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Assessing the effects of climate change and political instability on sorghum production: Empirical evidence from Somalia

Abdimalik Ali Warsame [a,c], Ibrahim Abdukadir Sheik-Ali [a,b,*], Osman M. Jama [d], Abdullahi Abdirahman Hassan [a,e], Galad Mohamed Barre [a,c]

[a] Garaad Institute for Social Research and Development Studies, Mogadishu, Somalia
[b] Faculty of Economics and Management, Jamhuriya University of Science and Technology, Mogadishu, Somalia
[c] SIMAD University, Mogadishu, Somalia
[d] Department of Science & Technology Communication and Policy, University of Science and Technology of China, Hefei, People's Republic of China
[e] Red Sea University, Galkacyo, Somalia

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ABSTRACT

Climate change induces a devastating effect on agricultural production in Somalia leading to crop yield to decline including sorghum. To this end, this study aims to ascertain the long-term and casual impacts of climate change – rainfall and temperature – on sorghum production in Somalia for the 1980–2017 period while accounting for the role of political instability, land under sorghum production, and agricultural labor. The empirical result demonstrates that average temperature, political instability and agricultural labor significantly hamper sorghum production in Somalia in the long-run, whereas average rainfall – albeit insignificantly – and area under sorghum production enhance sorghum production in the long-run. In contrast, a unidirectional causality is established from political instability to sorghum production. Based on empirical results, the study recommends to policymakers enact policies aimed to eliminate conflicts to create a stable environment, and establishing a crop diversification plan in land under cultivation that would eliminate volatility caused by climatic and biological variations and accelerate the shift from low-productivity to a high-productivity economy.

1. Introduction

Climate change is an urgent and evolving threat to global food security and agricultural yield. The main impacts of climate change on agricultural productivity include increasing occurrence and severity of extreme climatic events such as temperature increase, changes in rainfall patterns, dry spells, prolonged drought incidents, water shortages, land degradation, and higher sea levels (Schmidhuber and Tubiello, 2007). All of these factors may wreak havoc on the global agricultural systems which in turn causes food insecurity in all of its facets – availability, stability, access, and consumption (Peng Weng & Elliot M Berry, 2019). Developing countries, such as Somalia are and will continue to experience a decline in agricultural productivity and food supply as result of climate variations (Fischer et al., 2001; Mendelsohn et al., 1994; Schmidhuber and Tubiello, 2007). For instance, Fischer et al. (2001) projected that 29 African countries are on the verge of losing 35 million tons of potential cereal harvest due to climate change.

Sorghum is an essential agricultural crop to food-insecure regions of Africa including Somalia (ICRISAT, 1996). In these regions, Sorghum serves as the main source of food for millions of people, and one-third of the population lives under the global poverty threshold of $1.25 per day (Gumma et al., 2017). It is such resilient grain that can flourish on marginal soils and is resistant to changing climate in semi-arid and sub-humid agro-ecological zones. It is drought tolerance and the capacity to withstand extreme temperatures brands it even a crucial agricultural crop for climate adaptation in small-scale households in Africa (Adhikari et al., 2015; Hadebe et al., 2017). Although it is a hardy crop, rainfall variability and excessive heat could seriously impact crop yield in many parts of the world (Sultan et al., 2013). According to Srivastava et al. (2010), the post-rainy sorghum yields are expected to decrease 7% by 2020, 11% by 2050, and 32% by 2080 owing to the climatic changes.

Climate change variations primarily influence sorghum during breeding or grain filling stages leading to crop loss. For instance, higher temperature significantly influences sorghum yields not only via pollen viability and seed set but also mainly by altering the pace at which

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* Corresponding author. Faculty of Economics and Management, Jamhuriya University of Science and Technology, Mogadishu, Somalia.
E-mail addresses: Ibrahim@just.edu.so, ibraahimcabdulqaadir@gmail.com (I.A. Sheik-Ali).

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biomass accumulates and the growing time of crops (Prasad et al., 2006). The impacts of climate change may also have a serious effect not only on productivity, but also on the nutritional quality of the crop as it is susceptible to dry spells (Chadalavada et al., 2021; Rurinda et al., 2013). The variation of early and mid-season rainfall distribution can have a significant impact on sorghum yield under the current climate (Rurinda et al., 2014). Sorghum production is particularly vulnerable to drought and extreme water shortages which inhibit fertilization or cause the spikes to dry out during the flowering phase, which may lead to a reduced yield (Assefa et al., 2013). In East Africa, it is reported that droughts reduce sorghum yield significantly during the early season (Elagib, 2015). Conversely, water availability influences foliage development rates, plant height, and leaf size during the early planting season (Assefa et al., 2013; Hadebe et al., 2017).

Somalia, which has been ravaged by conflicts for the past 20 years, is one of the developing post-conflict countries that has experienced recurrent natural disasters, and a depleted natural environment (Diriye, Jama, Chong, & Abdi, 2021; Jama et al., 2020). The Somalia's National Adaptation Programme of Action outlines four key climate - related risks based on various discussions with the community all over the country. Drought, severe flooding, rising temperatures, and heavy winds have been recognized (Federal Republic of Somalia, 2013). Pastoralists and agro-pastoralists in the country are extremely susceptible to weather and climatic extremes. At times of food shortage, for example, selling livestock to buy food and cereals from smallholder communities provides a feasible safety net (Hussein et al., 2021). This is commonly practiced by the Somali pastoral communities whose life mainly relies on rain-fed crops. Droughts cause crop failure as well as a decline in livestock numbers, leading to increased poverty, destruction of property, absence of livelihood opportunities, and the potential of famine situations (MHADM, 2018). Severe weather variations may obliterate this buffering mechanism, making rural communities more vulnerable to shocks. Major flooding occurrences in the country reduce agricultural land productivity owing to soil logging, causing loss of fertile topsoil and deforestation (Warsame et al., 2021). The loss of fertile topsoil through soil erosion has also been accelerated by strong winds, which in turn reduces land productivity. High temperatures have caused the failure of agricultural harvests as a result of higher evapotranspiration, reduced water availability, and increased insect invasion (Warsame et al., 2021).

Overall, the sorghum production in Somalia has shown an unstable trend over the years due to among others–droughts, conflicts, and climate change as depicted by Fig. 1. Sorghum production was relatively constant between 1960 and 1970 with upward growth in 1971. This steady progress is attributable to the significant investment for the development of new model farms with improved agricultural practices aimed to attract farmers from all over the nation. Nevertheless, that growth plummeted from 1972 to 1974, owing to the well-known (Dabadheer) droughts that occurred in Somalia in the early years of the 1970s. The productivity level has increased quickly by setting a record level of 330,000 tons in 1988. Succeeding the overthrow of the Central government in 1991, sorghum production fell drastically, from its highest peak of 330,000 tons in 1990 to around 80,000 tons in 1991. The collapse of 'public space and institutions,' coupled with the military governments' political and economic failures attributed to this decline. Despite a sharp increase in sorghum output between 1993 and 1995, the production level continued to fall and fluctuate on account of the various conflicts between the Transitional Federal Government of Somalia, warlords, and Islamic Courts Union (ICU). However, sorghum production dropped to a record low of 50,000 tons by 2011. This was accredited by the catastrophic droughts that ultimately evolved into famine which had a devastating effect on predominantly agropastoral society in southern Somalia. Even though the sorghum harvest soared again after the removal of the Somali government from the transitional period in the 2012 elections, the production level of the country has been subject to many constraints which led the sorghum yield to slide a downhill direction. These obstacles are both technological and socio-economic in nature. Diseases and pests' infestations, soil fertility, agronomic and physiological conditions are examples of technical impediments, while Smallholder size, insufficient quantity of supplies and resources are examples of socio-economic challenges.

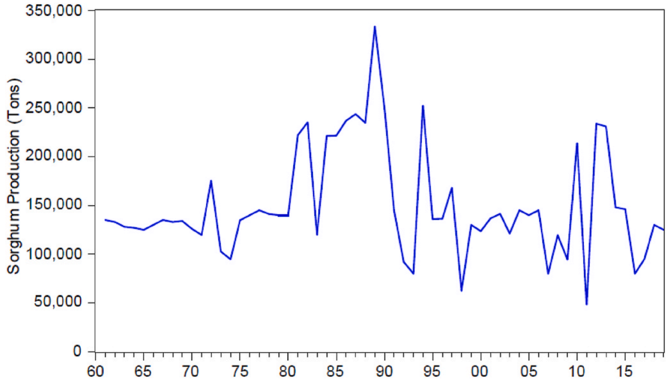

Fig. 1. Sorghum production in Somalia between 1960 and 2019. Data source: FAO (2020)

Furthermore, conflicts over natural resources control and use (arable land) that have emerged over time have aggravated additional internal conflicts and migration of people, as natural resources become increasingly limited (Déhérez, 2009). Moreover, excessive extraction practices exacerbate the negative effects of severe weather patterns on the current natural resource base (Waaben Thulstrup, Habimana, Joshi and Mumuli Oduori, 2020). Tragically, decades of violence have seriously hindered the capacities of the agricultural sector, which historically and continues to be the main pillar of the country's economy (Hussein et al., 2021). For instance, with agricultural production significantly decreasing, food imports have grown considerably since the late 1980s, representing around 60% of current local consumption (World Bank, 2018). Moreover, there have been repeated droughts and serious land degradation which has lowered agricultural production capacity, causing serious food shortfalls and considerable urban migration of the rural people (Federal Government of Somalia, 2018). As reported by Hastings et al. (2020), conflicts and political instability have an impact on food costs for some food items such as rice imports. The impact of political instability resulting from conflicts and armed insurgencies is typically affecting imported food costs in rural regions, where pastoral and agropastoral production takes place, but conflict can also influence the supply of domestic goods, especially if the conflict disrupts key supply routes in urban areas (Hussein et al., 2021).

In Somalia, the empirical evidence of the effect of climate and non-climate variables on sorghum production still remains unknown, particularly the effect of rainfall, temperature, agriculture labor, and political instability on sorghum production. Ample of recent empirical studies have attempted to investigate how climate variables affect agricultural productivity; yet, this line of research has been unable to reach a concise conclusion. For instance, a recent study conducted in Nepal by Chandio et al. (2021)a,b,c concluded that average temperature and rainfall significantly improve rice production in the long-run whereas CO2 emissions exacerbate it. In the same vein, Ahmed et al., (2021) reported similar findings in their study of China in which CO2 emissions have a negative significant impact on cereal production in the long-run. However, a recent panel study in lower-middle-income countries by Kumar et al. (2021) found out that CO2 emissions improve cereal production in the long-run. Elsewhere, Chandio et al. (2021b) discovered that CO2 emissions and rising temperature hampers the rice production of major Asian countries in the long-run, whereas rainfall significantly enhances rice production in the long-run. Pickson et al. (2020) revealed that CO2 emissions and temperature have a significant adverse effect on china's cereal production in the long-run. Zhao et al. (2017) argued that climate change measured in rising temperature and changes in rainfall pattern has an enormous negative effect on crop yields. Similarly, Pickson et al. (2021) documented out similar findings in china.

In fact, these mixed findings can be attributed to many factors. Among them include the different measurements that researchers employed to measure agriculture production. For instance, some studies utilized individual crops such as rice by Chandio et al. (2021a) in Nepal, wheat by Arshed and Abduqayumov (2016) in Bangladesh, maize by Luhunga (2017) in Tanzania, sorghum by Sultan et al. (2013) in West Africa region, and cotton by Abbas (2020) in Pakistan. There are other strands of studies that utilized aggregate measurements (see, Chandio et al., 2021c, 2020 Eregha et al., 2014; Warsame et al., 2021). Consequently, this leads to a mixed finding. In recent studies of climate – agriculture nexus found out a conflicting result. Warsame et al., (2021) reported that CO_2 emissions do not exert any significant impact on cereal production in Somalia, whereas it has a positive significant impact on rice production in panel countries (Demirhan, 2020). On the contrary, Chandio, et al. (2020) found out a negative effect of CO_2 emissions on cereal production in Turkey. The inconclusive result in the climate change-agriculture production literature is due to the difference in geographical location, climate change adaptation measures, development level, political and environmental conditions.

Plausible explanations for the ample studies about climate change and agriculture nexus in the existing literature could be attributed to the importance of this sector to the livelihoods of developing countries and its susceptibility to climate change. First, agriculture is the main source of income for developing countries. For instance, two-thirds of Sub-Saharan African (SSA) countries' labor force work in the agriculture sector (ILO, 2007). Second, it represents an essential source of food. For instance, sorghum production is the second most-consumed crop in Somalia. Despite this importance, agriculture is considered one of the most susceptible sectors to climate change. Nevertheless, climate change is not the only tangible threat to agriculture. Recent reports of FAO et al., (2018 & 2020) documented out that civil conflicts and political instability undermine agriculture production that ultimately inhibits food security besides climate change. But unfortunately, there are scanty studies in the existing literature that address civil conflicts, political instability, and agriculture production nexus. Given this, this is the first study that investigates the effect of climate change variables, – measured in rainfall and temperature – and political instability on sorghum production in Somalia. This study differs from the existing literature in several ways. First, this undertaking addresses the role of climate change – rainfall and temperature – on sorghum production by incorporating political instability dummy variables in which the previous literature has failed to consider. Second, most of the previous studies measured agriculture production by utilizing aggregate variables such as; agriculture value-added or crop production index which could be associated with bias. This study uses sorghum crop to measure the agriculture productivity of Somalia since it is the second most-consumed crop in Somalia after Staple food crops (FAO & World Bank, 2018). In doing so, this study can be drawn from a coherent and robust climate impact on sorghum yield. Third, this study performs several econometric analyses to produce robust results that could lead to reliable and sound conclusions and policy inferences.

Following this section, the subsequent sections include data source and econometric model employed, results of the econometric model, summary, and policy implications.

2. Materials and data

2.1. Data

This study used balanced annual time series data which was sourced from the world bank and FAO to examine the effect of rainfall, temperature, agriculture labor, political instability, and sorghum area under cereal on Somalia's sorghum production for the period between 1980 and 2017. Since it has become a common practice to utilize a natural logarithm in order to interpret the results in an elasticity form as well as minimize the variance across variables; therefore, we converted the scrutinized variables except for the political instability into a natural logarithm. Table 1 shows the definitions and sources of the variables used in this study.

2.2. Model estimations and procedures

To achieve the objective, this study followed the model specification of Adelaja & George (2019), Chandio et al. (2020), and Warsame et al. (2021) who added not only climate change variables — temperature and rainfall but also included other variables in their model specification such as Agriculture labor, political instability, and land area under sorghum cereal which are key to the fitness and soundness of the model. Mathematically, the model is written as follows:

$$lnSP_t = \beta_0 + \beta_1 lnAR_t + \beta_2 lnAT_t + \beta_3 AL_t + \beta_4 lnSUC_t + \beta_5 lnPIS + \varepsilon_t \tag{1}$$

$lnSP_t$ is the log of sorghum production in year t, $lnAR_t$ is the log of average rain in year t, $lnAT_t$ is log of average temperature in year t, $lnAL$ is log Agriculture labor in year t, $lnSUC_t$ is the log of sorghum area under cultivation in year t, PIS is a dummy variable which is intended to account for the effect of political instability on sorghum production in Somalia. Hence, we gave a value of '0' and '1' in the events of political stability and instability, respectively. Finally, ε_t represents the error term in time t.

As part of the steps to checking the presence of a cointegration relationship in our model, we conducted unit root analysis. This is the first step undertaken in time series analysis before performing cointegration analysis. The is due to the fact that we were avoiding finding spurious results. Hence, we used the two commonly applied tests in time series econometrics —Augmented Dickey Fuller (ADF) and Philips Perron (PP) tests to determine the order of integration of the variables used in this study. In order to proceed to the detection of the presence of cointegration in the model, the variables of interest must be integrated of order one or I (1). To this end, we applied Johansen and Juselius (1990) cointegration method. The preference of this cointegration approach over other competing cointegration methods is that it determines the number of cointegrating vectors in an unrestricted vector autoregressive (VAR) system by using a maximum likelihood method, and the error correction form of this process is expressed in the following equation.

$$\Delta Y_t = \prod Y_{t-k} + \sum_{i=1}^{K-1} \Gamma i \Delta Y_{t-1} + \mu + \varepsilon_t \tag{2}$$

Where ΔY_{t-1} represents the first difference of an (n × 1) vector of the n variables, $\prod$ and Γ stands for the estimated coefficients of the matrix, μ

Table 1
Variable descriptions and sources.

Variable	Symbol	Unit of measurement	Source
Sorghum production	SP	Thousand tons	FAO
Rainfall	AR	Average annual precipitation (mm)	World Bank
Temperature	AT	Average annual temperature in (°C)	World Bank
Political Instability	PIS	It is a dummy variable. We gave a value of '0' during the political stability period and a value of '1' during the political instability period.	
Agriculture labor	AL	Rural population	World Bank
Sorghum area under cultivation	SUC	Square Kilometer area	FAO

denotes a vector of constant, Y_{t-1} represents the previous values of Y_t, and finally ε_t is a vector of white noise residuals. Subsequently, we started with our estimation of Johansen and Juselius (1990) cointegration approach by first determining the rank of matrix Π. In doing so, we can separate the cointegrating rank matrix Π into two parts— the long-run and speed of adjustment as expressed in equation (3).

$$\prod = \alpha\beta^{'} \tag{3}$$

where α is the vector of the speed of the adjustment, whereas β is the vector of long-run equilibrium. If the rank of matrix Π becomes one, it can be said that there is at least one single cointegrating vector in the model; hence, proving the evidence of cointegration association among the variables of our model. To determine the number of cointegrating vectors in our model, we utilize trace and maximum eigenvalue statistic tests. Mathematically, it is specified in the following form:

$$\lambda_{trace} = \ -\mathrm{T}\sum_{i=r+1}^{n} ln\left(1\ -\lambda_i^2\right) \tag{4}$$

$$\lambda_{max}(r,\ r+1) = \ -\mathrm{T}\ln(1-\lambda_{r+1}) \tag{5}$$

Where the value of λ_i denotes the estimated matrix, while T stands for the sample period observations after lag adjustment. we can reach the conclusion that there is a cointegration relationship if the t-statistics results from the two tests are lower than the critical value of each test.

Once it is estimated the long-run relationship among variables of our model, the next step is to estimate the long-run coefficient elasticities of the variables. Among the various estimation methods, we employ the fully modified ordinary least squares (FMOLS) method to this end. The choice of this estimation method is based on the fact it can solve diagnostic problems associated with serial correlation, and endogeneity problems (Phillips & Hansen, 1990). Under the FMOLS method, our dependent and independent variables must satisfy the following condition in order to use the FMOLS method.

$$Y_t = X_t^{'}\beta + d_t^{'}\alpha + \mu_{1t} \tag{6}$$

$$X_t = X_{t-1}\ + \mu_{2t} \tag{7}$$

Where d_t refers to a vector of deterministic trend regressors; $\mu_t = (\mu_{1t}, \mu_{2t}^{'})^{'}$, stands for the error terms. Following this, the next step is to estimate the long-run covariance matrix, Λ and Ω, using equations (8) and (9), respectively.

$$\Lambda = \sum_{i=0}^{\infty} E\left(\mu_t\mu_{t-1}^{'}\right) = \begin{matrix} \lambda_{11} & \lambda_{12} \\ \lambda_{21} & \Omega_{22} \end{matrix} \tag{8}$$

$$\Omega = \sum_{i=-\infty}^{\infty} E\left(\mu_t\mu_{t-1}^{'}\right) = \begin{matrix} \Phi_{11} & \Phi_{12} \\ \Phi_{21} & \Lambda_{22} \end{matrix} \tag{9}$$

Subsequently, suppose $\mathrm{Y_t}^{+} = \mathrm{Y_t} - \widehat{\Phi_{12}}\widehat{\Omega_{22}}^{-1}\Delta\mathrm{X_t}$; $\widehat{\lambda_{12}}^{+} = \widehat{\lambda_{12}} - \widehat{\Phi_{12}}\widehat{\lambda_{22}}\Delta\mathrm{X_t}$, where $\widehat{\lambda_{12}}$, $\widehat{\Phi_{12}}$, $\widehat{\Omega_{22}}^{-1}$, and $\widehat{\lambda_{22}}$ are estimated parameters. Thus, The FMOLS estimator is specified as follows:

$$\begin{bmatrix} \widehat{\beta} \\ \widehat{\alpha} \end{bmatrix} = \left(\sum_{t=1}^{T} \mathrm{z}_t\mathrm{z}_t^{'}\right)^{-1}\left(\sum_{t=1}^{T} \mathrm{z}_t\mathrm{y}_t - T\begin{bmatrix} \widehat{\lambda_{12}}^{+'} \\ 0 \end{bmatrix}\right) \tag{10}$$

Where. $\mathrm{z}_t\ = (\mathrm{x}_t{'}, \mathrm{d}'_t)^{'}$

3. Empirical results and analysis

3.1. Descriptive statistics

Table 2 presents the descriptive statistics of the data series under examination. descriptive statistics is essential to assess the summary characteristics of the investigated variables. Land under sorghum cultivation shows the highest mean value – 12.8, while political instability is recorded to have the lowest mean value – 0.70. Sorghum output and land under sorghum cultivation have maximum values of 12.7 and 13.3, respectively. Moreover, the average temperature is the only variable that has a long right tail, thus showing positive skewness compared to all other variables that are negatively skewed. Political instability has shown the highest volatility due to its high standard deviation (0.46) compared to other variables. The Jarque-Bera test of the normal distribution reveals that all the data series are normally and identically distributed at a 5% significance level.

Besides, Table 2 also reports the correlation of the data series. It reveals that sorghum production is negatively correlated with average temperature and political instability, whereas sorghum production has a positive correlation with land under sorghum cultivation, average rainfall, and agricultural labor. In addition, average temperature and political instability have a negative relationship with land under sorghum cultivation. On the contrary, land under sorghum production is positively related to average rainfall and agricultural labor. Concerning climate variables, the average temperature is positively correlated with average rainfall and political instability, and it is negatively related to agricultural labor. Average rainfall has a negative association with political instability and agricultural labor. In summary, the lack of perfect correlation among the variables verifies the absence of multicollinearity.

3.2. Unit root test

As a precondition of J & J cointegration method, FMOLS, and CCR methods, the data series of the interested variables should be stationary

Table 2
Descriptive statistics.

lnSP	lnSUC	lnAT	lnAR	PIS	lnAL	
Mean	11.91058	12.80956	3.301822	3.109788	0.702703	4.194593
Median	11.88449	12.82316	3.301953	3.103335	1.000000	4.211965
Maximum	12.71758	13.33941	3.334483	3.509205	1.000000	4.293701
Minimum	10.78872	12.03910	3.276998	2.656198	0.000000	4.028632
Std. Dev.	0.438431	0.316382	0.012893	0.191617	0.463373	0.078921
Skewness	−0.464532	−0.339070	0.378609	−0.075417	−0.886969	−0.701978
Jarque-Bera	1.386912	1.328313	0.912192	0.068420	7.120832	3.644044
Probability	0.499846	0.514708	0.633753	0.966369	0.028427	0.161698
Correlation						
lnSorghum	1					
lnSAH	0.6874	1				
lnAVT	−0.3932	−0.4833 1				
lnAVR	0.2125	0.0896	0.1274	1		
PIS	−0.5625	−0.5547	0.4923	−0.0069	1	
lnRP	0.3164	0.6128	−0.7771	−0.2562	−0.6706	1

at the first difference I (1). The study employs the Augmented Dickey-Fuller test (ADF) and Philips Perron test (PP) including trend and trend with an intercept to test for stationarity of the interested variables. The outcome of ADF and PP were reported in Table 3. It showed that some variables contain unit root problems at their level I (0); but, all the variables turned into stationary at the first difference I (1) as denoted by the values of ADF and PP which are higher than their critical values at the 5% significance level.

Subsequently, after checking the unit root test, we verify the presence of long-run cointegration among the variables. We employ Johansen and Juselius cointegration to execute this objective. The null hypothesis states that the variables are not cointegrated in the long-run, whereas the alternative hypothesis mentions that the variables are cointegrated in the long-run. To reach a decision about the hypothesis, we compare the Trace t-statistics and Maximum Eigenvalue vectors to their critical values. If the Trace t-statistics and Maximum Eigenvalue are greater than the critical values, we conclude that the variables are cointegrated in the long-run. However, the outcome presented in Table 4 demonstrates that sorghum production, average rainfall, average temperature, land under sorghum production, political instability, and agricultural labor are cointegrated in the long-run. It shows that there are at least three cointegrating vectors.

After verifying the existence of long-run cointegration between the variables, we subsequently examined the long-run coefficient of the variables. We utilize FMOLS and CCR methods to estimate the long-run coefficient of the parameters. The FMOLS result reported in Table 5 indicates that average temperature, political instability, and agricultural labor significantly hamper sorghum production in Somalia in the long-run. On the contrary, average rainfall – albeit insignificantly – and area under sorghum production enhance sorghum production in the long-run. This means average temperature and agricultural labor undermine sorghum production by about 10.8% and 3.14%, respectively, in the long-run for a 1% increase in average temperature and agricultural labor. It is notable that they have an elastic coefficient value. Additionally, political instability inhibits sorghum production by about 0.43%, if political instability rises in one unit. On the other hand, a 1% increase in land under sorghum production improves sorghum production by about 0.95% in the long-run.

Canonical cointegration regression has been espoused as robustness to verify the long-run results of FMOLS. Its result presented in Table 5 reveals that average temperature and agricultural labor significantly reduce sorghum production by about 9.4% and 2.6%, respectively, in the long-run, if they are increased by 1%. In the same vein, a 1 unit increase in political instability decreases sorghum production by 0.40% in the long-run. Moreover, land under sorghum production raises sorghum production by about 0.93% in the long-run, if it is increased by 1%. In summary, the long-run coefficient findings of the FMOLS are robustly consistent with the results of the CCR method. Besides, the adjusted R-squared is 0.60 which represents 60%. It implies that the explanatory variables explain 60% of the variations that occur in sorghum production. Other remaining 40% variance is explained by other variables that are not included in our model.

Comparing our findings to the previous results, our result of the negative impact of temperature on sorghum production is supported by plenty of previous studies (see; Sultan et al., 2013). Likewise, Pickson, He, Ntiamoah, & Li, (2020) and Abbas & Mayo, (2020) have reached the same conclusion – that temperature rise hampers agricultural production. But it is contradictory to the results of Chandio, Jiang, Ahmad, Adhikari, & Ain, (2021)b who found that temperature rise contributes to the increase of rice production in Nepal. Rainfall is even though, insignificant but has shown a positive coefficient and several other studies emphasized the importance of rainfall on agriculture production (Ben Zaied and Ben Cheikh, 2014; Jan et al., 2021). Moreover, our result of political instability's adverse effect on sorghum production is consistent with previous studies who came to the same conclusion that political instability hampers agricultural production (Arias et al., 2018; Adelaja and George, 2019). It is also supported by the study of Warsame, Sheik-Ali, Barre, & Ahmed, (2021b) who concluded that political instability impedes maize production in Somalia.

Furthermore, the inhibiting effect of agricultural labor corroborates with the studies of Warsame et al., (2021) in Somalia but contradicts the studies of Chandio et al., (2020) in Turkey and Pickson et al., (2020) in

Table 3
Unit root tests.

Variable	ADF		PP	
	Level		Level	
	Intercept	Intercept & Trend	Intercept	Intercept & Trend
lnSUC	−3.4683**	−5.3305***	−3.3482**	−5.2620***
lnSP	−5.0579***	−6.0667***	−5.1554***	−6.0671***
lnAT	−2.7224*	−5.9611***	−2.5689	−6.5323***
lnAR	−6.6817***	−6.7283***	−6.8118***	−7.7236***
lnAL	−1.4912	−1.1631	3.1735	−0.8832
PIS	−1.6299	−1.5753	−1.6276	−1.5753
	First difference		**First difference**	
	Intercept	Intercept & Trend	Intercept	Intercept & Trend
lnSUC	−7.0502***	−6.9426***	−22.9723***	−22.5737***
lnSP	−10.8327***	−10.6803***	−37.0554***	−37.856***
lnAT	−9.4082***	−9.3523***	−17.5761***	−22.8945***
lnAR	−8.212***	−4.0958**	−27.1397***	−36.311***
lnAL	−5.4607***	−5.9087***	−5.4578***	−7.167***
PIS	−6.1644***	−6.2071***	−6.1644***	−6.2187***

Notes: ***, ** and * indicate significance level at 10%, 5% and 1% respectively.

Table 4
J&J cointegration test result.

Hypothesized Trace Test	Test Statistic	5% Critical Value Prob.**	
r ≤ 0 [a] 235.7932	95.75366	0.0000	
r ≤ 1[a] 121.7180	69.81889	0.0000	
r ≤ 2 [a]	57.73096	47.85613	0.0045
r ≤ 3	27.66998	29.79707	0.0863
r ≤ 4	13.90642	15.49471	0.0855
r ≤ 5 [a]	4.378535	3.841466	0.0364
Maximum Eigenvalue Test			
r ≤ 0 [a]	114.0752	40.07757	0.0000
r ≤ 1 [a]	63.98702	33.87687	0.0000
r ≤ 2 [a]	30.06097	27.58434	0.0235
r ≤ 3	13.76357	21.13162	0.3848
r ≤ 4	9.527884	14.26460	0.2448
r ≤ 5 [a]	4.378535	3.841466	0.0364

Max-eigenvalue test indicates 3 cointegrating eqn(s) at the 0.05 level.

[a] Denotes rejection of the hypothesis at the 0.05 level.

Table 5
Long-run coefficient elasticities.

Dependent Variable: lnSP		
Method:	(FMOLS)	(CCR)
Variable	Coefficient	Coefficient
lnAT	−10.8272***	−9.4120*
(-3.1397)	(-1.8475)	
lnAR	0.15334	0.2605
(0.89065)	(1.0185)	
lnPIS	−0.4270***	−0.4002***
(-5.0298)	(-4.3592)	
lnSUC	0.9449***	0.9254***
(8.1750)	(5.0554)	
lnAL	−3.1387***	−2.7413**
(-4.3263)	(-2.6724)	
Adjusted R-squared	0.5980	0.5878
S.D. dependent var	0.4445 0.4445	
S.E. of regression 0.2818	0.2854	
Sum squared resid 2.3830 2.4437		

China who found that agricultural labor enhances agriculture production in both countries. On the contrary, it is observed that land under sorghum production stimulates sorghum production in Somalia. This result is supported by previous studies (see; Guntukula & Goyari, 2020; Warsame et al., 2021b; Abbas, 2020) who found that land under cereal cultivation enhances agricultural production.

Somalia's ecosystems are part of Africa's dry and semi-arid zones, which consist of trees that supply firewood and livestock grazing and are dependent on rainfall availability (Abdi et al., 2017). It is a form of dryland with a low seasonal average rainfall of (about 282 mm) and droughts that occur every 2–3 years, followed by seasonal floods in the dry river valleys. In southern Somalia however, rainfall is essential for agricultural production and food security, as this part of the country has the highest crop yields receives about 400 mm of rainfall, but the northern coastline obtains little rainfall with up to 50 mm. Agricultural crop productions are sensitive to rainfall extreme events, but when it comes to sorghum production, it is quite more drought resistant. It can grow in arid lands as well as fertile lands successfully compared to other crops such as maize and wheat (World Bank, 2021). However, this justifies our insignificant effect of rainfall on sorghum production; even though, it accompanies a positive coefficient. In contrast, temperature rise poses the highest significant threat to sorghum production as a result of an excessive rise of temperature which causes poor sorghum productivity since increased day and night temperatures interrupt flower initiation leading to primordia development while at the same time causing irregular rainfall patterns which creates a friendly environment for fungus and mold to grow which ultimately inhibit the pre-harvesting and post-harvesting of sorghum production in Somalia (Wielogorska et al., 2019).

Furthermore, our result of agricultural labor reveals that it inhibits sorghum production in Somalia. One possible explanation for this inhibition might be the lack of sufficient skills and training as well as inadequate equipment in Somalia's agricultural labor. it is also notable that agriculture labor has been increasing while agriculture production including sorghum is stagnant since the 1960s (Gavin et al., 2019). Therefore, this puts pressure on the limited supply of sorghum crop which is already suffering from extreme weather events and civil conflicts. Conversely, land under sorghum production enhances sorghum production by providing adequate land for sorghum cultivation. On the other side, political instability has crippled agricultural production in Somalia in general, and southern and central Somalia in particular. It exerts farm owners and labor to flee from their residents – mainly in southern Somalia – due to conflicts, which ultimately leads to the reduction of crop productions including sorghum. In addition, foreign and Somali investors who would have invested in the country's agriculture to produce enough crops for domestic consumption and export could not invest due to political instability and ongoing conflict.

3.3. *Different measurements of climate change for robust analysis*

Climate change is measured for various measurements including, inter alia rainfall, temperature, and CO_2 emissions (Warsame et al., 2022; Chandio et al., 2020; Pickson et al., 2020). Hence, we employed rainfall and temperature as climate change proxies. We further examine the role of CO_2 emissions – as a climate change proxy – in sorghum production in Somalia. Its result reported in Table 6 revealed that CO_2 emission does not significantly affect sorghum production in the long run in Somalia, even though, it has a negative coefficient. This could be justified that Somalia is among one of the least energy consuming nations in the world (Warsame et al., 2021a; Warsame, 2022). Consequently, the emission of CO_2 in Somalia is a negligible amount. Notably, all other regressors have confirmed the results of the previous models employed. Land under sorghum production significantly enhances sorghum output, whereas agriculture labor and political instability hamper sorghum production in the long run. More importantly, incorporating CO_2 in the model has produced the absence of long run Cointegration among the scrutinized variables as shown by Johansen Cointegration result reported in Table 7.

Table 6
Long-run coefficient elasticities.

Method:	(FMOLS)	(CCR)
Variable	Coefficient	Coefficient
lnSUC	0.8833***	0.8332***
	(4.9929)	(3.3153)
$lnCO_2$	−0.1082	−0.1750**
	(−0.2272)	(−0.3285)
lnAL	−1.5439*	−1.2909
	(−2.004)	(−1.3567)
PIS	−0.6063**	−0.6373*
	(−2.2712)	(−2.0416)
Constant	8.2219	8.2517
	(1.6036)	(1.4072)
Adjusted R-squared	0.5233	0.5134
S.D. dependent var	0.4501	0.4501
S.E. of regression	0.3107	0.3140
Sum squared resid	2.6080	2.6623

Trace test indicates 1 cointegrating equations at the 0.05 levels and Max-eigenvalue test indicates no Cointegration at the 0.05 level.

3.4. *Granger causality test*

To detect the direction of causation of the interested variables, we utilize the Granger causality test. Its result presented in Table 8 reveals that a unidirectional causality is detected from political instability to sorghum production. A bidirectional causality is established between average temperature and land under sorghum cultivation. Agricultural labor granger causes average temperature. This implies that temperature rise is a consequence of land usage for agriculture activities – deforestation and population increase. Moreover, unidirectional causations are found from agricultural labor to land under sorghum cultivation and from average temperature to average rainfall. It is notable that environmental pollution induces a rise in temperature which ultimately causes irregular rainfall patterns (Warsame and Sarkodie, 2021). This justifies the result that average temperature causes average rainfall in Somalia.

4. Conclusion and policy implication

Climate change and political instability pose a great threat to the agricultural sector on which the livelihoods of least developed countries' populations depend on. Hence, this study ascertains the impact of climate change and political instability along with other explanatory variables (agriculture labor and area under cultivation) on sorghum production in Somalia – a conflict- prone nation that is susceptible to climate variabilities. FMOLS, CCR, and Johansen & Juselius cointegration methods have been employed by using time series data between

Table 7
Johansen cointegration result.

Hypothesis	T-Statistic	5% Critical Value	Prob.**
Trace Test			
$r \leq 0$ *	79.90186	69.81889	0.0063
$r \leq 1$	47.81108	47.85613	0.0505
$r \leq 2$	25.65943	29.79707	0.1392
$r \leq 3$	12.42275	15.49471	0.1378
$r \leq 4$	0.912182	3.841466	0.3395
Maximum Eigen value Test			
$r \leq 0$	32.09078	33.87687	0.0804
$r \leq 1$	22.15165	27.58434	0.2127
$r \leq 2$	13.23668	21.13162	0.4307
$r \leq 3$	11.51057	14.26460	0.1304
$r \leq 4$	0.912182	3.841466	0.3395

Table 8
Pairwise granger causality tests.

Null Hypothesis:	Obs	F-Statistic	Prob.
lnSAH ≠ lnSorghum	38	0.28403	0.7546
lnSorghum ≠ lnSAH	0.37148	0.6926	
lnAVT ≠ lnSorghum	35	1.59052	0.2205
lnSorghum ≠ lnAVT	2.54410	0.0954	
LAVR ≠ lnSorghum	35	0.53064	0.5936
lnSorghum ≠ lnAVR	1.61539	0.2156	
PIS ≠ lnSorghum	38	7.86807	0.0016
lnSorghum ≠ PIS	0.98031	0.3859	
lnRP ≠ lnSorghum	55	0.34357	0.7109
lnSorghum ≠ LRP	0.99510	0.3769	
lnAVT ≠ lnSAH	35	4.17354	0.0252
lnSAH ≠ lnAVT	5.71617	0.0079	
lnAVR ≠ lnSAH	35	1.94564	0.1605
lnSAH ≠ lnAVR	0.44595	0.6444	
PIS ≠ lnSAH	38	2.12040	0.1360
lnSAH ≠ PIS	0.20410	0.8164	
lnRP ≠ lnSAH	36	7.99114	0.0016
lnSAH ≠ lnRP	0.00129	0.9987	
lnAVR ≠ lnAVT	35	1.17498	0.3226
lnAVT ≠ lnAVR	6.29574	0.0052	
PIS ≠ LAVT	35	1.20702	0.3132
lnAVT ≠ PIS	0.85335	0.4361	
lnRP ≠ lnAVT	35	13.9673	5.E−05
lnAVT ≠ lnRP	0.08223	0.9213	
PIS ≠ lnAVR	35	1.28591	0.2912
lnAVR ≠ PIS	1.68462	0.2026	
lnRP ≠ lnAVR	35	1.87430	0.1710
lnAVR ≠ lnRP	0.10471	0.9009	
PIS ≠ LRP 36	0.05035	0.9510	
lnRP ≠ PIS	0.05828	0.9435	

≠ denotes that variable 'x' does not granger cause variable 'y'.

1980 and 2017. Johansen's cointegration method revealed that the variables are cointegrated in the long-run. Furthermore, FMOLS found that political instabilities, agricultural labor, and temperature significantly hamper sorghum production in Somalia in the long-run. Whereas rainfall – albeit insignificantly – and land under sorghum cultivation enhance sorghum production in the long-run. The study utilized CCR as a robust analysis for FMOLS long-run results, and it produced the same results as FMOLS. Besides, Granger causality has been used to detect the direction of causation of the variables. It detected unidirectional causation from political instability to sorghum production. A bidirectional causality is established between average temperature and land under sorghum cultivation. Moreover, a unidirectional causation is found from agricultural labor to land under sorghum cultivation, from average temperature to average rainfall and from agricultural labor to average temperature.

Based on empirical results, the study suggests several policy implications. First, since the agricultural laborers do not have adequate training and equipment, the Federal Government of Somalia and its member states – policymakers – should provide training and equipment to farmers to increase overall agricultural production and especially sorghum. Second, implementing clear policies to eliminate all kinds of conflicts such as; clan conflicts, land dispute conflicts, and political conflicts creates a stable environment that can attract the attention of local and foreign investors. Third, durable and efficient agriculture needs a significant change in the way Somali smallholder farmers practice their farming activities. Climate-smart farming methods are one of the recently recognized agricultural practices that can assist smallholder farmers in poor countries like Somalia to deal with degraded natural resources and recuperate the crop production sector in a sustainable manner. This can be done by implementing site-specific climate-smart agricultural methods that would allow farmers to use resources more efficiently, less volatility, and be more resilient and stable to shocks, hazards, and long-term climate changes. Hence, we suggest an extensive adoption of advanced agricultural practices such as improved seeds, high-yielding cultivars, and more irrigation, this will definitely lead to significant improvements in agricultural productivity and poverty alleviation. Investing in irrigation is critical to enhance productivity and sustain crop yields by minimizing dependency on rainfall. Fourth, the adoption of comprehensive soil and water conservation efforts is required in Somalia. This is a technique for optimizing soil moisture by storing and boosting absorption while decreasing runoff and evaporation. The technique is essential to guarantee that crop yields can withstand the stresses of changing climate and is one of the most effective strategies to accommodate agricultural production to climate change and rainfall fluctuation.

Finally, in order to maximize the utilization of land, water, as well as other inputs, establishing a crop diversification plan in land under cultivation would eliminate volatility caused by climatic and biological variations and accelerate the shift from low-productivity to a high-productivity economy because the more diversified an agricultural system is, the greater it is able to adapt to climate change on aggregate. As a result, we recommend an integrated crop-non-timber forest product system that might make Somalia's smallholder farmers highly tolerant to climate change by offering them adaptation advantages, while also lowering local temperatures, and boosting rainfall and the availability of water. And, in the long run, this will lessen the impact of extreme weather events on crops, animals, and other commodities; reduce soil erosion; enhance productivity; and add further socio-economic advantages by increasing the range of things farmers may grow for survival or sale.

Data availability

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

Ethical approval

Not applicable.

Consent to participate

Not applicable.

Consent to publish

Not applicable.

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CRediT authorship contribution statement

Abdimalik Ali Warsame: Data curation, Formal analysis, performed the design of the study, data collection and analysis, and improved the overall paper. **Ibrahim Abdukadir Sheik-Ali:** Writing – review & editing, Methodology, wrote the methodology, revised introduction and literature; reviewed and edited the paper. **Osman M. Jama:** Writing – review & editing, wrote the introduction and policy implication, reviewed and edited the paper. **Abdullahi Abdirahman Hassan:** Writing – review & editing, wrote the conclusion, policy implication, and abstract. **Galad Mohamed Barre:** Writing – review & editing, reviewed and edited the paper.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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