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Weathering the Storm: The Role of Climate Variability and Production Inputs in Shaping Somalia's Agricultural Output

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ABSTRACT

Agriculture is the backbone of Somalia's economy, providing livelihoods for the majority of its population. However, the sector faces severe challenges from climate variability, deforestation, and resource-based conflicts, which threaten its ability to sustain rural productivity and economic stability. This study examines the effects of climate variability and production inputs—rainfall, temperature, land, labor, and capital—on agricultural productivity over the period 1989 to 2021. Using advanced econometric techniques, including Vector Autoregressive (VAR) and Vector Error Correction Models (VECM), the study analyzes short- and long-term relationships. Results show that rainfall positively influences livestock and food production, while rising temperatures adversely affect livestock productivity. Land demonstrates a positive contribution to agricultural output, whereas labor and capital show mixed effects, revealing inefficiencies in resource allocation. These findings underscore the urgent need for improved resource management, climate adaptation strategies, and infrastructure development to enhance agricultural resilience. By addressing these challenges, the study contributes to the broader discourse on sustainable agricultural practices and offers actionable policy recommendations tailored to Somalia's unique context.

1. INTRODUCTION

Agricultural production is crucial, particularly in developing nations, as it greatly enhances livelihoods, ensures food security, and creates employment [1]. This encompasses both food and livestock production, which not only fulfill the needs of rural populations but also boost the overall economy. Several factors, including climate conditions, availability of land, labor, capital, and technological advancements, affect agricultural output [2].

Agricultural production is not only essential for developing nations but also plays a pivotal role globally, contributing to both rural and urban economies [3]. In developed countries, innovations in agricultural technology have led to increased productivity, while in developing nations, the focus remains on improving basic infrastructure and access to resources [4]. Globally, agriculture faces common challenges, such as climate change, land degradation, and water scarcity [5].

The United Nations, through initiatives like the Sustainable Development Goals (SDGs), emphasizes sustainable agricultural practices to address both local and global food security needs [6]. These goals highlight the significance of addressing the vulnerabilities of agriculture, particularly in regions where production systems rely heavily on rain-fed agriculture, making them susceptible to climate variability. This is especially relevant in sub-Saharan Africa, where poor infrastructure, limited access to finance, and outdated farming techniques further constrain agricultural productivity [5].

Agriculture also significantly contributes to economic development by providing raw materials for agro-industries, creating jobs, and boosting export revenues. For low-income countries, it accounts for approximately 25% of GDP and is a highly effective sector for poverty reduction [7]. However, the increasing impacts of climate change—rising temperatures, erratic rainfall, and extreme weather events—threaten the long-term sustainability of agricultural systems [8].

In Somalia, agriculture is a cornerstone of the economy, with livestock contributing around 40% of the GDP and 80% of export earnings. Livestock and crop production are critical sources of income for pastoral and agro-pastoral communities [9]. However, recurring droughts, erratic rainfall, and limited access to modern technologies have led to reduced productivity and heightened food insecurity. Additionally, disease outbreaks among livestock, exacerbated by weakened immunity due to climate stressors, have further worsened the situation [8, 10].

Despite its importance, there is limited empirical research examining the combined effects of climate variability and production inputs land, labor, and capital on agricultural outputs in Somalia. Existing studies, such as Warsame et al. [11] highlights the positive effects of rainfall on livestock but fail to explore the interactions between climate variability and production inputs comprehensively. Similarly, Mohamed and Nageye [12] focus on land degradation but exclude critical factors like labor and capital. Furthermore, adaptation strategies tailored to other regions are often unsuitable for Somalia's unique challenges [13, 14].

This study bridges these gaps by investigating the mutual effects of climate variability and production inputs on livestock and food production in Somalia. Specifically, it aims to examine the short- and long-term effects of climate variability, particularly rainfall and temperature, on agricultural productivity. Additionally, the study evaluates how key production inputs—land, labor, and capital—interact with climate factors to influence livestock and food production. By addressing these dynamics, the research provides an integrated analytical framework to identify strategies for improving agricultural resilience. The findings contribute to sustainable development by offering actionable policy recommendations tailored to Somalia's specific agricultural challenges.

2. LITERATURE REVIEW

Climate variability, particularly changes in rainfall and temperature, significantly impacts agricultural productivity worldwide. Schlenker and Roberts [15] found that rising temperatures negatively affect crop yields, especially in developing countries reliant on rain-fed agriculture. Similarly, Lobell et al. [16] highlighted how climate change reduces livestock productivity due to increased heat stress and limited water availability.

In the Somali context, studies like Abdi et al. [17] and Ahmed et al. [18] emphasize the vulnerabilities of livestock and crop production to climate shocks, with droughts being a primary driver of food insecurity. Additionally, Dercon and Christiaensen [19] found that production inputs such as land, labor, and capital interact with climate factors to shape agricultural resilience.

While previous research has examined these relationships separately, there is a gap in understanding the combined effects of climate variability and production inputs on Somalia's agricultural sector. This study builds on existing literature by integrating these variables, using an econometric approach to analyze both short- and long-term impacts. The findings will contribute to policy discussions on improving agricultural resilience amid climate uncertainty.

2.1 Theoretical framework

The theoretical basis of this study draws on two key frameworks: the Production Function Theory and the Climate Change and Agricultural Risk Theory. Together, these frameworks provide a comprehensive understanding of how climate change impacts agricultural productivity, particularly in Somalia's context.

The Production Function Theory illustrates the relationship between inputs—land, labor, and capital—and outputs, such as livestock and crops. Rainfall and temperature are incorporated as essential environmental inputs that influence the productivity of traditional factors. For instance, a decline in rainfall diminishes land fertility, while rising temperatures reduce labor efficiency. This study employs a Cobb-Douglas production function, a classical economic model extensively used to examine environmental impacts on agricultural productivity [20-22].

In Somalia's context, this theory highlights how limited access to productive resources and climate variability exacerbate the challenges faced by the agricultural sector. It underscores the need for efficient resource allocation and climate adaptation to sustain productivity. For example, increasing investments in irrigation infrastructure can mitigate the effects of erratic rainfall.

On the other hand, The Climate Change and Agricultural Risk Theory focuses on the heightened risks posed by climate variability, such as unpredictable rainfall patterns and rising temperatures, to agricultural systems. This theory stems from risk management literature and emphasizes the importance of adaptation strategies. Studies by Mendelsohn et al. [21] and Schlenker and Roberts [15] demonstrate the adverse effects of climate change on agricultural outputs and highlight the necessity for resilience-building measures.

In Somalia, where rain-fed agriculture predominates, this theory is particularly relevant. It provides a framework to understand how unpredictable weather exacerbates land degradation, increases livestock vulnerability to diseases, and necessitates investments in high-value capital such as irrigation systems and drought-resistant crop varieties. These insights inform the development of targeted policies to enhance resilience and reduce risks associated with climate variability.

By integrating these frameworks, this study develops an analytical model to evaluate the interplay between climate factors and production inputs, providing a robust foundation for policy recommendations tailored to Somalia's unique agricultural challenges.

2.2 Empirical evidence

Many studies have explored the impact of climate change on livestock production and agricultural outputs, concentrating on specific regions and particular contexts. Leweri et al. [23] explored how erratic rainfall and increased droughts in Tanzania's Ngorongoro Conservation Area have led to reduced pasture availability, prompting pastoralists to diversify their livestock. Similarly, Tiruneh and Tegene [24] reviewed climate change's impact on Ethiopian livestock, noting a 1°C rise in national temperatures since the 1960s, which has caused feed shortages and diminished productivity. In Nigeria, Okoro [25] assessed rainfall variability over 42 years, revealing mixed impacts on different livestock categories, while Araujo et al. [26] in the Brazilian Pantanal highlighted how floods and droughts disrupt cattle management. In Mexico, Murray-Tortarolo and Jaramillo [27] studied the effects of the 2011 drought, finding a 3% reduction in cattle and goat stocks, illustrating the vulnerability of livestock to extreme weather events. On the other hand, Warsame et al. [11] used econometric models to analyze climate change's effect on Somalia's livestock, demonstrating how rainfall positively influences livestock in the long run, while rising temperatures negatively impact production.

Studies on food production under climate variability also yields significant insights. In Kenya's Homa Bay County, Oke et al. [28] found that reduced rainfall leads to decrease crop yields, exacerbating food insecurity. Affoh et al. [29] expanded this analysis to Sub-Saharan Africa, finding that rainfall positively influences food availability, whereas temperature has a negative impact. Similarly, Pickson and Boateng [30] highlighted how climate change exacerbates food insecurity across Africa, highlighting the necessity for enhanced agricultural techniques and irrigation infrastructure. Studies like those by Olayide and Alabi [31] in Nigeria further reveal the close link between rainfall variability and food poverty, advocating for focused policy actions to tackle these issues.

Regarding the elements of production, research by Mohamed and Nageye [12] in Somalia demonstrated that land degradation and climate change significantly reduce agricultural productivity, while Gorain et al. [32] focused on India, quantifying the economic losses caused by land degradation. Zhou et al. [33] examined the effect of labor migration in rural China, demonstrating how it destabilizes conventional crop-livestock systems, while Lemishko [34] analyzed capital reproduction trends in Ukraine's agricultural sector, identifying a trend towards greater equity capital, even as total capital shares decrease.

Studies on mitigation and adaptation strategies highlight regional variations in coping mechanisms. Sloat et al. [13] identified global patterns of precipitation variability, showing how it affects livestock densities, while Hristov et al. [14] in the U.S. discussed strategies to mitigate heat stress in dairy cattle. In tropical regions, Oke et al. [28] reviewed livestock's physiological responses to heat, recommending environmental modifications to alleviate heat stress. While these studies provide critical insights, most are region-specific and lack broader, global applicability, pointing to a need for further empirical research that integrates climate models with long-term adaptation strategies, especially in vulnerable regions like Sub-Saharan Africa.

This review, while underlining huge contributions from diverse regions, calls for far broader empirical work on the complex inter-relationships between climate change, livestock production, and food security. Further studies must now reflect in framing pragmatic policies of adaptation and present land, labor, and capital within the matrix of climate change in all its ramifications for a wholesome view of sustainable agricultural productivity in the face of increasing climatic variability.

3. METHODOLOGY

3.1 Data

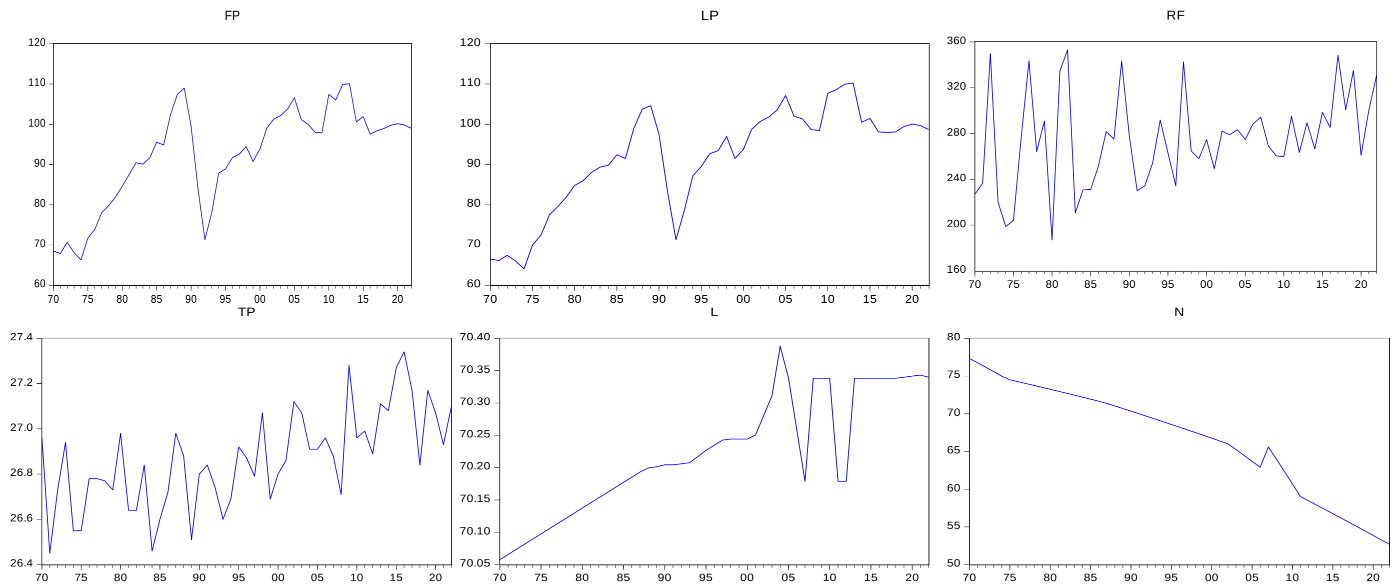
This study examines the impact of climate change on agricultural productivity in Somalia over a 32-year period (1989 to 2021) using time-series data. This time frame was chosen for its policy relevance and the availability of reliable historical data.

The data used in this study were sourced from distinguished and reliable databases. Table 1 provides a clear summary of the variables, their codes, types, and sources, ensuring transparency and reliability in the selection of data for analysis. Additionally, Figure 1 illustrates the trends of these variables over the study period, offering a visual representation of their changes and patterns.

The study faced challenges in data collection, including the need to address outliers and ensure consistency in the dataset. Rigorous data cleaning methods were applied to standardize formats and remove anomalies, enhancing the dataset's reliability and validity.

Table 1. Data distributions

Variable	Code	Type	Sources
Livestock production	LP	Livestock-production index	World bank
Food production	FP	Food-production index	World bank
Rainfall	RF	Average annual precipitation (mm)	CCKP
Temperature	TP	Average annual temperature in (°C)	CCKP
Land	L	Agricultural Area, % of Land Area	SESRIC
Labour	N	Rural population (% of total population)	World bank
Capital	K	Gross-Capital Formation, Constant 2015 Prices	SESRIC



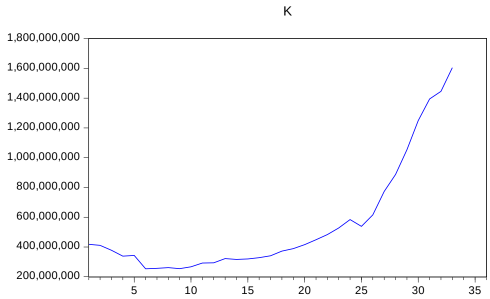


Figure 1. The trends of livestock production (LP), food production (FP), rainfall (RF), land (L), labour (N), and capital (K) respectively

The operationalization of variables was carefully designed to align with the study's objectives. Sustainable development was measured indirectly by assessing the efficiency of resource use (land, labor, and capital) and agricultural resilience to climate variability. Agricultural productivity was operationalized using the Livestock Production Index (LP) and Food Production Index (FP), which serve as key indicators. Climate variability was represented by average annual rainfall (RF) and temperature (TP), capturing the most critical environmental factors affecting agriculture in Somalia.

This study employed advanced econometric techniques to analyze the short- and long-term relationships between variables. The Augmented Dickey-Fuller Test was applied to check for stationarity in the time-series data, a critical step for accurate model selection. The Johansen Cointegration Test examined long-run equilibrium relationships between climate variables and agricultural production. Finally, Vector Auto Regressive (VAR) and Error Correction Models (ECM) were employed to investigate the dynamic interactions between climate factors and agricultural productivity, providing insights into both short-term fluctuations and long-term trends.

This comprehensive approach aims to uncover the nuanced effects of climate change on agricultural productivity in Somalia and provide actionable insights for policy recommendations tailored to enhance resilience and sustainability.

The longitudinal feature of the present study is a major characteristic, ranging from 1989 to 2021. Whereas earlier studies have usually covered a relatively shorter period, this research neatly depicts long-run trends and relationships. To this end, two adaptive econometric models are used: the Vector Autoregressive (VAR) model and the Vector Error Correction Model. The VAR model primarily focuses on short-run dynamics, while the VECM is more suitable to analyze long-run equilibrium with its respective adjustment mechanisms. This bifurcated methodology allows for deeper insights that appreciate the interaction of transient variations with enduring patterns, which previous studies frequently neglected as a result of their dependence on more simplistic models.

Using advanced techniques in the forms of VAR, VECM, cointegration analysis, dynamic modeling, and Granger's causality test, the paper provides a deeper study of the specific effect of public expenditure on the economic growth of Somalia. This, consequently, enhances the accuracy and strength of the results more concretely than what has been evidenced in past literature.

There is limited current research on the relationship between climate change and agricultural productivity in Somalia, with most of the studies not considering using advanced econometric methods. The study attempts to fill this gap by applying modern tools for a more careful analysis of this relationship. Intricate econometric models have been employed in order to address endogeneity problems and confounding variables, rendering reliable results with regard to the responsive dynamics of climate change towards livestock and food production.

Ultimately, this research contributes significantly to the academic discourse and policy-making by rendering a clearer understanding of how climate changes and factors of production implicate Somalia's agricultural production.

3.2 Estimation technique

This study employed an empirical approach by applying the Vector Autoregressive (VAR) and vector error correction model (VECM). The equation provided represents the practical model:

$$FP_t = \beta_0 + \beta_1 RF_t + \beta_2 TP_t + \beta_3 L_t + \beta_4 N_t + \beta_5 K_t + \varepsilon_{t\ 1}$$
$$LP_t = \beta_0 + \beta_1 RF_t + \beta_2 TP_t + \beta_3 L_t + \beta_4 N_t + \beta_5 K_t + \varepsilon_{t\ 2}$$

where, LP_t, FP_t are livestock production and food production at time t. RF_t, TP_t, L_t, N_t, K_t represent rain fall, temperature, land, labour and capital at time t. It is commonly represented as either a percentage or a numerical change. β_0 is the intercept, β_1, to β_5 are coefficients, ε_t is the error term, which accounts for the factors not explained by the model.

In this model, t represents the residuals, while the remaining variables specified. Economic theory suggests that good and favorable environment increase agriculture production (livestock and food). Increase in factors of production also leads increase in output keeping everything else constant.

To depict the levels of a VAR, the following equation can has be used through a representation series:

$$y_t = \beta_1 y_{t-1} + \beta_2 y_{t-2} + \cdots + \beta_l y_{t-l} + \varepsilon_t \quad (1)$$

If y_t is a vector of products with dimensions (n×1), and β is a coefficient matrix of dimensions (n×n). Generally, this connection can be stated as vector error correction (VECM) and is formulated as follows:

$$\Delta y_t = \delta_1 \Delta y_{t-1} + \delta_2 \Delta y_{t-2} + \cdots + \delta_{l-1} \Delta y_{t-l+1} + \prod \Delta y_{t-l} + \varepsilon_t \quad (2)$$

$$\delta_i = \sum_{i=1}^{l-1} -\beta_i; \prod = I_n + \delta_{l-i}$$

3.2.1 The test cointegration

Cointegration tests are essential in time series analysis, especially when examining long-term relationships among variables. According to theory of Engel and Granger [35] cointegration tests, linear combinations can transform non-stationary variables into stationary variables. The cointegration test is an important component of the Johansen cointegration test, which has utilized to determine whether a cointegration relationship exists between multiple time series variables. This test has used to understand the number of cointegration vectors that represent the long-term relationship between these variables. The corresponding test statistics are:

$$\lambda_{trace}(r) = -n \sum_{i=r+1}^{m} \quad ln\,(1 - \hat{\lambda}_t) \qquad (3)$$

The test was conducted sequentially, under the assumption of the null hypothesis with a maximum of r=0, 1, …, m-1 co-integrating vectors such that:

$$H_0: r = 0 \text{ vs } H_1: r > 0$$
$$H_0: r \leq 1 \text{ vs } H_1: r > 1$$
$$H_0: r = m - 1 \text{ vs } H_1: r = m$$
$$H_0: r(\prod) \leq m$$

There are at most r groups of cointegrating vectors, H_1: r(∏)>m where ∏ represents the number of groups of independent vector matrices, that is, H. The number of eigenvalues is not equal to zero. N represents sample. r represents the number of groups of composite vectors. $\hat{\lambda}_r$ represents the estimate of the i-th eigenvalue. M represents the number of eigenvalue results examined against distribution 2.

The Maximum Eigenvalue Test is a method used to analyze regression statistics equations.

$$\lambda_{max}(r, r+1) = -nln\,(1 - \hat{\lambda}_{r+1}) \qquad (4)$$

The test was conducted sequentially under the null at most r=0, 1, …, m-1 co-integrating vectors, ensuring that:

$$H_0: r = 0 \text{ vs. } H_1: r = 1$$
$$H_0: r = 1 \text{ vs } H_1: r = 2$$
$$H_0: r = m - 1 \text{ vs } H_1: r = m$$

H_0: r(∏)=m. There exists a set of cointegration vectors H_1: r(∏)=m+1, where n represents the number of samples, m represents the number of groups of cointegration vectors and ƛ^_t is the estimate of the eigenvalue at t which follows. After conducting the chi-square distribution test This study employs the JJ approach, which was devetest, d by Johansen [36], and Johamen and Jtiselius [37]. The key strength of the JJ method is related to series of order I (2) or higher, provided that the series have a common order of integration. The study variables are consistent, as reflected by the first differences. Therefore, the authors considered the JJ approach to test the variable integration.

4. RESULTS AND DISCUSSION

4.1 Descriptive statistics

The descriptive statistics in Table 2 provide an overview of the key variables in the study. Livestock production (LP) has a mean of 97.7 and a standard deviation of 8.54446, with a maximum value of 110.21 and a minimum of 71.33. The skewness of -1.16 indicates a slight negative skew, while the kurtosis of 4.61 suggests a peaked distribution. Food production (FP) shows similar trends, with a mean of 97.63, a standard deviation of 8.63596, a maximum of 110.05, and a minimum of 71.33. Its skewness is -1.12, indicating a negative skew, and its kurtosis of 4.44 also points to a peaked distribution. Rainfall (RF) records a mean of 280.3 and a standard deviation of 29.8845, with a maximum value of 348.33 and a minimum of 230.07. The skewness of 0.68 suggests a moderate positive skew, while the kurtosis of 3.19 shows a moderate peak. Temperature (TP) has a mean of 26.94 and a very low standard deviation of 0.19717, indicating little variability. The maximum value is 27.34, and the minimum is 26.51. Its skewness is close to zero at 0.09, indicating a nearly symmetrical distribution, with a kurtosis of 2.58 reflecting a near-normal distribution.

Land (L) has a mean of 70.28 and a small standard deviation of 0.06485, suggesting very low variability, with maximum and minimum values of 70.39 and 70.18, respectively. The distribution is nearly symmetrical, with a skewness of -0.03, and the kurtosis of 1.48 indicates a flatter distribution. Labor (N) has a mean of 63.15 and a standard deviation of 5.60403, with values ranging from a maximum of 70.688 to a minimum of 53.269. Its skewness is -0.37, reflecting a slight negative skew, while its kurtosis of 1.72 shows a flatter-than-normal distribution. Lastly, Capital (K) has a mean of 5.51E+08, but the high standard deviation of 3.79E+08 indicates substantial variability. The maximum recorded value is 1.60E+09, and the minimum is 2.53E+08. A skewness of 1.60 shows a positive skew, while the kurtosis of 4.32 reflects a peaked distribution. The Jarque-Bera test suggests that LP, FP, and K do not follow a normal distribution, while RF, TP, L, and N show no significant deviation from normality.

Table 2. Descriptive statistics

	LP	FP	RF	TP	L	N	K
Mean	97.7	97.63	280.3	26.94	70.28	63.15	5.51E+08
Median	98.81	99.47	277.73	26.91	70.26	64.469	3.89E+08
Maximum	110.21	110.05	348.33	27.34	70.39	70.688	1.60E+09
Minimum	71.33	71.33	230.07	26.51	70.18	53.269	2.53E+08
Std. Dev.	8.54446	8.63596	29.8845	0.19717	0.06485	5.60403	3.79E+08
Skewness	-1.16	-1.12	0.68	0.09	-0.03	-0.37	1.601809
Kurtosis	4.61	4.44	3.19	2.58	1.48	1.72	4.323594
Jarque-Bera	10.97	9.72	2.59	0.28	3.24	3.02	16.52072
Probability	0.005	0.008	0.28	0.87	0.1999	0.2218	0.000259
Sum	3224.1	3221.92	9251.63	888.84	2319.11	2084.02	1.82E+10
Sum Sq. Dev.	2336.25	2386.56	28578.7	1.24402	0.13459	1004.97	4.60E+18
Observations	33	33	33	33	33	33	33

Source: Computed by authors

4.2 Correlation tests

The correlation analysis in Table 3 explores the relationships between livestock production (LP), food production (FP), and various influencing factors.

Livestock production (LP) is highly positively correlated with land (L) (0.9109), suggesting that increases in available land significantly contribute to higher livestock production. There is also a moderate positive correlation between livestock production and temperature (TP) (0.3932), indicating that temperature fluctuations have a notable influence on livestock productivity. Additionally, rainfall (RF) shows a moderate positive correlation with livestock production (0.3711), suggesting that higher rainfall can positively impact livestock.

On the other hand, labor (N) is negatively correlated with livestock production (-0.368), indicating that higher labor does not necessarily lead to higher livestock productivity, possibly due to inefficiencies in labor allocation. Capital (K) has a weaker positive relationship with livestock production (0.2124), implying that capital investments may have a limited effect on boosting livestock production in this context.

For food production (FP), a positive correlation with rainfall (RF) (0.4090) suggests that rainfall positively impacts food production. However, land (L) has a strong negative correlation with food production (-0.7581), indicating that greater land availability may not always translate into higher food production, which could be due to land being more efficiently used for other purposes. Labor (N) shows a moderate positive correlation (0.3681), suggesting that labor contributes positively to food production.

In conclusion, the analysis highlights that land and temperature are key positive factors for livestock production, while rainfall positively influences both livestock and food production. However, labor and capital exhibit varying levels of impact, and the relationship between land and food production appears to be more complex.

Table 3. Correlation pairs

LP	1						
FP	_	1					
RF	0.3711	0.4090	1				
TP	0.3932	0.3509	0.1187	1			
L	0.9109	-0.7581	-0.9315	-0.4715	1		
N	-0.368	0.3681	0.1963	0.5679	0.3677	1	
K	0.2124	0.2313	0.3726	0.3920	0.5031	-0.845	1

Source: Computed by authors (2024)

4.3 Unit root tests

The findings shown in Table 4 demonstrate the outcomes of the Augmented Dickey-Fuller (ADF) test, revealing the absence of stationarity across all variables at the fundamental level. This implies that LGDP and the other independent variables do not demonstrate zero-order integration, denoted as I(0). The Augmented Dickey- Fuller (ADF) test findings indicate that all variables exhibit stationarity after undergoing first-order differencing, hence suggesting the absence of a unit root. As a result, they are classified inside the first level of integration, denoted as I(1).

The second procedure entails doing an analysis of cointegration and assessing the correlations in both the short-run and long-run between the dependent variable, LGDP, and the independent variables, namely LG-EXP, LFDI, LGFCF and the rate of population increase. The achievement of this objective will be facilitated by the use of Johansen cointegration tests. In the event that cointegration is detected, the use of a Vector Error Correction Model (VECM) will be employed. When the presence of cointegration is not detected, a Vector Autoregression Model (VARM) will be used. Furthermore, a comprehensive set of diagnostic tests will be performed. The evaluations will cover examinations for serial correlation, heteroskedasticity, normality, and stability. More specifically, the investigation of autoregressive roots will be conducted as a component of the stability assessment.

Table 4. Unit root test

Variables	Level		First Difference	
	Intercept	Trend & Intercept	Intercept	Trend & Intercept
LP	-1.849136	-2.762065	-4.073856**	-4.060791**
FP	-2.115012	-0.4836	-4.05897**	-3.711642**
RF	-3.408903**	-6.763756**	-9.239385**	-9.111342**
Tp	-4.047985**	-5.496624**	-8.344175**	-8.240327**
L	-3.013548**	-5.125109**	-6.981862**	-6.84546**
N	0.936941	-1.786281	-5.199148**	-5.414149**
K	2.44445	-1.622073	-3.673142**	-5.909852**

Source: Computed by the authors (2024)

** Symbol shows the four tests: ADF is significant at a 5% level and the first difference of the variables.

4.4 Cointegration

The cointegration tests, both Trace (in Table 5) and Maximum Eigenvalue (in Table 6), confirm the existence of significant long-run relationships between the variables in both **Model 1** and **Model 2**. The significant trace statistics for the first three ranks in both models suggest that there are at least two cointegrating equations, indicating a stable long-term equilibrium relationship between the dependent variables (livestock and food production) and the independent variables (rainfall, temperature, land, labor, and capital).

In **Model 1**, the trace test results highlight two cointegrating equations, as evidenced by the trace statistic values exceeding the critical values at the 0.05 significance level. Similarly, the

Maximum Eigenvalue test also supports two cointegrating equations, reinforcing the existence of long-term equilibrium relationships among the variables.

In **Model 2**, the results are consistent with **Model 1**, where both the Trace and Maximum Eigenvalue tests indicate two significant cointegrating equations. This outcome suggests that climate variables such as rainfall and temperature, alongside factors like land, labor, and capital, have long-term effects on agricultural productivity in both models.

These findings provide strong evidence for the existence of both short- and long-run cointegration among the variables in the study. The significance of these relationships implies that the data series can be used in further cointegration analysis to explore both long-term and short-term dynamics between climate change and agricultural production, ensuring robust conclusions on the impact of climate variables on the agricultural sector in Somalia.

Table 5. Unrestricted cointegration rank test (Trace)

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob.**
Model 1				
None *	0.835903	156.2813	95.75366	0.0000
At most 1 *	0.797692	100.2550	69.81889	0.0000
At most 2*	0.615107	50.71816	47.85613	0.0263
At most 3	0.366763	21.11971	29.79707	0.3502
At most 4	0.198327	6.955504	15.49471	0.5828
At most 5	0.003311	0.102818	3.841465	0.7485
Model 2				
None *	0.835538	157.5087	95.75366	0.0000
At most 1 *	0.792302	101.5514	69.81889	0.0000
At most 2*	0.627777	52.82972	47.85613	0.0159
At most 3	0.372649	22.19359	29.79707	0.2879
At most 4	0.219661	7.739886	15.49471	0.4936
At most 5	0.001646	0.051070	3.841465	0.8212

Sources: Computed by Author (2024)
Trace test indicates 2 cointegrating eqn(s) at the 0.05 level
* Denotes rejection of the hypothesis at the 0.05 level
**MacKinnon-Haug-Michelis (1999) p-values

Table 6. Unrestricted cointegration rank test (Maximum Eigenvalue)

Hypothesized No. of CE(s)	Eigenvalue	Max-Eigen Statistic	0.05 Critical Value	Prob.**
Model 1				
None *	0.835903	56.02630	40.07757	0.0004
At most 1 *	0.797692	49.53687	33.87687	0.0003
At most 2 *	0.615107	29.59845	27.58434	0.0272
At most 3	0.366763	14.16421	21.13162	0.3517
At most 4	0.198327	6.852686	14.26460	0.5067
At most 5	0.003311	0.102818	3.841465	0.7485
Model 2				
None *	0.835538	55.95726	40.07757	0.0004
At most 1 *	0.792302	48.72171	33.87687	0.0004
At most 2 *	0.627777	30.63613	27.58434	0.0196
At most 3	0.372649	14.45371	21.13162	0.3290
At most 4	0.219661	7.688816	14.26460	0.4112
At most 5	0.001646	0.051070	3.841465	0.8212

Sources: Computed by Authors (2024)
Max-eigenvalue test indicates 2 cointegrating eqn(s) at the 0.05 level
* Denotes rejection of the hypothesis at the 0.05 level
**MacKinnon-Haug-Michelis (1999) p-value

4.5 Cointegration equation normalized

Once a cointegration relationship (in Table 7) is identified among the variables in both Model 1 and Model 2, the normalized cointegration equation allows for an understanding of the long-term equilibrium relationships between livestock production (LP) and the independent variables (rainfall (RF), temperature (TP), land (L), labor (N), and capital (K)).

In Model 1, the coefficients for rainfall (RF) and labor (N) show positive relationships with livestock production, with coefficients of 0.156245 and 1.059936, respectively. This indicates that increases in rainfall and labor contribute positively to livestock production. On the other hand, temperature (TP) and land (L) exhibit significant negative relationships with coefficients of -71.60091 and -78.77268, respectively. These negative coefficients suggest that higher temperatures and greater land allocation may negatively impact livestock production. Capital (K) has a relatively small positive coefficient (9.19E-09), indicating a minimal impact on livestock production in the long run. Similarly, in Model 2, the relationship between rainfall (RF) and livestock production remains positive, although the coefficient is smaller at 0.054208. Labor (N) continues to have a positive effect with a coefficient of 1.093011, suggesting its consistent importance across both models. However, temperature (TP) and land (L) again show negative impacts on livestock production, with coefficients of -79.52878 and -58.84179, respectively. Capital (K) also maintains a small positive influence with a coefficient of 7.07E-09.

These results highlight that, in both models, labor and rainfall positively contribute to livestock production, while temperature and land exhibit a negative long-term impact. The minimal effect of capital suggests that investment in capital may not play a major role in livestock production within the context of this study. Understanding these relationships is crucial for forming effective strategies to mitigate the adverse effects of climate change on agriculture in Somalia.

Table 7. Cointegration equation normalized

Normalized Cointegrating Coefficients (Standard Error I n Parentheses)					
Model 1					
LP	**RF**	**TP**	**L**	**N**	**K**
1.000000	0.156245	-71.60091	-78.77268	1.059936	9.19E-09
	(0.07004)	(12.9613)	(31.3969)	(0.56204)	(7.2E-09)
Model 2					
LP	**RF**	**TP**	**L**	**N**	**K**
1.000000	0.054208	-79.52878	-58.84179	1.093011	7.07E-09
	(0.06935)	(12.9365)	(31.0924)	(0.56343)	(7.2E-09)

Sources: computed by Author (2024)

4.6 Diagnosis tests

The diagnostic tests in Table 8 assess the robustness of **Model 1** and **Model 2** in terms of residual heteroskedasticity and serial correlation.

For the **VEC Residual Heteroskedasticity Test**, both models show no evidence of heteroskedasticity. In **Model 1**, the Chi-square statistic is 563.9047 with a probability value of 0.2891, indicating that we fail to reject the null hypothesis of homoskedasticity at the 5% significance level. Similarly, for **Model 2**, the Chi-square statistic is 562.1588, with a probability of 0.3070, which also fails to reject the null hypothesis, confirming homoskedasticity in this model as well.

The **VEC Residual Serial Correlation LM Test** examines whether serial correlation exists in the residuals. For **Model 1**, the LM-statistics for the first three lags are 43.41375, 41.03032, and 26.00709, with corresponding probability values of 0.1847, 0.2594, and 0.8903, respectively. Since all probability values are above the 0.05 threshold, we conclude that there is no significant serial correlation in the residuals of Model 1. In **Model 2**, the LM-statistics for the first three lags are 35.00858, 39.17074, and 27.79592, with probability values of 0.5156, 0.3295, and 0.8344, respectively. Again, since the probability values exceed 0.05, we find no evidence of serial correlation in the residuals of Model 2.

These diagnostic results confirm that both models are free from heteroskedasticity and serial correlation, ensuring the validity and robustness of the estimated coefficients.

Table 8. Diagnosis results

VEC Residual Heteroskedasticity Tests					
	Model 1			Model 2	
Chi-sq	Df	Prob.	Chi-sq	Df	Prob.
563.9047	546	0.2891	562.1588	546	0.3070
VEC Residual Serial Correlation LM					
	Model 1			Model1 2	
Lags	LM-Stat	Prob	Lags	LM-Stat	Prob
1	43.41375	0.1847	1	35.00858	0.5156
2	41.03032	0.2594	2	39.17074	0.3295
3	26.00709	0.8903	3	27.79592	0.8344

Source: Computed by the authors (2024)

4.7 The short run ECM results

The short-run VECM results shown in Table 9 provide insight into the dynamic relationships between the variables in **Model 1** and **Model 2**. For **Model 1**, the coefficient for **rainfall (RF)** is positive and significant, with a coefficient of 0.089555 and a p-value of 0.0000, indicating that rainfall positively affects livestock production in the short run. In contrast, **temperature (TP)** has a significant negative impact, with a coefficient of -3.389442 and a p-value of 0.0000, showing that higher temperatures reduce livestock productivity. **Land (L)** also exhibits a positive and significant effect with a coefficient of 1.780157, suggesting that land allocation has a beneficial effect on livestock production. On the other hand, **labor (N)** and **capital (K)** both show negative coefficients, with values of -1.861559 and -2.06E-08, respectively, indicating that they negatively impact livestock production in the short run. The error correction term (ECM) is significant and positive, confirming the speed of adjustment to the long-run equilibrium.

For **Model 2**, the coefficient for **rainfall (RF)** is positive but less significant than in Model 1, with a coefficient of 0.058592 and a p-value of 0.0434. This suggests a weaker but still positive short-run effect of rainfall on livestock production. **Temperature (TP)** again shows a negative relationship with a coefficient of -2.940855, but this time it is not statistically significant, with a p-value of 0.5495. **Land (L),** although positive, is also not statistically significant in Model 2, with a coefficient of 8.110441. **Labor (N)** and **capital (K)** exhibit negative coefficients, similar to Model 1, but neither are statistically significant in the short run for Model 2. The error correction term (ECM) is positive but just below significance at a p-value of 0.0789, suggesting a slower adjustment process to long-run equilibrium compared to Model 1.

These findings highlight the importance of rainfall and land in influencing livestock production in the short run, with temperature playing a key negative role in Model 1. In Model 2, the effects are weaker, and many variables are not statistically significant. The significant error correction terms in both models confirm that the system adjusts towards long-term equilibrium, although at different speeds.

Table 9. Short run VECM result

Variables	Coefficient	Std. Error	t-Statistic	Prob.
		Model 1		
D(RF(-3))	0.089555	1.36E-16	6.57E+14	0.0000
D(TP(-3))	-3.389442	2.42E-14	-1.40E+14	0.0000
D(L(-3))	1.780157	9.02E-14	1.97E+13	0.0000
D(N(-3))	-1.861559	6.26E-15	-2.97E+14	0.0000
D(K(-3))	-2.06E-08	7.36E-23	-2.79E+14	0.0000
D(ECM(-3))	1.000000	9.64E-16	1.04E+15	0.0000
		Model 2		
D(RF(-3))	0.058592	0.027596	2.123186	0.0434
D(TP(-3))	-2.940855	4.849361	-0.606442	0.5495
D(L(-3))	8.110441	18.12732	0.447415	0.6583
D(N(-3))	-0.387741	1.229033	-0.315484	0.7549
D(K(-3))	-1.86E-09	1.44E-08	-0.128707	0.8986
ECM(-3)	0.361804	0.197839	1.828782	0.0789

Source: Computed by the authors (2024)

4.8 Discussions

This study found that, in the short term, rainfall contributes positively and significantly to both livestock and food production, supporting the need for improved access to water for agricultural development and pasture to boost livestock productivity. Similar observations were made by Leweri et al. [23], who reported that rainfall variability plays a crucial role in the sustainability of livestock production in Tanzania. In a related study, Ogenga et al. [28] demonstrated that fluctuations in rainfall have a direct impact on agricultural output in Kenya. These findings align with the Production Function Theory, which emphasizes how critical environmental inputs like rainfall enhance the productivity of traditional factors such as land.

Conversely, rising temperatures negatively affect livestock production in the short term, as heat stress caused by increasing temperatures compromises animal health and productivity. These findings are consistent with those of Tiruneh and Tegene [24], who reported the negative impact of rising temperatures on livestock production in Ethiopia, and Warsame et al. [11], who documented the adverse effects of high temperatures on livestock production in Somalia. This outcome also aligns with the Climate Change and Agricultural Risk Theory, which highlights the increased risks posed by temperature variability.

Land use shows a positive short-term effect on livestock production, indicating that allocating more land for grazing increases livestock output. This was similarly demonstrated by Mohamed and Nageye [12], who highlighted the importance of securing land access to enhance farming productivity in Somalia. However, labor and capital exhibit negative impacts on livestock production in the short term, suggesting inefficiencies in labor deployment and the limited effect of capital investments within a short period. This observation aligns with the findings of Zhou et al. [33], who found that labor migration negatively affected traditional crop-livestock systems in rural China, resulting in inefficiencies.

In the long term, rising temperatures present a significant challenge to both livestock and food production, with sustained increases leading to an overall decline in agricultural productivity. This demonstrates that Somalia's agricultural sector is highly sensitive to long-term climatic changes.

Schlenker and Roberts [15], similarly found that rising temperatures in the United States caused a long-term decline in crop yields. Likewise, Murray-Tortarolo and Jaramillo [27], found that extreme events, particularly droughts, could lead to long-term losses in livestock numbers in Mexico. Although precipitation has a positive long-term impact on agricultural production, its contribution is less substantial compared to the short-term benefits. This aligns with the complex effects of rainfall variability reported by Okoro [25], in the context of livestock production across regions in Nigeria.

Furthermore, financial investments have a negligible long-term effect on agricultural productivity, indicating that monetary resources alone are insufficient to enhance productivity without effective resource management and infrastructure improvements. This finding is consistent with Lemishko [34], who demonstrated that capital investments without accompanying infrastructure development do not significantly affect agricultural productivity. These results further support the Production Function Theory by emphasizing the critical role of infrastructure and technological adaptation in translating inputs into outputs effectively.

Overall, these findings justify the need for a multi-faceted approach to agricultural development in Somalia. Improving water access, investing in modern technologies, and enhancing labor efficiency through targeted capacity-building programs are necessary steps for fostering resilience. Moreover, integrating climate adaptation strategies with resource optimization is essential to ensure sustainable development, as highlighted in both theoretical frameworks and supported by the results of this study.

5. CONCLUSIONS

This paper aims to examine the effects of climate and non-climate variables on agricultural productivity in Somalia between 1989 and 2021 employing advanced econometric techniques such as VAR and VECM. The study highlights the significance of climatic factors, particularly rainfall and temperature, on sustained changes in livestock and food production. Other inputs and outputs, including land and labor, also play important roles, though these are not consistent across all agricultural sectors.

Seasonal rainfall, in particular, boosts livestock and food production, as evidenced by the short-term benefits of adequate water for agriculture. In contrast, temperature has a negative short-term impact, especially on livestock production, highlighting the detrimental effects of heat on animal rearing. Non-climate-related variables such as labor and land allocation also present varying impacts. For example, labor has different effects on livestock and food production, while land positively affects livestock production but has a mixed impact on food production.

The study demonstrates that climate change, particularly rising temperatures, is a long-term obstacle to agriculture in Somalia. This underscores the vulnerability of the Somali agricultural sector to climate variability, with cumulative negative effects on food production, particularly in the livestock sector. In the long run, rainfall continues to have a positive impact, but its effect is relatively weaker than short-term variations. Non-climatic variables such as capital stock show a slight degree of persistence, indicating that while financial capital is necessary to enhance agricultural productivity through investments, it is insufficient without complementary improvements in physical capital and resource endowments.

The cointegration tests suggest long-term associations between climate parameters and agricultural yields, emphasizing the importance of considering both short- and long-term impacts of climate variations in policy decisions. These findings suggest that climate change mitigation and adaptation efforts should focus on moderating temperature increases and conserving water to protect agricultural yields. The study also emphasizes the need to increase labor productivity and optimize land use to improve agricultural output.

In conclusion, this research fills a gap in understanding how climate and non-climate variables affect agricultural production in Somalia. The results underscore the need for continued implementation of climate change solutions that integrate climate considerations into agricultural policies for sustainable development and food security, despite ongoing climate challenges.

5.1 Recommendations

The empirical evidence from this study clearly shows that rising temperatures impair livestock and food productivity in both the short and long run. Policymakers should promote climate-adapted practices, such as breeding heat-resistant livestock and cultivating drought-resistant crops. Both social and financial capital should be invested in climate-smart agriculture to reduce the vulnerability of Somalia's agricultural sector.

Rainfall availability plays a crucial role in boosting agricultural production, particularly in the short term. To mitigate the impacts of irregular rainfall patterns, the government and development partners should focus on enhancing water quality and quantity, rainwater harvesting systems, and water conservation initiatives. These measures will help make water supply a more reliable factor and improve agricultural sustainability, particularly in arid and semi-arid regions.

As demonstrated in this paper, land availability has both positive and negative effects on production, highlighting the need for improved land utilization. Sustainable land use practices, livestock-crop integration, and policies to prevent over-exploitation of land and resources should be prioritized. Effective land-use planning and zoning could also improve land productivity, particularly in agricultural areas.

While labor has shown positive effects on food crop productivity, its impact on livestock productivity has been mixed. To address the imbalance in labor distribution within farms, the government and stakeholders in the agricultural sector should fund training programs aimed at improving labor efficiency. These programs should focus on innovation in farming techniques, livestock rearing, and managing weather-related challenges.

The limited role of capital in agricultural production indicates that financial capital alone cannot drive significant advancements in the sector. Policymakers should focus on improving infrastructure, physical facilities, technology, and training to ensure that capital investments are effectively utilized, leading to productivity gains.

Given the long-term negative impacts of climate change on Somali agriculture, the government must strengthen its climate change adaptation measures. Policies should focus on enhancing agricultural resilience through adaptive technologies, crop diversification, livestock production strategies, and early warning systems for climate risks. Incorporating climate change considerations into national agricultural strategies is crucial for long-term resilience.

Further research is needed to better understand the impact of climate factors on agricultural yields. Governments and academic institutions should invest in agricultural research to address climate change challenges specific to Somalia. Collaborating with national and global researchers will help develop locally relevant solutions.

The fluctuating relationship between climate factors and agricultural production requires constant monitoring. Establishing a climate-agriculture data monitoring system would enable policymakers to track climate trends and their effects on agriculture. This system should provide real-time data to support decision-making and enable flexible management of agricultural resources in response to climate volatility.

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