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RESEARCH ARTICLE

Extreme climatic effects hamper livestock production in Somalia

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Abstract
Given the enormous impact of the livestock sector on Somalia's economy and its vulnerability to climate variations, this study investigates short and long-term changes in climatic effects on livestock production by using data spanning from 1985 to 2016. To this end, the ARDL bounds testing and causality techniques were employed to model the long-run and short-run relationships, and direction of causality among sampled variables. Overall, the empirical results confirmed the existence of a stable long-run cointegration between variables. Rainfall and temperature patterns were found to have a significant positive and negative impact on livestock production both in the long run and short run, respectively. The observed carbon dioxide emissions have no significant impact on livestock production in the long run but enhance livestock production in the short run. Interestingly, growth in rural population declines livestock production in the long run but not in the short run. Besides, a unidirectional causality is confirmed from temperature to rainfall and CO_2 whereas livestock production has a bidirectional causal relationship with rainfall and temperature. While CO_2 emissions granger cause livestock production, a unidirectional causation is observed from rural population to temperature and livestock production. This study suggests adaptation and mitigation policies that combat the negative consequences of climate change.

Keywords Somalia · Climate change · Granger causality · Livestock production · ARDL

JEL Classification Q54 · C22 · Q56

Introduction

It is widely believed that the global demand for livestock and its related products will grow significantly in the near future (Nardone et al. 2010), mainly owing to a myriad of factors including fast urbanization, rising incomes, shifts to dietary patterns, and population growth (Ayanlade and Ojebisi 2020; Mihiretu et al. 2019; Thornton et al. 2009). Nevertheless, there is a growing concern worldwide associated with the ability of the livestock sector to satisfy the ever-increasing demand for its products, because it is facing an imminent threat from climate change and extreme weather events (Escarcha et al. 2018). Climate change influences the livestock sector through various aspects. On one hand, it reduces the amount of water available for animals to drink (Mihiretu et al. 2019)—which in turn impairs animal productivity (Rojas-Downing et al. 2017). It is also expected that rising temperatures will further accelerate the demand for water intake by animals by a factor of 2 or 3 (Nardone et al. 2010).

Climate change, especially a rise in temperature that results in a reduction in rainfall, hampers the growth of forages that is necessary for livestock feeding and their growth (Rojas-Downing et al. 2017). Thus, any reduction in the supply of feed and forage crops results in decreasing in livestock production efficiency via milk and meat production, and the reproduction system. Moreover, a rise in temperature and irregular rainfall—in the form of floods or droughts—pose a potential threat to the health and wellbeing of animals—by exposing them to various diseases either directly or

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indirectly. It is important to note here that the effects are not uniform—as it depends on the type of animal, region, nature of the disease, and animal immunity (Thornton et al. 2009). The foremost direct impact of these two factors on the livestock sector include animal death (Nardone et al. 2010) and morbidity (Rojas-Downing et al. 2017), while the indirect effects range from inducing the increase of pathogens or parasites, accelerating the outbreak of existing or/and new diseases, the transmission of diseases related to vector-borne and food-borne (Nardone et al. 2010; Thornton et al. 2009).

Furthermore, there is another dire consequence of climate change, especially changes in precipitations, which many studies have documented (Ayanlade and Ojebisi 2020; Descheemaeker et al. 2016; Martin et al. 2014; Maxwell and Fitzpatrick 2012; Roever et al. 2015; Thornton et al. 2015). These studies reveal that countries, particularly sub-Saharan African countries (SSA), that hugely depend on rainfall for the growth of natural pastures (Ayanlade and Ojebisi 2020) are more susceptible to rain irregularities compared to other countries (Mihiretu et al. 2019). This is because of shifts in rain-pattern result in the incidence of extreme drought. Indeed, several studies (Martin et al. 2014; Waaben et al. 2020) have reported several consequences of drought frequency including the death of animals and humans (Maxwell and Fitzpatrick 2012; Maxwell et al. 2012; Thornton et al. 2009). Other consequences include rural–urban migration from unaffected pasture areas (Ayanlade and Ojebisi 2020), a drastic increase in the poverty rate, conflicts (Waaben et al. 2020; Warsame et al. 2021b) , and a decline in export earnings and economic growth (Mihiretu et al. 2019).

Although climatic effects on the livestock sector are considered a global challenge, countries differ to the extent of climate change damage that depends on climate variability, adaptation, and mitigation measures (Sarkodie and Strezov 2019). Developed countries are less prone to climate-related problems compared to developing countries (Warsame et al. 2021a) . A plausible explanation might be that developed countries are swifter in response to climate-related disasters as they can mobilize massive resources to minimize the damage (Sarkodie and Strezov 2019). Furthermore, it contributes an insignificant amount to the GDP of developed nations and a tiny fraction of the population is highly dependent on the livestock sector for livelihood and employment. In contrast, developing countries, especially SSA nations, rely heavily on the livestock sector for livelihood, employment, export earnings, and economic growth.

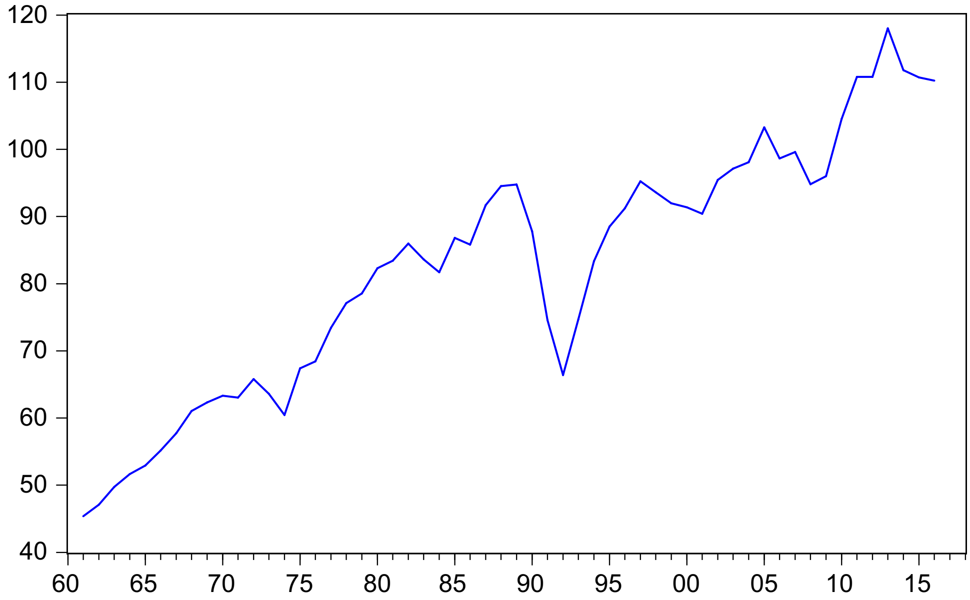
In the context of Somalia, livestock production is considered one of the most important sectors for Somalia's economy since it accounts for 40% of GDP, 80% of the foreign exchange earnings, and creates 65% of the employment opportunities (FAO 2012; Too et al. 2015). In addition to that, livestock rearing is a common culture in Somalia—where 80% of the population is nomadic or semi-nomadic according to the central bank of Somalia. The livestock sector is the most essential source of income and food for these predominantly rural populations. Despite the importance of livestock production to the Somali economy and livelihood, the vulnerability of the country to climate change poses a threat to this sector. It is noteworthy that Somalia is categorized as one of the most exposed countries to the changes in the climate (Wheeler 2011; Too et al. 2015).

The increasing temperature leads to changes in precipitation patterns which results in droughts and floods (IPCC 2001). Droughts have severe effects on the livelihoods and food security of pastoralists and agro-pastoralists. Moreover, lack of pasture and shortage of water availability resulted from the drought lead to acute morbidity, increasing mortality of living animals, and high common disease. Despite the existence of prolonged political instabilities and environmental challenges in Somalia (Warsame and Sarkodie 2021), livestock production has managed to show an upward increase from 1961 to 2016 as shown in Fig. 1. However, livestock production exhibit declines in some years, marginally or substantially, due to droughts caused by climate variability. There is only 1 year (1974) that has observed a notable reduction in livestock production for the period between 1960 and 1991. This is attributed to the rising temperature which resulted in rain failures followed by extreme drought which is named after "dabadheer" (long-tailed). Consequently, the livestock production index has only changed slightly from 65.78 in 1972 to 60.43 in 1974, due to the military government's swifter response to the incident.

On the other hand, the frequency of the droughts and livestock production reductions turned into recurrent events since the Somali state collapsed in 1991, mainly owing to the absence of effective government and increasing temperature. Following the collapse of the military government in 1991, Somalia experienced one of its worst droughts which caused a massive reduction in livestock production from 87.76 in 1990 to 66.41 in 1992. Conversely, the highest livestock production index was reported in 2005 when the index skyrocketed at 103.29, but this did not last long. It dropped out to 98.64, 99.61, and 94.8 during 2006, 2007, and 2008, respectively, due to the civil wars that broke out in South and central Somalia.

Subsequently, the other two destructive droughts occurred in 2011 and 2017. Even though the former led to famine, the latter undermined livestock production harshly. It started in 2015 in the northern regions where an acute drought was reported, and this was followed by short rains in the southern part which was below the average level. The drought loomed and reported its peak in the Deyr season in 2016 (October–December) which lasted until March 2017. The drought undermined the livestock productions sharply as evidenced by the huge decline to the livestock production index from 118 in 2013 to 110.21 in 2016—making the

Fig. 1 Somali livestock production index. Data source: World Bank (2020)



largest number of livestock index slumps observed in our sample observations (1960–2016). The latest drought crises in 2016–2017 incurred a lot of livestock casualties, with more than 6.4 million livestock which represents 12% of the total livestock in the country died owing to droughts (World Bank Group and FAO 2018). This represents \$350 million in terms of monetary value. The massive reduction of feed crops for livestock due to the drought resulted in lower milk output—which has been estimated at \$1.2 billion. The total combination of losses and damages was valued at \$1.6 billion (Federal Government of Somalia 2018; World Bank Group and FAO 2018). It is notable that the vertical line value is the livestock production index while its horizontal line represents the number of years.

Given the enormous role that the livestock sector plays in Somalia's economy and its vulnerability to climate variations, there is a sense of urgency to examine the role of climatic effects on livestock production in Somalia. Although there are numerous studies conducted in developing countries in general and SSA countries in particular (Ayanlade and Ojebisi 2020; Descheemaeker et al. 2016; Mihiretu et al. 2019), yet, there are probably no empirical studies that assess the impact of climate vulnerabilities on livestock production in Somalia. Provided the empirical findings from other countries cannot be generalized to include Somalia due to the difference in geographical location, animal vulnerability, political, and environmental conditions, our study provides new perspectives to the theme. Thus, from a policy perspective, it is paramount to conduct this study to identify the strategies and policies to cope with climatic consequences on livestock production in Somalia. This study employs a recent econometric methodology based on the autoregressive distributive lag model (ARDL) to estimate the role of temperature, CO_2 emissions, and rainfall on livestock production between 1985 and 2016. Since most of the studies in the literature have neglected to utilize econometric methodologies to examine climate change-livestock production nexus, our study, therefore, attempts to fill this research gap by using the ARDL approach.

Subsequent sections include data source and econometric model employed, results of the econometric model, summary, and policy implications.

Methodology

Statistical data

We used annual time series data from 1985 to 2016—sourced from the OIC database, and World Bank. The period of sample observations starting from 1985 relates to drought events that occurred after this period. In the late 1980s, the central government of Somalia faced wars from insurgent militias, which have weakened the services offered by the government to the citizens. Therefore, starting the sample period of the study from 1985 tends to capture the consequences of these events on livestock production. The dependent variable of the study is livestock production whereas rainfall, temperature, CO_2 emissions, and agricultural labor—measured in rural population—are the explanatory variables. The detailed description and sources of the data are shown in Table 1, while Fig. 2 depicts the trend of the interested variables throughout

Table 1 Variable descriptions and sources

Variable name	Symbol	Definition	Data source
Livestock production index	LP	Livestock production index (2004–2006 index)	OIC database
Rainfall	R	Mean annual precipitation (mm)	World Bank
Temperature	T	Mean annual temperature (°C)	World Bank
Carbon dioxide	CO_2	Carbon dioxide emission metric tons per capita	World Bank
Agricultural labor	AL	Percentage of rural population to the total population	World Bank

the sample period. All the sampled variables are transformed into natural logarithms to interpret the coefficients as elasticity. It is notable that the vertical lines in Fig. 2 represent the value of the variables whereas their horizontal line stands for the number of years.

Econometric model

Following the empirical literature (Lia et al. 2013 and Seo and Mendelsohn 2008), we employed the following model to examine the effect of rainfall, temperature, carbon dioxide, and agriculture labor, measured in rural population, on livestock production in Somalia:

$$lnLP_t = \beta_0 + \beta_1 lnR_t + \beta_2 lnT_t + \beta_3 lnAL_t + \beta_4 lnCO_{2t} + \varepsilon_t \quad (1)$$

where $lnLP_t$ is the natural logarithm of livestock production in the year t, lnR_t represents the natural logarithm of average rainfall in the year t, lnT_t indicates the log of average annual temperature in the year t, $lnAL_t$ denotes natural logarithm of rural population which is proxied as agricultural labor in the year t, $lnCO_{2t}$ represents the natural logarithm of CO_2 emission in the year t, and ε_t is the disturbance term in time t.

The above-specified model is estimated using the ARDL model pioneered by Pesaran et al. (2001) to examine the impact of climatic factors on livestock production in Somalia. We chose this model over other traditional cointegration models for many reasons. First, the ARDL model can be applied in small sample size-based models; therefore, it is very suitable for this study since our sample is only 31 observations. Second, the ARDL model solves the requirement of the standard cointegration methods that all study variables are first-difference [I (1)] stationary. Alternatively, the ARDL model does not require variables to be in the same order of integration. Finally, the ARDL model outperforms other cointegration tests in estimating the long- and short-run relationships among variables under consideration in a single equation.

Concerning the estimation of the ARDL model, Eq. (1) was re-expressed as an ARDL form to incorporate short-run multipliers in the model along with the long-run multipliers. Thus, it is written as follows.

$$\begin{aligned}\Delta LnLP_t = \alpha_0 &+ \sum_{i=1}^{n} b_i \Delta LnLP_{t-1} + \sum_{i=1}^{n} c_i \Delta LnR_{t-1} + \sum_{i=1}^{n} d_i \Delta LnT_{t-1}, \\ &+ \sum_{i=1}^{n} f_i \Delta LnAL_{t-1} + \sum_{i=1}^{n} g_i \Delta LnCO_{2t-1} + \delta_1 LnLP_{t-1} + \delta_2 LnR_{t-1} + \delta_3 LnT_{t-1} \\ &+ \delta_4 LnAL_{t-1} + \delta_5 LnCO_{2t-1} + \varnothing ECT_{t-1}\end{aligned} \quad (2)$$

where $lnLP$, lnR, lnT, $lnAL$, $lnCO_2$, andε_t are denoted as previously. Δ is the first difference operator; α is the intercept, n is the lag length; ECT_{t-1} represents the error correction term; b_i, c_i, d_i, f_i, g_i and $\delta_1, \delta_2, \delta_3, \delta_4, \delta_5$ are short-run and long-run coefficients of the model, respectively.

Concerning the long-run and short-run association among climate change variables and livestock production in Somalia, the study employed the joint F-statistics to test the null hypothesis of no level relationship among the climate change variables and livestock production in Somalia which is expressed as ($H_0 : \delta_1 = \delta_2 = \delta_3 = \delta_4 = \delta_5 = 0$) against the alternative hypothesis indicates that there is cointegration among the climate change variables and livestock production which is indicated as ($H_a : \delta_1 \neq \delta_2 \neq \delta_3 \neq \delta_4 \neq \delta_5 \neq 0$). Finally, for optimal lag selection criteria, we chose Hendry's general to specific approach over others.

Empirical analysis and discussion

In this section, the study estimates climatic indicators and control variables on livestock production index. This study analyzes climatic impact such as rainfall, temperature, CO_2, and agricultural labor (measured in rural population) on livestock production index in the case of Somalia from 1985 to 2016, by employing the ARDL model technique. Finally, we validate the estimated model by applying diagnostic and model stability tests.

Descriptive statistics

Descriptive statistics is essential for assessing the initial summary characteristics of the variables. The descriptive statistics and correlation matrix of the sampled variables are presented in Table 2. Average temperature, agriculture labor, and livestock production are negatively skewed, while average rainfall and CO_2 emissions are positively

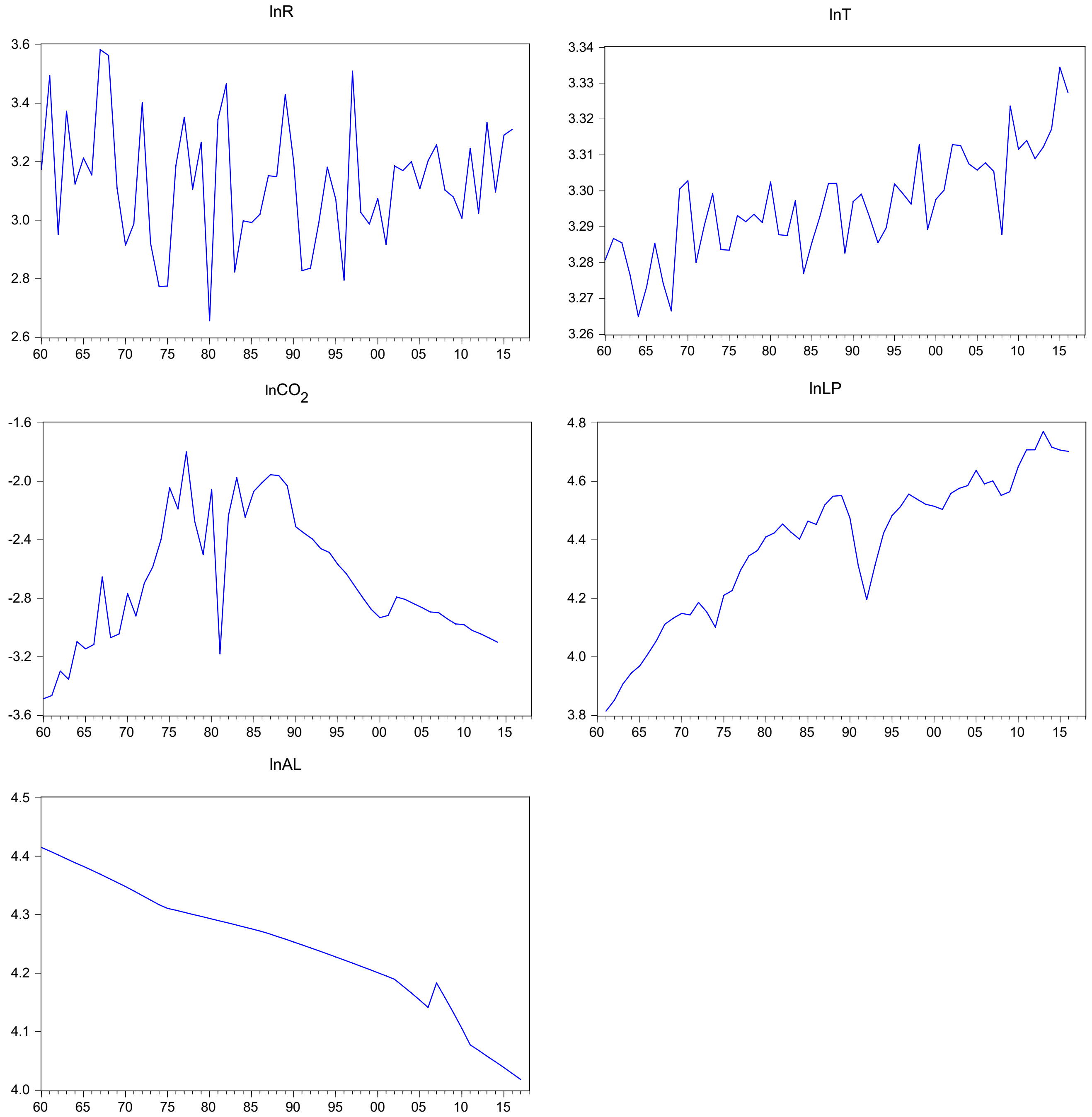


Fig. 2 Trend of the sampled variables series. *Notes*: lnR, lnT, lnCO_2, lnLP, and lnAL denote the natural logarithm of mean rainfall, mean temperature, CO_2 emission, livestock production, and agriculture labor, respectively

skewed. Besides, Jarque–Bera test implies that the data are normally and identically distributed. Similarly, Table 2 also shows the correlation matrix of the variables. A positive correlation is established between average rainfall, average temperature, and livestock production, whereas CO_2 emissions and agriculture labor are observed to have a negative association with livestock production. The average rainfall, average temperature, and livestock production have a negative correlation with CO_2 emissions. Conversely, rural population, which is a proxy of agriculture labor, is observed to have a positive correlation with CO_2 emissions. More importantly, the maximum correlation coefficient of 0.7984 rules out the existence of multicollinearity among the explanatory variables.

Table 2 Descriptive statistics for the data for the period of 1985–2016

	lnR	lnT	lnCO$_2$	lnLP	lnAL
Average	3.102306	3.300991	0.073098	4.532503	4.192873
Median	3.096991	3.301953	0.059169	4.548917	4.206512
Maximum	3.509205	3.323656	0.132430	4.770854	4.279385
Minimum	2.795235	3.276998	0.044062	4.195848	4.048667
Std. Dev	0.160942	0.011287	0.028243	0.122557	0.067591
Skewness	0.352231	−0.169396	0.971509	−0.551325	−0.713987
Jarque–Bera	0.778271	0.750829	5.101419	2.320541	2.953238
Probability	0.677642	0.687005	0.078026	0.313401	0.228409
Correlation					
lnR	1				
lnT	0.1375	1			
lnCO$_2$	−0.0440	−0.5650	1		
lnLP	0.5063	0.6308	−0.5074	1	
lnAL	−0.1938	−0.7072	0.7984	−0.7819	1

Unit root

Applying descriptive statistics and correlation among the variables is not mandatory for cointegration analysis. The analysis begins by testing the order of integration of sampled variables, to circumvent potential spurious regression. Philips–Perron (PP) and Augmented Dickey-Fuller (ADF), two of the most widely used unit root testing were used to check the data. The result of the unit root test is presented in Table 3. It suggests that rainfall and temperature are free from the unit root problem at level, whereas other variables are not. At first difference level I (1), all the variables are stationary both in ADF and PP tests. Thus, the study is eligible to proceed with its estimation by using the ARDL method.

Selecting the optimal lag length is the next prerequisite step for ARDL estimation after the data passed the unit root test. There are several lag selection criteria, however, we applied Hendry's general to a specific approach to our study, since this criterion is good at dealing with serial correlation and model stability problems when the estimated model suffers from these serious problems as emphasized by Pesaran et al. (2001). During the lag selection process by using this method, it omits the variables which have the highest *P*-values until the error term of the variables is uncorrelated with each other and the model parameters are stable. Due to the small observations of our data, we applied 3 lags maximumly to the study and are shortened to 2 and 1 lags.

Subsequently, we determined the existence of cointegration between livestock production (dependent variable), rainfall, CO_2, temperature, and rural population (independent variables), after we confirmed the variables' order of integration is not greater than the first difference I (1)

Table 3 Unit root tests

Variable	ADF level		PP level	
	Intercept	Intercept and trend	Intercept	Intercept and trend
lnLP	−1.988	−3.4178***	−2.0851	−2.8252
lnR	−7.0383***	−6.9876***	−7.023	−6.9663
lnT	−0.1557	−6.3411	−2.8308*	−6.2786***
lnAL	−1.467	−0.3549	1.7738	−0.3801
lnAL	−1.467	−0.3549	1.7738	−0.3801
lnCO$_2$	−2.0482	−2.1875	−2.5893	−2.433
	First difference		First difference	
	Intercept	Intercept and trend	Intercept	Intercept and trend
lnLP	−5.4227***	−5.4668***	−5.1795***	−5. 2484***
lnR	−7.3608***	−7.3598***	−24.410***	−28.910***
lnT	−9.8450***	−9.8765***	−20.704***	−32.981***
lnAL	−6.7538***	−6.9866***	−6.7552***	−6.9782***
lnCO$_2$	−3.4245**	−12.167***	−11.894***	−13.1972***

***, **, and * represent significance level at 1%, 5%, and 10%, respectively

Table 4 *F*-bound cointegration tests

	F-statistic	Significance level	Bounds test critical values	
lnLPI = f(lnAR, lnAT, ln lnCO$_2$, lnAL)			*K* (4)	
			I (0)	I (1)
	8.515729	1%	4.824	6.56
		5%	3.326	4.73
		10%	2.752	3.922

The critical values are based on Narayan (2005). *K* = number of explanatory variables

and selected the best lag. We regressed these variables by using the ordinary least square (OLS) and then estimated Wald *F*-test to ascertain cointegration. Results of the *F*-test statistics and critical values are presented in Table 4. It is worth considering that the critical values of Pesaran et al. (2001) were formulated for studies whose sample observations are ≥ 100. Therefore, because our observation spans 32 years, Pesaran et al.'s (2001) critical values do not apply to it. Instead of these critical values, we use critical values postulated by Narayan (2004) to fit our small sample studies that range between 30 and 80 observations. The calculated *F*-statistic of 8.52 is greater than the given critical values of 6.56 at 1% significance level. Hence, we conclude the existence of a cointegration relationship between livestock production and the independent variables.

Table 5 presents the long-run cointegration elasticities among livestock production and average rainfall, average temperature, CO$_2$ emissions, and agriculture labor. A positive cointegration exists between average rainfall and livestock production in the long run. A 1% increase in average rainfall spurs livestock production by 0.158% in the long run. This result is in line with existing findings (Lia et al. 2013 and Nhemachena et al 2010) that reported rainfall tends to increase livestock production. On the contrary, average temperature undermines livestock production in the long run. A 1% increase in average temperature decreases livestock production by ~ 5.35% in the long run. This is consistent with findings (Nhemachena et al. 2010) that reported that temperature hinders the net revenue of specialized livestock herders if the temperature goes above 27 °C by using a Ricardian analysis method in panel sub-Saharan African countries. Furthermore, CO$_2$ emission is not different from zero, which means it is insignificant and does not cointegrate into livestock production in the long run. The rural population has an inhibitory effect on livestock production in the long run. Thus, it tends to decrease livestock production by 0.928% in the long run if increased by 1%. Our results are consistent with a study (Seo and Mendelsohn 2008) that concluded that large family households reduce the net revenue of livestock per farm.

Table 5 Long-run coefficient elasticities

Explanatory variable	Coefficient
Constant	23.0124** (2.7457)
lnR	0.1590** (2.3616)
lnT	– 5.3546** (– 2.2639)
lnAL	– 0.9282*** (– 3.5999)
lnCO$_2$	– 0.0435 (– 1.6012)

***, **, and * indicate significance level at 1%, 5%, and 10%. *T* statistics are in parentheses

Some of the remarkable results in the analysis are that average temperature substantially hampers livestock production in the long run because it has an elastic coefficient. Moreover, the rural population has a clear deleterious impact on livestock production—owing to its 1% significance level and having the second highest coefficient elasticity of the explanatory variable.

The role of rainfall in livestock production can be explained by its importance for the breeding and production of livestock animals, milk, and meats. Precipitation improves growth of pastures such as shrubs and grasses which are used as grazing fields by the livestock. Besides, rainfall is a key source of drinking to livestock and pastoralist communities. Pastoralists and livestock during drought periods encounter a harsh situation of lack of pasture and water. One of the popular adaptability measures for this crisis is to move to a place where there are good pasture and enough water. However, this mobility creates movement and interaction between livestock which ultimately leads to the transmission of diseases. This is because Somalia's livestock does not have enough care such as vaccines from the government or any other institution.

On the contrary, the inhibitory effect of increasing temperature on Somali livestock production can be attributed to the rising temperature that leads to drier conditions, evapotranspiration, and rain failures, which could impact the grazing of the livestock. More importantly, it inhibits water available for drinking for both livestock and pastoralists. Consequently, this leads to drastic morbidity, a rise of livestock mortality, and dramatic reductions in milk and meat yields, which would ultimately cause severe food insecurity to the pastoralists and agro-pastoralists whose livelihoods depend on livestock production. Furthermore, floods, another consequence of the rising temperature, also result in borne virus created by mosquitoes. This virus leads to a particular fever called rift valley. It is the reason why Somalia's livestock exports have been banned several times by the importing countries especially in Middle Eastern countries—which is Somalia's main livestock export market (World Bank Group and FAO 2018). As a result of these trade sanctions, the price of livestock has fallen—trade balance has dramatically plummeted. Since a large share of the country's export depends on livestock, the value of Somali shillings keeps depreciating. Hence, these factors affect the economy in general and the pastoralists' power of purchasing specifically. Moreover, the inhibitory effect of temperature rise on livestock is exacerbated by the absence of investigating and identifying diseases and vaccinating the livestock from diseases. The CO_2 emissions incorporated in this study may have insignificant influence on livestock production in the long run due to the low level of CO_2 emissions per capita in Somalia (Globalcarbonatlas 2018).

On the other hand, the adverse role of agricultural labor, measured in rural population, on livestock production can be related to the massive meat consumption of the Somali population. Even though Somalia has the second-longest coastline in Africa, consuming seafood meat is not popular. So, the increasing population of both urban and rural populations puts pressure on the herds which are already suffering from environmental challenges and a lack of clear national veterinary policies owing to weak governance in Somalia.

Short-run dynamic effect and error correction term which shows the speed of adjustment is determined after the long-run cointegration. Table 6 illustrates the short-run dynamic effect of cointegration among the variables and error correction term. Last year and the third-year livestock production cointegrates with the current livestock production positively in the short run, despite their significance at 10% and 5% levels, respectively. Average rainfall and CO_2 emissions enhance livestock production. A 1% increase in average rainfall and CO_2 emissions spur livestock production by about 0.137% and 0.325%, respectively, in the short run. But average temperature and agriculture labor undermine livestock production. Average temperature and last year's agriculture labor are observed to decrease livestock production by about 2.33% and 2.7%, respectively, in the short run if increased by 1%. On the other hand, the error correction term shows a long-run cointegration among livestock production and sampled explanatory variables, since the error correction term (-0.65) is significant and has a negative coefficient sign. Interpretively, the disequilibrium that happens in livestock production in the short run is adjusted by the independent variables by about 65% yearly in the long run.

Table 6 Short-run dynamic effect and error correction model

Explanatory variable	Coefficient
$\Delta \ln LP_{t-1}$	0.3404* (1.783)
$\Delta \ln LP_{t-3}$	0.5334** (2.5970)
$\Delta \ln R$	0.1374** (2.6098)
$\Delta \ln R_{t-1}$	0.0961 (1.1645)
$\Delta \ln R_{t-2}$	0.0719 (1.2919)
$\Delta \ln T$	− 2.3333*** (− 2.9977)
$\Delta \ln AL$	− 1.0738 (− 1.5518)
$\Delta \ln AL_{t-1}$	− 2.7181*** (− 3.6036)
$\Delta \ln CO_2$	0.3257** (2.5726)
$\Delta \ln CO_{2t-1}$	0.2063* (1.7517)
$\Delta \ln CO_{2\,t-2}$	0.2344** (2.62)
$\Delta \ln CO_{2t-3}$	− 0.0686 (− 1.5618)
ECT_{t-1}	− 0.6532*** (− 4.569)

***, **, and * indicate the significance level at 1%, 5%, and 10%. *T* statistics are in parentheses. *Δ* differencing, *ECT* error correction term

To ensure robustness of the model and reliable empirical findings of our study, we took several measures for stability and diagnostic tests such as the CUSUM test, CUSUM square test, autocorrelation, normality, and Ramsey reset test as shown in Table 7. Fortunately, no diagnostic issues was detected. Moreover, CUSUM square and CUSUM verified the stability of the parameters as exhibited in Figs. 3 and 4.

Granger causality

The ARDL cointegration test is not enough to detect the causality among the scrutinized variables. To achieve this objective, the Granger causality test was used, with results presented in Table 8. We observe unidirectional causation from temperature to rainfall and CO_2. The causal effect of temperature on rainfall is in line with the fact that a rise in temperature leads to the variability of rainfall. It could cause either flash floods or droughts. We find bidirectional causality between livestock production and rainfall, and livestock production and temperature. Another climate variable namely CO_2 granger causes livestock production. Besides, unidirectional causality is observed from rural population to temperature and livestock production. We highlight that all the climate variables such as temperature, rainfall, and CO_2 are critical to livestock production. Likewise, livestock production causes anomalies in rainfall and temperature. The interesting finding is that the climate variables exhibit symbiotic granger causality. Temperature granger causes rainfall and CO_2, but not the other way around. The rise in temperature changes rainfall patterns, and increases the frequencies of the extreme weather—which results in droughts and floods (IPCC 2001).

Table 7 Diagnostic test statistics

Adjusted *R*-square	0.7808
Reset test	0.7709 (0.4005)
Serial correlation	0.8153 [0.4727]
Jarque–Bera	0.4032 [0.8174]

T statistics are in parentheses. *P*-values are in brackets

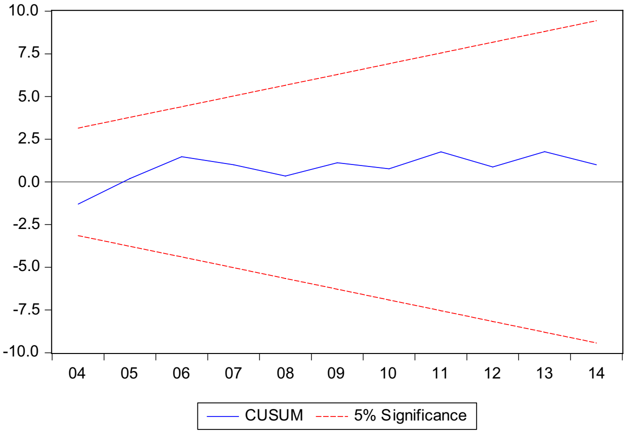


Fig. 3 CUSUM test

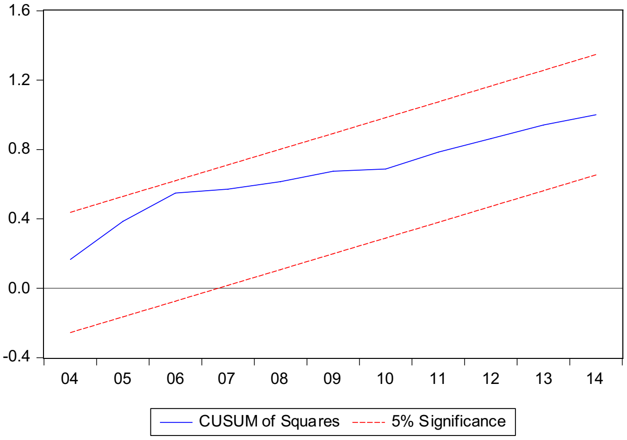


Fig. 4 CUSUM square test

Robust analysis

This study further employed Johansen and Juselius cointegration to verify the long-run cointegration of the ARDL estimation. The cointegration results displayed in Table 9 found at least more than two cointegrating vectors both in trace statistics and maximum eigenvalue. This confirms a long-run cointegration between temperature, rainfall, CO$_2$ emissions, agriculture labor, and livestock production index. Thus, this verifies the results of the ARDL result.

Impact accounting

To ascertain the responses of livestock production to shocks from the regressors, we apply variance decomposition (VD) and impulse response function (IRF). The outcomes of VD and IRF are presented in Table 10 and Fig. 5, respectively.

The results of VD reveal that a shock in rainfall is responsible for 37.5% of future fluctuations in livestock production—the highest percentage compared to other regressors.

Table 8 Pairwise Granger causality tests

Null hypothesis:	*F*-statistic	*P*-value
lnT $\nRightarrow$ lnR	4.95505	0.015**
lnR $\nRightarrow$ lnT	0.79355	0.4629
lnCO$_2$ $\nRightarrow$ lnR	0.82722	0.4493
lnR $\nRightarrow$ lnCO$_2$	1.96943	0.1614
lnLP $\nRightarrow$ lnR	5.25320	0.0121**
lnR $\nRightarrow$ lnLP	6.56222	0.0049***
lnAL $\nRightarrow$ lnR	1.59674	0.2218
lnR $\nRightarrow$ lnAL	0.13525	0.8741
lnCO$_2$ $\nRightarrow$ lnT	2.76352	0.0832*
lnT $\nRightarrow$ lnCO$_2$	3.66788	0.0407**
lnLP $\nRightarrow$ lnT	3.54245	0.0436**
lnT $\nRightarrow$ lnLP	3.44304	0.0472**
lnAL $\nRightarrow$ lnT	11.7267	0.0002***
lnT $\nRightarrow$ lnAL	0.07900	0.9243
lnLP $\nRightarrow$ lnCO$_2$	0.73219	0.4913
lnCO$_2$ $\nRightarrow$ lnLP	5.03576	0.0149**
lnAL $\nRightarrow$ lnCO$_2$	0.38213	0.6865
lnCO$_2$ $\nRightarrow$ lnAL	0.07043	0.9322
lnAL $\nRightarrow$ lnLP	6.11974	0.0066***
lnLP $\nRightarrow$ lnAL	0.43934	0.6492

Note: *, **, and *** represent significance level at 10%, 5%, and 1%, respectively; $\nRightarrow$ denotes does not granger cause

CO$_2$ emissions and temperature-driven shocks cause 21% and 18% of future livestock fluctuations, respectively. Besides, 30% of future fluctuations in rainfall patterns are caused by temperature shocks, whereas shocks in agriculture labor cause 12.8% future fluctuations in rainfall. Future fluctuations in CO$_2$ emissions by 36% and 14.7% are due to shocks in temperature and agriculture labor, respectively. Also, agriculture labor contributes 21.8% of variations in

Table 9 Result of cointegration test

Hypothesis	Test statistic	5% critical value	P-value
Trace statistic			
$r \leq 0$ *	166.4058***	69.81889	0.0000
$r \leq 1$	85.70739***	47.85613	0.0000
$r \leq 2$	42.53856***	29.79707	0.0010
$r \leq 3$	19.49939**	15.49471	0.0118
$r \leq 4$	6.129406**	3.841466	0.0133
Maximum eigenvalue			
$r \leq 0$	80.69840***	33.87687	0.0000
$r \leq 1$	43.16882***	27.58434	0.0002
$r \leq 2$	23.03917***	21.13162	0.0266
$r \leq 3$	13.36998	14.26460	0.0689
$r \leq 4$	6.129406	3.841466	0.0133

Note: *** and ** show the significance level at 1% and 5%

Table 10 Variance decomposition

Variance decomposition of lnLP:						
Period	S.E	lnLP	lnT	$lnCO_2$	lnR	lnAL
1	0.0331	100	0	0	0	0
2	0.0545	56.4975	0.6825	4.95734	34.7567	3.106
3	0.0833	27.6553	17.3247	10.562	41.1317	3.3264
4	0.0982	20.0046	24.0247	11.9306	39.9098	4.1304
5	0.1041	19.2301	23.6293	11.7007	40.1352	5.3047
6	0.1054	19.3098	23.0751	11.9392	39.1136	6.5623
7	0.1096	18.2465	22.1544	15.2422	38.232	6.125
8	0.1169	16.4582	20.1425	19.175	38.4047	5.8197
9	0.1211	15.8261	18.7739	21.1283	38.1391	6.1327
10	0.123	15.5195	18.2169	21.2013	37.5742	7.4882
Variance decomposition of lnR:						
Period	S.E	lnLP	lnT	$lnCO_2$	lnR	lnAL
1	0.149882	0.042606	2.293174	7.9939	89.6703	0
2	0.189535	5.805926	11.75924	6.57334	71.2266	4.63494
3	0.222254	4.586936	30.85715	6.40198	54.7019	3.45199
4	0.236791	4.974063	29.24965	7.51218	51.3612	6.90294
5	0.244595	5.188935	27.66293	8.37981	52.0497	6.7186
6	0.250265	5.272532	26.53355	8.19066	49.8116	10.1916
7	0.250865	5.373126	26.51291	8.21501	49.5981	10.3009
8	0.262995	4.943639	28.7713	8.3797	46.878	11.0273
9	0.271766	5.216382	30.48617	7.93471	43.9027	12.46
10	0.27295	5.182027	30.22783	7.86649	43.8465	12.8771
Variance decomposition of $lnCO_2$:						
Period	S.E	lnLP	lnT	$lnCO_2$	lnR	lnAL
1	0.046441	2.047631	1.328936	96.6234	0	0
2	0.079814	0.916455	9.962442	76.5383	12.2544	0.32849
3	0.109543	0.67667	8.174402	70.1452	19.8683	1.13549
4	0.134505	0.459822	7.248601	66.8276	24.6823	0.7817
5	0.143025	0.521099	7.774487	67.1381	23.7953	0.77105
6	0.147986	0.714022	11.28107	65.0386	22.2267	0.73954
7	0.155705	1.62263	16.58679	59.8287	20.222	1.73991
8	0.17264	2.985788	24.13681	49.215	17.416	6.24635
9	0.195917	2.823466	31.44543	38.7134	14.6352	12.3825
10	0.213307	2.543351	36.40919	32.8165	13.4799	14.7511
Variance decomposition of lnT:						
Period	S.E	lnLP	lnT	$lnCO_2$	lnR	lnAL
1	0.006702	0.6451	99.3549	0	0	0
2	0.010764	0.261282	76.22117	0.02494	1.8051	21.6875
3	0.012643	6.581445	58.48348	1.59363	10.369	22.9724
4	0.013358	7.433099	60.4184	1.58758	9.5062	21.0547
5	0.013453	7.411661	60.62165	1.57417	9.49276	20.8998
6	0.014119	6.772706	62.11039	2.02539	8.6237	20.4678
7	0.014186	6.710287	61.5295	2.72477	8.65458	20.3809
8	0.014558	6.396592	58.79679	3.32376	9.7792	21.7037
9	0.015161	6.572992	55.46987	4.70408	13.1743	20.0788
10	0.015494	6.33311	53.43483	5.2214	13.1269	21.8838
Variance decomposition of lnAL:						
Period	S.E	lnLP	lAT	$lnCO_2$	lnR	lnAL
1	0.01572	0.761915	31.5843	0.00957	26.9678	40.6765
2	0.022302	2.42721	30.26069	0.0053	29.5978	37.709

Table 10 (continued)

3	0.026602	1.715534	33.719	0.04948	26.6452	37.8708
4	0.029233	1.421061	37.26179	0.24153	25.1301	35.9456
5	0.030916	1.375537	38.44605	0.35512	25.0173	34.806
6	0.033577	1.182341	37.20945	0.50331	26.4651	34.6398
7	0.037079	1.077824	36.64684	0.50523	27.1851	34.585
8	0.041239	0.910096	37.44842	0.42435	26.3352	34.882
9	0.045473	0.760543	38.8137	0.38543	25.4187	34.6217
10	0.048487	0.787211	39.57152	0.40027	25.4074	33.8336

To save space, we only reported the response of livestock production to the shocks in the explanatory variables

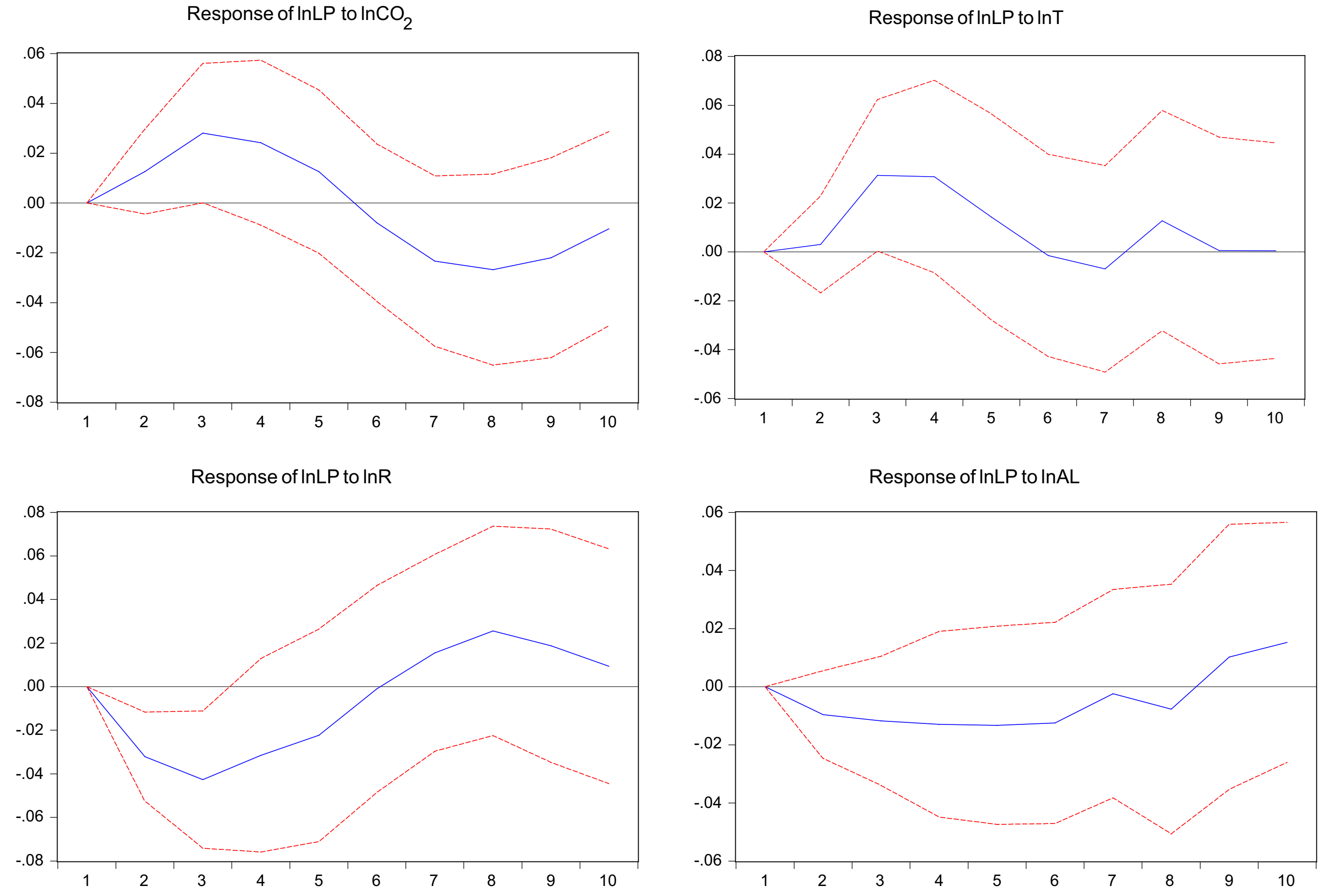


Fig. 5 Impulse response function

temperature, which is also the highest variable responsible for changes in temperature. However, this result is not surprising, as previous studies concluded that human activities are the main cause of global warming, resulting from increasing temperature. Variations in agriculture labor are due to 39.5% and 25.4% shocks in temperature and rainfall, respectively.

On the other hand, the IRF outcome shows that one standard deviation shock in CO_2 emissions leads to an increase in livestock production (lnLP) in the first 5 periods, but after period 5.5, the response of lnLP turns negative. It is also established that a shock in temperature (lnT) leads to a positive response of lnLP in the first 5 periods—but it is negative from period year 6 to 7.5—then turns positive until year 9. Besides, livestock production responds negatively from period 1.5 year to year 6, if one standard deviation shock in rainfall, but turns positive in year 6 to year 10. Moreover, one standard deviation increase in agriculture labor results in a decrease in livestock production from the first year to year 8, but increases from year 8.5 with shocks in agriculture labor.

Conclusion

Climate change and its related impacts have been a potential threat to Somalia in the last decades. The country has witnessed an inter-annual rainfall variation that results from the increasing temperature. A rising temperature induces dry and wet conditions and rain failures. Consequently, livestock production bears the highest cost of this disaster. To find out research-based evidence for policy formulations of mitigation and adaptation strategies, we examined the impact of rainfall, CO_2, temperature, and rural population on livestock production in Somalia. The study employed annual time series data of 31 observations, 1985–2016, with an ARDL cointegration method, Granger causality test, Johansen and Juselius (J&J) cointegration, impulse response function, and variance decomposition.

The empirical results confirmed the existence of cointegration among rainfall, temperature, rural population, and livestock production. The mean rise in rainfall tends to increase livestock production both in the long run and short run. Conversely, temperature undermines livestock production both in the long run and short run. Livestock production is relatively more sensitive to temperature, hence, a 1% increase in temperature hinders livestock productivities by about 5.4% in the long run. Besides, CO_2 emission is observed to have no impact on livestock production in the long run but enhances livestock production in the short run. Interestingly, rural population growth impedes livestock production in the long run but not in the short run. On the other hand, Granger causality was used to ascertain the causality between sampled variables. A unidirectional causality is established from temperature to rainfall and CO_2. Livestock production has a bidirectional causality relationship with rainfall and temperature. This somewhat affirms the role of livestock production in global warming. Moreover, CO_2 emissions granger cause livestock production whereas unidirectional causation is observed from rural population to temperature and livestock production. To ensure robustness and unbiased empirical results, we tested for residual independence using diagnostic and model stability tests. We found no evidence of serial correlation, and misspecification, but detected residual normality. Similarly, stability tests such as CUSUM and CUSUM squares verified the model stability for policy formulation. Similarly, the J&J cointegration method validated the results of the ARDL long-run cointegration among variables. The VD and IRF found that shocks in climate variables such as temperature, rainfall, and CO_2 explain the variation that occurs in livestock production in Somalia.

Based on the empirical findings, this study suggests policymakers design an adaptation policy to combat the negative consequences of climate change. We suggest all stakeholders, such as herders, non-governmental organizations (NGOs), community leaders, livestock traders, and brokers, be invited in the process of formulating the policy if the policy is intended to be effective and implemented accordingly. Other areas that the policymakers need to pay attention include increasing the number of veterinary centers in the country, since veterinary services are essential for the health of animals, especially during critical times where Somalia is facing a rising temperature and rainfall irregularities. Currently, the number of veterinary centers is not only sufficient but also beyond the reach of the herders—because most of them are located in urban cities, while herders rear their animals in the far rural areas. Furthermore, Somalia relies heavily on natural pastures to feed the livestock, and it faces enormous challenges in the event of rain failures. These challenges include loss of animals, low exports and economic growth, malnutrition, deterioration of the quality of the animals and meat, and lower milk output. Thus, policymakers could reduce the high dependence on rainfall to overcome these rainfall-related consequences by drilling dams which could be used during periods of rainfall failure. Finally, reducing environmental degradation could enhance efforts towards mitigating climate change and its negative consequences on pastoralists and their livestock.

Author contribution Abdimalik Ali Warsame performed the concept and design of the study, data collection and analysis, material preparation, some parts of the introduction, and the combination of the whole manuscript.

Ibrahim Abdukadir Sheik-Ali wrote some parts of the introduction and the improvement of the whole manuscript.

Abdullahi Abdirahman Hassan contributed to the manuscript by writing the methodology and improvement of the manuscript.

Samuel Asumadu Sarkodie reviewed and edited the manuscript.

Data availability The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

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