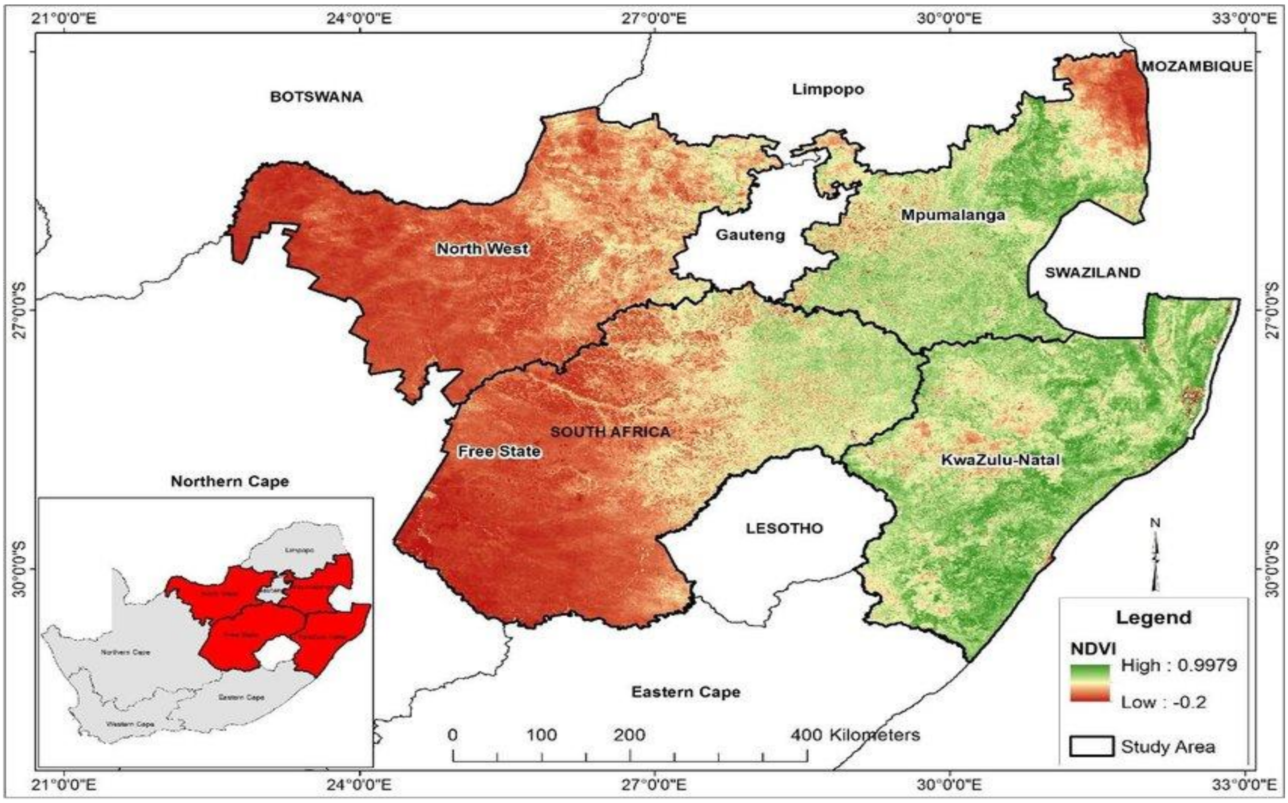

Figure 1. Map of primary maize-producing provinces in South Africa.

Source: (Adisa, 2018).

3.3. Data analysis

This study will employ the Autoregressive Distribution Lag cointegration (ARDL) technique, and the Augmented Dickey-Fuller test to assess the relationship between these variables thoroughly (Shoko et al., 2019). The ARDL model was initially developed by Pesaran et al. (2001) and it is also known as the bounds testing cointegration technique and it has been known for its conveniency in assessing the impacts of climate change and the utilisation of fertilizer on the production of maize in a sufficient manner. This model was employed in various studies where it succeeded in estimating the relationship between the productivity of the crops and the climate change. This model is efficient in assessing the long term and the short-term relationship between the variables (Shoko et al., 2019). The ARDL technique is more suitable to be applied in situations where there is an integration of variables that differ in order and it is more robust in the small sample size where there is a single long run relationship amongst the underlying variables, the statistical tools such as *F*-statistics (Wald test) are used to determine the long term relationship of the underlying variables (Mmelesi and Mosikari, 2024). The first step was to contact a bound to determine if ever there is an existence of a long-term relationship between the dependent variable and the independent variable. The judgement of whether the relationship or not will be based on the comparisons between the *F*-test and the *T*-test against the lower and upper bound values. If the *F*-test and the *T*-test are greater than the critical values of the upper and the lower bound, then we reject the null hypothesis that says the variables are not cointegrated. If the variables are cointegrated the ARDL Error Correction Model (ECM) will be employed to estimate the coefficients in the short run. The ARDL requires that all the variables be not integrated in the second order, therefore the unit root test such as Augmented Dickey Fuller (ADF) were utilized to determine the order of integration for the included variables. The diagnostic checks such as the Jarque-Bera were employed to determine the goodness of fit of the model and to avoid the consequences that comes with the model misspecification.

3.4. Data collection

The study used the annual time series data containing 22 observations starting from 2001 until 2023 and secondary data was used to compile these observations. The export volume measured in metric tons is the dependent variable.

Data treatment

The study treats both temperature and rainfall data as proxies for climate change, thus temperature and rainfall are seen as key indicators of climate variability and change, influencing crop growth and yield. Trends in temperatures and rainfall patterns are analysed to using the annual time series data.

3.5. Analytical framework

Given the fact that we are extrapolating countrywide data on temperature and rainfall and using it to represent the maize producing area, we therefore develop scenarios. The first scenario is that the moderate tolerance for maize production ranges between 20° and 38° Celsius. The second scenario is that for the dryland maize, an annual rainfall ranging between 500 mm to 750 mm, or more. We noted that the average rainfall and temperature in the graph in **Figure 2** is actually below the norm. Given this limitation, our analysis and results are applicable in the context of the data that we have. Once the data has been identified and gathered, a crucial step involves establishing the stationarity order of the chosen variables.

The equation below will be utilized to calculate the results,

$$\begin{aligned} \Delta lnEXPV_t = \beta_0 + \sum_{i=1}^{p} \beta_1 \, \Delta lnGVPR_t + \sum_{i=0}^{p} \beta_2 \, \Delta lnFRTC_t + \sum_{i=0}^{p} \beta_4 \, \Delta lnAARF_t \\ + \sum_{i=0}^{p} \beta_4 lnAAST_t + \varepsilon_t \end{aligned} \tag{1}$$

where, $lnEXPV_t$ denotes export volume in tons which is the dependent variable, there are four regressors which are $lnAARF_t$ (average annual rainfall), $lnAAST_t$ (average annual surface temperature), $lnFRTC_t$ (fertilizer consumption), $GVPR_t$ (gross value of production in rands).

4. Discussion and results

4.1. Analysis of trends in temperature and rainfall patterns

Climate change has profound implications for agriculture, particularly in regions like South Africa where maize cultivation plays a crucial role in food security and economic stability. Temperature and rainfall are key indicators of climate variability and change, influencing crop growth and yield. Maize thrives under specific temperature and rainfall in South Africa, and some of those areas include the maize belt including the Free-State, North West, and Mpumalanga.

Ideal rainfall and temperature for maize crop in South Africa

Maize is a warm-season crop and requires temperatures between 20 °C and 30 °C during its growing period for optimal growth and development. Extreme temperatures, both high and low, can adversely affect maize productivity. Moreover, rainfall patterns for maize requires adequate and well-distributed rainfall throughout its growing season. In South Africa, this typically ranges from about 450 mm to 900 mm annually, depending on the region.

The **Figure 2** below shows a trend analysis of the temperature and rainfall and any deviations from the optimal ranges could be an indicate potential challenges or risks posed by climate change to maize production. This is critical given that temperature and rainfall serve as critical proxies for understanding climate change impacts on maize agriculture in South Africa.

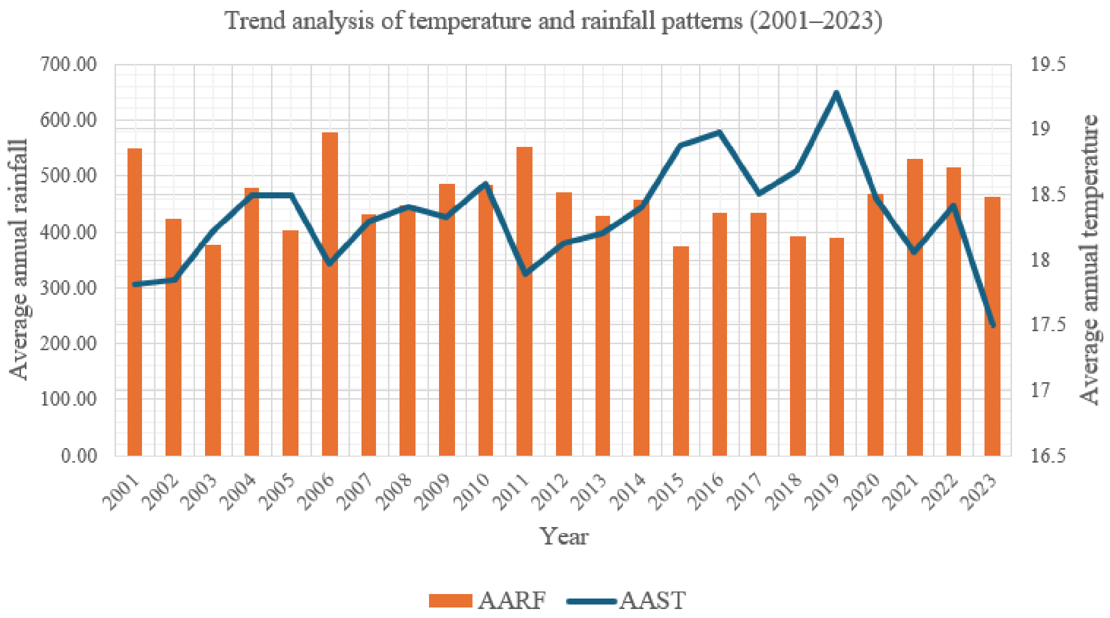

Figure 2. Trend analysis of rainfall and temperature in South Africa between 2001 and 2023.

Source: (Author, 2024).

4.2. ARDL analysis

The results starts with the testing of stationarity using Augmented Dickey Fuller (ADF) test, which indicates that all included variables are integrated at different levels [*I(0)* and *I(1)*]. Thereafter, bound test was performed to check for co-integration amongst the included regressors, which shows that there is occurrence of cointegration and this necessitates the long-term as well as short-term effects. Thereafter a bound test for integration is conducted using the f-stat and t-stat for upper boundary and lower boundary, respectively. To assess the soundness of the model, diagnostics tests were performed using Durbin Watson, Breusch-Godfrey test, White's test (Heteroskedasticity), and the Jarque Bera (Normality). Moreover, to assess the presence of errors we used the Error Correction Model (ECM). To test the stability of the model the Cumulative Sum (CUSUM) test was conducted.

Table 1 is an illustration of the statistical information that the export value fertilizer cost and the gross value of production are highly statistically significant after taking the first difference, which implies that the series becomes stationary after first difference, and they are integrated at first order. The annual average rainfall is statistically significant which implies a stationarity at level, and it is also integrated at 1(0) order.

Table 1. Stationarity test for variables in the model.

Variables	**Maize**			
	Level [I(0]	***Level [I(1)]***	***Lag Order***	***Order of integration***
	t-stats	***t-stats***		
$lnEXPV_t$	−1.767	−5.456***	1	*I(1)*
$lnGVPR_t$	−0.222	−4.264***	1	*I(1)*
$lnFRTC_t$	0.527	−11.072***	1	*I(1)*

$lnAARF_t$	−4.387		0	*I(0)*
$lnAAST_t$	−2.687	−5.079***	1	*I(1)*

Source: Own calculations.

Majority of the variables are integrated at first level difference while there is one variable that is integrated at 0(1), therefore the ARDL model will be proper in this case since it works well with variables that are integrated at different levels. There is possible cointegration between all the variables that are stationary after the first difference, which is an implication that there is a long term equilibrium between these variables.

Table 2 illustrates the bound test for cointegration for maize model. The ARDL bound test is applied to find long run relationships among variables. The calculated test statistics value is 13.8 and its more than both the upper bound and the lower bound. Therefore, the variables in the model are cointegrated based on the *F*-test since it exceeds the upper bound of 4.01, indicating statistical significance at the 95% confidence level. The calculated t-statistic (−8.036) is below the lower bound of −3.99, indicating statistical significance at the 95% confidence level. Therefore, the variables in the maize model are also cointegrated based on the *t*-test. These are ideal results for the model since they suggest that the variables in the model share a common stochastic trend, which can inform better understanding and prediction of their interactions over time.

Table 2. Bound test for cointegration for maize model.

Cointegration test		***Maize***			
		Calculated test statistics	***95% lower bound***	***95% upper bound***	***Decision***
	F-stats	13.800	2.86	4.01	Cointegrated
	t-stats	−8.036	−2.86	−3.99	Cointegrated

Source: Own contributions.

Table 3 shows the ARDL analysis results. The model outcomes suggest that export volumes, gross value of production, average annual rainfall and fertiliser consumption display statistically significant results with a correct sign. These variables represent the impact of lagged maize exports, and agricultural production (In volume terms).

Table 3. ARDL analysis results.

Variables	***Maize***	
	$\Delta lnEXPV_t$	
	Coefficient	***Prob.***
Constant	−13.343*	0.056
$\Delta lnEXPV_{t-1}$	0.669***	0.007
$\Delta lnGVPR_t$	1.279***	0.006
$\Delta lnFRTC_t$	1.919**	0.036
$\Delta lnFRTC_{t-1}$	1.712*	0.064

$\Delta lnAARF_t$	2.184*	0.056
$\Delta lnAAST_t$	−0.650	0.991
$\Delta lnAAST_{t-1}$	−11.819***	0.050
Lag length (AIC)	ARDL (1,0,1,0,1)	
R^2	68	
Adj. R^2	51	
F-Stats	4.01	
Prob (F-stats)	0.015	

Source: Own contributions.

Moreover, the ARDL model shows a good overall fit, with R-squared indicating a substantial portion of the variation in export volumes is explained by the independent variables and indicates that 68% of the variation in export volume (tonnes) is explained by the independent variables. Adjusted R-squared adjusts for the number of predictors, providing a more conservative estimate of model fit. The F-statistic tests Prob (F-stats) of 0.015 indicates that the model is statistically significant at the 0.05 level, suggesting that at least one of the regressors is significantly related to the dependent variable whereas the leg length AIC points out the lag structure of the ARDL model used, where (1,0,1,0,1) refers to lag lengths selected based on the Akaike Information Criterion (AIC).

The coefficient for export volumes for previous year denotes a statistical significance ($p < 0.01$), indicating that lagged values of export volumes significantly influence its current value or rather the present volumes. The coefficient for the gross value of product representing the impact of changes in maize production on export volume is statistically significant at the 0.01 level.

Moreover, the coefficient for fertiliser consumption, indicating its impact on the export value for maize is statistically significant at the 0.05 level, and the coefficient for the lagged value of fertiliser consumption for the previous year ($t - 1$) is also marginally significant at the 0.1 level, thus fertiliser use of the previous year has an impact for the current year's maize exports. These findings are in line with the ones that were reported by (Shoko et al., 2019) who has also reported that an increase in the fertiliser consumption lead to a potential improvement in the export volume.

The coefficient for the average annual rainfall is also marginally significant at the 0.1 level, which aligns with the idea that a reduction in rainfall affects the maize value-chain significantly (including export volumes). However, the coefficient for average annual surface temperature is not statistically significant ($p > 0.05$) whereas the coefficient for the lagged value of the average annual surface temperature for the previous year is statistically significant at the 0.05 level since the maize growth can only be affected by high temperatures mostly in formative years and consequently affecting export volumes for the current year. This outcome aligns with established economic rationale. These results concur with the ones that were reported by (Noorunnahar et al., 2023; Rizwanulla et al., 2023; Shoko et al., 2019) who also found to be having a positive influence on the productivity of the maize.

Table 4 shows the Error Correction Model (ECM) results after determining the long-term coefficient and the details of the short-term coefficient after calculations.

In terms of the Error Correction Term (ECT_t): The negative coefficient (−1.669) points out that deviations from the long-run equilibrium for export volumes are corrected by approximately 1.669 units in the next period. The significant *p*-value (0.004) indicates strong statistical significance. For the long run results this is important because, variables such as gross value of a product and fertiliser consumption show significant positive impacts on maize export volume in the long run, suggesting that changes in maize production and related agricultural factors have lasting effects on maize export volumes, thus on the maize trade performance for South Africa. As for the Short-run results or effects, fertiliser consumption and average annual surface temperature also influence export volumes in the short run, although the average annual surface temperature's impact is notably high with a coefficient of 11.819.

Table 4. Error Correction Model (ECM) results.

Variables	***Maize***	
	$\Delta lnEXPV_t$	
	Coefficient	***p-Value***
$Constant$	−13.343	0.056
ECT_t	−1.669***	0.004
Long-run results		
$lnGVPR_t$	0.766***	0.004
$lnFRTC_t$	2.175**	0.031
$lnAARF_t$	1.309**	0.054
$lnAAST_t$	−7.120	0.188
Short-run results		
$\Delta lnFRTC_t$	1.712*	0.064
$\Delta lnAAST_t$	11.819	0.050

Source: Own contributions.

Table 5 illustrates the findings of the diagnostic tests. The Durbin Watson demonstrated that the model is free from serial correlation. A value close to 2 indicates no serial correlation and for this model the statistic of 1.77 suggests that there is no significant serial correlation in the data. Moreover, The Breusch-Godfrey test is another test for autocorrelation in the residuals of a regression model and it demonstrated that the model is free from autocorrelation. White's test is used to detect heteroskedasticity, which is the presence of non-constant variance in the residuals of a regression model. A higher statistic and a non-significant *p*-value (here, 0.397) suggest that there is no significant heteroskedasticity in the data. The Jarque Bera test checks the normality of the residuals. A statistic close to zero and a higher *p*-value (here, 0.565) indicate that the residuals are normally distributed, supporting the assumption of normality.

Table 5. Diagnostic tests results.

Tests	**Maize**	
	Statistics/*p*-value	**Decision**

Durbin Watson	1.77	No Serial correlation
Breusch-Godfrey test	0.485(0.486)	No autocorrelation
White’s test (Heteroskedasticity)	21(0.397)	No heteroskedasticity
Jarque Bera (Normality)	1.141(0.565)	Normal distribution

Source: Own calculations.

Figure 3 illustrates the stability or tests if there are shifts in the mean or variance over time for the model. The graph above of the cumulative sum (CUSUM) lies within the 5% critical boundaries, indicating the stability of the model.

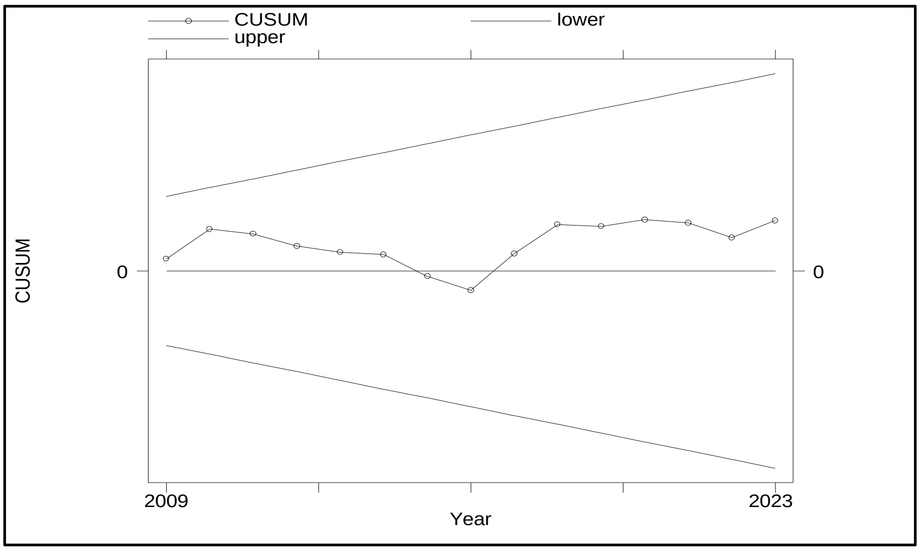

Figure 3. Cumulative sum (CUSUM) test.

5. Conclusions

The study used an annual data series from 2001 up to 2023, a timespan of the past 22 years with the aim to assess the impact of climate change on the South African trade performance of maize. It is evident that annual rainfall has the most significant positive impact on export volumes of maize, which suggests that an increase in average rainfall is likely to cause an increase in the export volumes of maize. These results are applicable in the context of data used in the study. The relationship between agricultural practice and the climate change is complex as the two influence other, therefore key policy recommendations place an emphasis on the need for conservative agricultural practices in the South African maize industry. However, further studies might consider the impact of climatic factors in the maize producing regions of South Africa.

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