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The effects of climate extreme events on selected food crop yields in Sub-Saharan Africa

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ABSTRACT

The agricultural sector is essential for economic growth. However, agricultural performance can be limited by factors such as climatic risks. This paper aims to analyse the effect of climate extreme events on selected food crop yield in sub-Saharan Africa (SSA). The study uses data from the Food and Agriculture Organisation (FAO) database for maize, rice, and sorghum yields. Also, we used data obtained from the International Disaster Database of the Centre for Research on the Epidemiology of Disasters (CRED) for floods and droughts over the period 1990–2020. The data were analysed based on the Fully Modified Ordinary Least Squares (FMOLS). The results showed that climate extreme events negatively affected maize, rice and sorghum yields. Also, the findings showed that floods and droughts in past years negatively influence current yields of maize, rice and sorghum. Moreover, agricultural labour force, fertilizer and financial development are the main transmission channels through which floods and droughts can affect maize, rice and sorghum yields. The study concludes by recommending that policies aimed at promoting climate change adaptation measures as well as agricultural insurance could make the agriculture sector more resilient to climate extreme events and in turn that could improve agricultural productivity and reduce food insecurity.

1. Introduction

Natural disasters are one of the major threats to sustainable development [1]. Among the natural disasters, floods are one of the most serious, accounting for 40 % of the world's natural disasters [2]. Flood disasters mostly occur in places with dense populations, large agricultural impact areas, concentrated rivers and lakes, and plentiful rainfall, such as the temperate and subtropical regions of the northern hemisphere [3]. Previous studies have revealed that natural disasters hinder agricultural productivity growth, as production in this sector is dependent on the present climatic and biophysical conditions [1,4–6]. Natural disasters mainly damage crops and livestock and lead subsequently to crop failure and a reduction in producers' income [1,7–9]. However, for [1], the overall influence can exceed direct production loss. As for the indirect influence, it is usually linked to agricultural infrastructure destruction such as storage constructions, irrigation systems, facilities, machinery, and equipment or environmental depletion [10,11]. Disasters' influence on agricultural growth is not limited to a single season, but it can have serious repercussions on local food shortages in the years after the disaster [1].

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Empirical evidence showed that natural disasters negatively influence agricultural production [2,7–9,12]. [7] found in the Philippines that typhoons significantly decreased production and the losses are estimated at 12.5 million tonnes since 2001 [7]. suggested that a Haiyan typhoon, which causes losses of around 260,000 tonnes, has a reappearance period of 13 years [8]. found that hurricanes in the Caribbean had a significantly negative influence on agriculture, although in the comparatively short run, with fewer islands remaining more vulnerable. However, the study proves that, aggregated and disaggregated data use shows that: (1) combining disaggregated agricultural commodity data can yield an additional sensibly measured of hurricane obliteration than aggregate data levels and (2) dissimilar agricultural commodities are inversely exposed by hurricanes, and there is considerable commodity heterogeneity in hurricane resilience. Using satellite imagery and geospatial data [12], assessed that about 4.66 million metric tonnes of grain crops were severely disturbed during the two months of the 2020 flood in the Yangtze River middle reaches. In China, the average annual grain loss due to natural disasters is estimated at 20 billion kg, and the monetary damage is close to 200 billion yuan [13]. The 2006 flood disaster in China resulted in losses estimated at 133.26 billion yuan in direct economic losses, affecting around 138.82 million people. African's countries where agriculture represents a source of food and employment for millions of people, majority are facing natural disasters, especially the Sahel countries. In 2019, economic losses related to disasters from droughts in East Africa, typhoons in Mozambique, and forest fires in the Amazon are estimated at 122 billion USD globally [14,15]. Losses over the period 2008–2018 are estimated at 30 billion USD for Africa (Sub-Saharan and North), and faintly less for Latin America and the Caribbean where they are estimated at 29 billion USD [15]. For the areas of North Africa, Central Africa, and Southern Africa, the production losses for the period 2008–2018 are about 4, 3 and 1 billion USD, respectively [15]. [16] found in the Northern Cape Province of South Africa that drought reduced agricultural productivity by 8.4 % in 2015.

Maize, rice, and sorghum are those crops in Africa which are under climatic threat. Indeed, maize yield during the period 1990–2020 (31 years), coupled with rice and sorghum production in Africa has experienced an unstable evolution [17]. Studies indicated that climatic risks would affect rice, maize, and sorghum production [2,7,18–21]. Maize will suffer a drop in yields [18,20,22]. [23,24] exhibited that an increase in temperature worsens maize production in China and sugarcane in Brazil, respectively. Maize speculation will decrease between 11 and 33 % in their yields by 2050 [18]. According to Ref. [18], rice will strengthen in yield by 10–39 % while [20,22] found that rice will drop in yield [2,7]. found that rice is negatively influenced by flood and typhoons disasters. Likewise, sorghum yields will be improved by climate change [18,22]. [12] found that grain crops, including rice and sorghum, are negatively influenced by the 2020 flood disasters in China. This previous literature have analysed climate change influence (temperature and rainfall) on agriculture production [18,19,24] and concluded that climate change is harmful for agricultural production but studies on the effects of extreme climatic phenomena such as flood and drought have received little attention, especially in SSA. This paper is more concentrated on extreme climatic phenomena impacts (flood and drought) on selected food crop (maize, rice, and sorghum) yields in SSA using non-stationary panel data econometric model. Also, previous studies did not investigate the transmission channel through which extreme climatic events influence agricultural production.

This study postulate that extreme climatic events had direct and indirect impacts on agricultural production. Indeed, directly extreme climatic events destroy agricultural infrastructure such as storage buildings, irrigation systems, machinery and disrupt production cycles, trade flows and livelihoods; this in turn reduces agricultural production. Indirectly, extreme climatic events affect non climatic factors such as capital (land and machinery), farm labour, fertilizers and financial development leading to soil infertility, agricultural labour force migration and credit constraints which in turn reduce agricultural production. For example, climate-related disturbances have impacted farmers' decisions regarding investments, leading to reduced spending on machinery, seeds, and pesticides [25]. Similarly, variations in weather patterns affect agricultural resources such as land, livestock, and farming tools [26]. Also based on [1] who stated that disasters' influence on agricultural growth is not limited to a single season, we investigated on the effect of past extreme climatic events effect on current agricultural production. This study tends to address all these gaps in the literature. Thus, this paper's main goal is to analyse the direct and indirect mechanisms through which climate extreme events influenced selected food crop yield in SSA while focusing also on the effect of the previous climate extreme events on current agricultural production. On others words, we answer the following questions:

(i) what are the direct effects of climate extreme events on selected food crop yields?
(ii) what are the indirect effects of climate extreme events on selected food crop yields? and,
(iii) what are the effects of previous climate extreme events on selected food crop yields?

One of the reasons to explore this relationship is that African's population is growing each year, and, in the future, the continent will be faced with food insecurity [27]. For example, in Africa alone, the population of food-insecure individuals has surged from 500 to 800 million, while globally, it has increased by 50 % to reach 2.3 billion, this corresponds to a prevalence rate of 26.2 % in SSA, 23.4 % in Africa, and 11.7 % worldwide [28]. Also, according to Ref. [14], respectively 27 million and 55 million of people are affected by floods and droughts during 1990 and 2020 in SSA. The increase of African's population coupled with their exposition to climate extreme events, provide food to African's population is threaten, so African's agriculture need to innovate by financing research on agricultural development to find solutions to climate extreme events to face future food demand [29]. This study thus contributes to the existing debate and enlightens policymakers on the necessity of accelerating adaptation measures in the agricultural sector in Africa. To conduct this study well, this paper's remainder is divided into three sections. The next section presents the literature review, then the paper presents the methodology to be used, and finally, the paper concludes and makes some policy recommendations.

2. Climate and climate extreme events effects on agriculture: a literature review

Studies have already shown that climatic risks have an impact on agriculture [2]. showed in China that when waterlogging time exceeds three days, the production efficiency is decreased. Another study on China conducted by Ref. [30] showed that from 1988 to 2016, the total silica damages from grain and straw harvests were estimated at 7.14 and 53.10 million tonnes, respectively with half of them triggered by drought.

[31], found in Ethiopia that drought lessens agricultural output especially when agriculture is dependent on rainfall [32]. found in South Africa that maize recorded the lowest production with 223,600 tonnes in 2014 and 119,050 tonnes in 2015, and sorghum recorded the lowest production in 2019, 2016, and 2015 with about 23,600, 24,640, and 24,150 tonnes, respectively. The findings also confirmed in 2015 and other years that maize and sorghum recorded the lowest production through the drought years [33]. found in Kenya that precipitation improves production in the short run but worsens it in the long run [34]. found that rainfall significantly and positively affects rainfall and enhances productivity.

[31] found in Pakistan that rainfall increases agricultural output. The author shows that rainfall is a main determinant of agricultural output in Ethiopia which is more dependent on rainfall in the long run [35]. showed in Vietnam that in the dry season, an increase in temperatures is favourable to all farms in the warmer southern areas, while an increase in precipitation will harm only irrigated farms in the Central and southern areas [36]. found in China a nonlinear and inverted U-shaped link between crop yields and climate.

In synthesis, the effect of climate extreme events (floods and droughts) on food production is sparse in the extant literature. Even if [31] have integrated drought in his analysis when exploring the determinants of agricultural output in Ethiopia and [32] evaluating in South Africa drought effects on food production, Africa continent is still under-exploring on the effects of climate extreme events on food production. Similarly, these above studies limited to drought, thus neglecting the effect of floods while floods are most occurring than droughts in the world [14]. Thus, in these conditions, it will be interesting to include floods in the study to analyse it effects on agriculture.

Based on the argument of [1] who stated that disasters' influence on agricultural growth is not limited to a single season, we investigated on the effect of past extreme climatic events effect on current agricultural production. Similarly, based on [25] who concluded that climate-related disturbances have impacted farmers' decisions regarding investments, leading to reduced spending on machinery, seeds, and pesticides and [26] who said that variations in weather patterns affect agricultural resources such as land, livestock, and farming tools, we explore the transmission channels through which floods and droughts affected agricultural yields.

3. Methodology

3.1. Conceptual framework

Studies analyse climate change and climate vulnerability (temperature and rainfall) impacts on crop production throughout the world [20,24,37–39], however, most of these studies did not include natural disasters such as flood and drought in their analysis, especially in SSA. A natural disaster according to Ref. [40] is a severe disturbance of the normal operation of a population or society due to the interaction of hazardous physical phenomena with socially vulnerable conditions, resulting in widespread human, material, economic or environmental adverse effects requiring immediate action to meet basic human needs and sometimes requiring external assistance for recovery.

To include natural disasters as factors which reduce crop production, this paper was undertaken to analyse the effect of climatic risks on crop production in SSA countries. Natural disasters such as floods and drought are becoming a serious threat to agriculture production which depends on meteorological conditions [1,2,7–9]. Thus, it is important to conceptualise how climate risks can affect food production (Fig. 1).

Fig. 1 shows that climate extreme events notably floods and droughts can directly reduce crop production through the destruction of agricultural infrastructure and disruption of production cycles, trade flows and livelihoods [10,11,41,42]. Indirectly, climate extreme events can also affect non-climatic factors. Indeed, climate extreme events can lead (i) to soil leaching, this in turn can reduce soil fertility and productivity, (ii) farm labour migration in another areas to do off farm activities, this reduces farm labour and in turn lessens food productivity and finally, (iii) increase farmer household credit constraints because financial institutions will provide less loan to farmers which experienced floods or droughts events; this can be an obstacle for farmers' to access capital to produce food. Similarly, climate-related disruptions (i) have affected farmers' investment choices, resulting in decreased expenditures on machinery, seeds, and pesticides [25] and, (ii) influence agricultural assets such as land, livestock, and farming equipment [26].

3.2. Model specification and estimation technique

Referring to our conceptual framework, to produce a country combines the non-climatic factors that are supposed to increase agricultural yield and the climatic factors that are supposed to decrease it. Based on [1,2] studies, this paper expresses agricultural production as a function of a set of farming inputs, as found in Equation (1):

$$Y_{it} = f(X_{it}, Z_{it}) \tag{1}$$

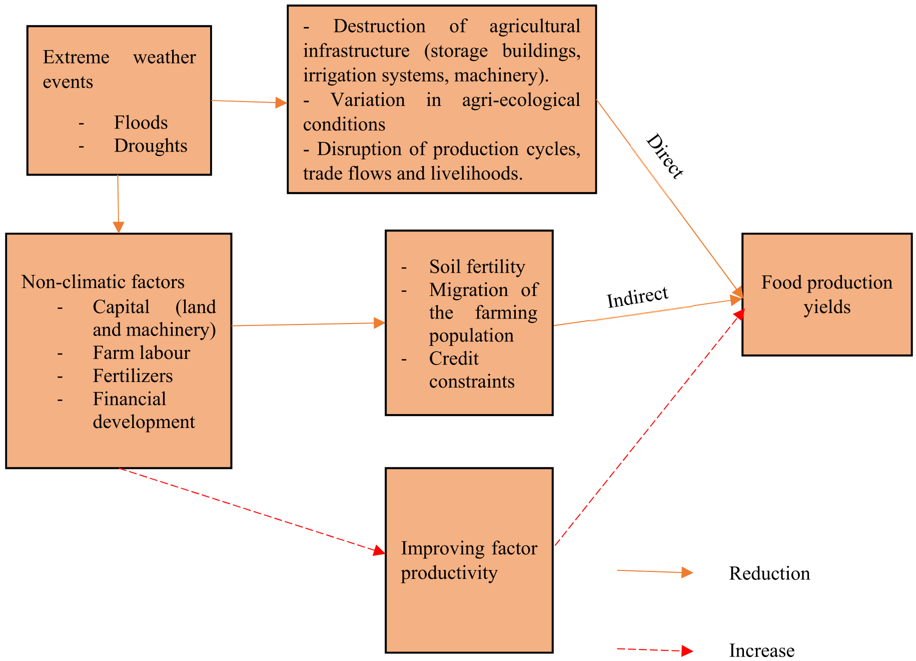

Fig. 1. Relationship between climatic risks and food production.
Source: Authors' own Compilation

Where Y are the yields of maize, rice and sorghum respectively measured in kg/ha. The yields values are the national productions of each crop divided by the national agricultural lands available for each crop. We also assume that a climate shock (flood and drought) in one region of the country will certainly affected the national yield. Indeed, floods and droughts occurrence reduce the area of arable land as well as the production. X represents non-climatic factors and is a vector of variables such as capital, farm labour and fertilizer consumption; Z denotes climatic factors such as floods and droughts; i is the individual dimension (country) and t designates the temporal dimension (year). Equation (2) presents the explicit form of the model

$$Y_{it} = \alpha + \beta X_{it} + \gamma Z_{it} + \varepsilon_{it} \tag{2}$$

In Equation (2), α is the constant term, β is the coefficient of non-climatic factors, $\beta(\beta = 1, 2..M)$, γ is the coefficient of climatic factors, $\gamma(\gamma = 1, 2..N)$, and ε is the white noise. The covariable of non-climatic factors is agricultural labour force (population engaged in agriculture as % of total employment), fertilizer consumption (nitrogen, potash and phosphate content sum of the various fertilizers consumed) and financial development (domestic credit to the private sector by banks as % of GDP) while the covariable of climatic variables is floods (number of flood events per year) and droughts (number of drought events per year). Given this, such that $X_{it} = PAGRI_{it}\ FERTI_{it}\ FD_{it}$ and $Z_{it} = FLO_{it}\ DRO_{it}$ the estimated model is given in Equation (3):

$$\ln Y_{it} = \alpha + \beta_1 PAGRI_{it} + \beta_2 FERTI_{it} + \beta_3 FD_{it} + \gamma_1 FLO_{it} + \gamma_2 DRO_{it} + \varepsilon_{it} \tag{3}$$

To take into account the indirect impact of floods and droughts, we insert interaction of floods and droughts with non-climatic factors (agricultural labour force, fertilizer consumption and financial development), respectively. Similarly, to capture the effect of past floods and droughts on current agricultural productivity, we introduce lags of floods and droughts. γ_3 and γ_4 are the coefficients of past floods and droughts on agricultural productivity, respectively while ρ_i $(i = 1, 2, 3)$ and φ_j $(j = 1, 2, 3)$ captured the indirect effect of floods and droughts. Thus, we obtained the following equation (4):

$$\begin{aligned}\ln Y_{it} = {} & \alpha + \beta_1 PAGRI_{it} + \beta_2 FERTI_{it} + \beta_3 FD_{it} + \gamma_1 FLO_{it} + \gamma_2 DRO_{it} + \gamma_3 FLO_{it-1} + \gamma_4 DRO_{it-1} + \rho_1 (FLO_{it} \times PAGRI_{it}) \\ & + \rho_2 (FLO_{it} \times FERTI_{it}) + \rho_3 (FLO_{it} \times FD_{it}) + \varphi_1 (DRO_{it} \times PAGRI_{it}) + \varphi_2 (DRO_{it} \times FERTI_{it}) + \varphi_3 (DRO_{it} \times FD_{it}) + \varepsilon_{it}\end{aligned} \tag{4}$$

To estimate the data, the following procedures are followed. First, the panel unit root test is performed for all variables. Thus, Fisher-type [43] was used and had as a null hypothesis that all the panels have a unit root. Contrary to Refs. [44–46], and [47] tests, Fisher-type tests are useful when we are faced with unbalanced panel data.

Secondly, the study employed the first-generation panel cointegration test to check for the long-run association. Different first-generation panel cointegration tests are used in the literature, but this paper applied [48] because it considers the fake regression for the panel data and proposes the DF and ADF type tests. The author meant four distinct DF kinds of test statistics and applied the successive limit theory of [49] to obtain these statistics asymptotic distributions.

Finally, because of the lack of coherence and asymptotic bias of the OLS estimator when utilised in a cointegrated panel as well as the regressors' possible endogeneity; the Fully Modified OLS (FMOLS) undertaken by Ref. [50] was retained [51–54]. We first used a long-term covariance matrix to adjust the dependent variable and then used the standard OLS [52,53,55,56].

3.3. Data and sources

This study used data covering the period from 1990 to 2020 obtained from different sources (Table 1). The sample consists of 34 countries in Sub-Saharan Africa.[1] Data on agricultural productivity (Yield), agricultural labour force (PAGRI), and fertiliser consumption (FERTI) are from the FAO database. Financial development (FD) data are from the World Bank's development indicators. Data on natural disasters such as floods (FLO) and droughts (DRO) are provided from the International Disaster Database, which is compiled by the Centre for Research on the Epidemiology of Disasters.

The following Table 1 summarises all the estimation variables as well as their measurement and expected sign.

4. Results and discussions

4.1. Descriptive analysis of the data

Table 2 summarises the descriptive statistics of the variables included in the estimate. Table analysis showed that the mean values of maize, rice and sorghum yields during the concerned period are 15,628.49 kg/ha, 20,708.110 kg/ha and 8990.161 kg/ha, respectively. Similarly, the standard deviation for maize, rice and sorghum yields are respectively 11,671.910, 10,309.160 and 5166.944, indicating disparities in terms of maize, rice and sorghum yields in SSA nations. Mauritius recorded the highest yield of maize in 2007 while Bostwana recorded the lowest yield in 2013. For rice yield, Kenya recorded the highest yield in 2019 while Mozambique recorded the lowest yield in 2005. Finaly, concerning sorghum yield, South Africa recorded the highest yield in 2018 while Namibia recorded the lowest yield in 2016. This heterogeneity between yields can be explained by several factors such as natural disasters phenomena faced by the countries. Thus, the mean value of floods and droughts are respectively 0,728 and 0.140 with countries which can face to a maximum of 7 floods and 2 droughts following the different regions of the country. The percentage of population engaged in agriculture in SSA nations during the study period is 55.836 % with a standard deviation of 21.256, indicating disparities in terms of agricultural employment in SSA nations. On the other hand, agricultural employment are more higher in some countries than another. The lowest value is recorded by South Africa in 2011 while the highest value is recorded by Burundi in 1996. The mean value of fertilizer consumption is relatively low and is 21.494 metric tons with a standard deviation of 52.137. This shows disparities in African nations regarding to fertlizer consumption. And finally, the mean value of domestic credit to the private sector by banks in percentage of GDP is 17.203 % with a standard deviation of 16.171. This reveals not only a low financial development in SSA but also an heterogeneity between SSA nations in terms of financial development.

In addition to descriptive statistics, we also make correlation matrix analysis which results are reported in Table 3. Analysis of the correlation matrix revealed that maize yield is positively correlated with floods (0.001), fertilizer (0.771) and financial development (0.666) but negatively with droughts (−0.035), and agricultural labour force (−0.382). Then, rice yield is positively correlated with floods (0.035), droughts (0.093), fertilizer (0.178) and financial development (0.231) but negatively correlated with agricultural labour force (−0.009). Finally, sorghum yield is positively correlated with flood (0.093), fertilizer (0.291) and financial development (0.313) but negatively correlated with drought (−0.036) and agricultural labour force (−0227).

4.2. Estimation of the impact of climatic risks on crop yields

Table 4 reported the outcomes of the Fisher panel unit root test using Augmented Dicker Fuller (ADF) and Philippe Perron (PP) chi2 statistics. This test null hypothesis is that all panels have a unit root and referring to the results, this hypothesis was rejected. Indeed, the p-values of the Chi-square statistics for ADF and PP for the variables maize yield, rice yield, sorghum yield, floods, droughts, agricultural labour force, fertiliser, and financial development are less than 1 %. Thus, the null hypothesis of rejection at 1 % was confirmed. Thus, variables such as maize yield, rice yield, sorghum yield, agricultural labour force, fertiliser, financial development floods and droughts are stationary in first difference. These outcomes indicate long-run relationship existence amongst the variables under analysis. Thus [48], co-integration test was performed to verify this long-run link.

Table 5 shows [48] co-integration test applied to check for the long-run association. The findings of [48] co-integration test revealed that the null hypothesis of no co-integration was disallowed, showing long-run relationship existence amongst estimates variables for maize, rice and sorghum equation, respectively.

The estimates of equation (4) using the FMOLS technique to obtain the long-run elasticity are reported in Table 6, 7 and 8. According to Refs. [53,57], FMOLS is robust in heterogeneity and endogeneity. It should be mentioned that to certify that the outcomes

[1] Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Central African Republic, Congo, Cote d'Ivoire, Democratic Republic of Congo, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Kenya, Madagascar, Mali, Mauritius, Mozambique, Namibia, Niger, Nigeria, Rwanda, Senegal, South Africa, Sudan, Tanzania, Togo, Uganda, Zambia, Zimbabwe.

Table 1
Description of model variables.

Factors	Measures	Sources	Sign
Yield	Rice, maize, and sorghum yields, measured in kg/ha	FAOSTAT	
PAGRI	Agricultural labour force, captured by the population engages in agriculture (% of total employment)	FAOSTAT	+
FERTI	The nitrogen, potash and phosphate content of the various fertilizers consumed sum, captured in metric tons	FAOSTAT	+
FD	Financial development, captured by domestic credit to the private sector by banks (% of GDP)	WDI	+/−
FLO	Floods, number of flood events per year	CRED	–
DRO	Drought, number of drought events per year	CRED	–

Source: Author's compilation

Table 2
Summary of descriptive statistics.

	Obs.	Mean	Std. dev.	Min.	Max.
Maize yield (kg/ha)	1026	15,628.49	11,671.910	849	94,537
Rice yield (kg/ha)	917	20,708.110	10,309.160	2034	64,255
Sorghum yield (kg/ha)	923	8990.161	5166.944	755	39,931
Flood (number)	1054	0.728	1014	0	7
Drought (number)	1054	0.140	0,350	0	2
Agricultural labour force (%)	986	55.836	21.256	4.6	92.370
Fertiliser (metric tons)	937	21.494	52.137	0	416,667
Financial development (% of GDP)	986	17.203	16.171	0.007	106.260

Note: Obs., Std. dev., Min. and Max. means observations, standard deviation, minimum and maximum, respectively.
Source: Author's computation

Table 3
Correlation matrix analysis.

	MYield	RYield	SYield	FLO	DRO	POP	Ferti	FD
MYield	1							
Ryield	0.304	1						
SYield	0.642	0.162	1					
FLO	0.001	0.035	0.093	1				
DRO	−0.035	0.093	−0.036	0.100	1			
POP	−0.382	−0.009	−0.227	0.078	−0.106	1		
Ferti	0.771	0.178	0.291	−0.087	−0.023	−0.463	1	
FD	0.666	0.231	0.313	−0.015	0.025	−0.600	0.647	1

Note: MYied, RYield and SYield means maize, rice and sorghum yields, respectively.
Source: Author's computation

Table 4
Fisher panel unit root test results.

	ADF Chi2 stat	PP chi2 stat.	Order
Log Maize yield	1943.790[a]	1547.689[a]	[1]
Log Rice yield	685.602[a]	1281.154[a]	[1]
Log Sorghum yield	777.728[a]	1598.364[a]	[1]
Floods	2596.303[a]	2596.303[a]	[1]
Droughts	2101.568[a]	2101.568[a]	[1]
Agricultural labour force	1598.364[a]	337.253[a]	[1]
Fertiliser	595.229[a]	1307.467[a]	[1]
Financial development	464.901[a]	793.434[a]	[1]

[a] $p<1$ %.
Source: Author's computation

are free from heteroskedasticity and endogeneity, the FMOLS approach applies heteroscedasticity standard errors that fit a model with heteroskedastic residuals [53,57]. In this study, it was applied to estimate the long-run parameters of climate extreme events on selected food crop yields.

Floods and droughts constitute one of the serious climate extreme events manifestations that had severe consequences on crop production due to the agricultural losses they caused. Outcomes globally showed that while floods and droughts are separately or together inserted in the equation, they negatively and significantly impact maize, rice and sorghum yields. This outcome indicates that floods and droughts directly affected maize, rice and sorghum yields as stated by Ref. [1]. This outcome is consistent with [31,58] who found in Ghana and Pakistan respectively that climate extreme events lessen agricultural production.

Table 5
Kao panel co-integration test.

	Maïs	Riz	Sorgho
Modified Dickey-Fuller t	−9157[a] (0,000)	−6282[a] (0,000)	−11,076[a] (0,000)
Dickey-Fuller t	−10,871[a] (0,000)	−5297[a] (0,000)	−12,216[a] (0,000)
Augmented Dickey-Fuller t	−4005[a] (0,000)	−1466* (0,071)	−6260[a] (0,000)
Unadjusted Modified Dickey-Fuller t	−18,728[a] (0,000)	−8311[a] (0,000)	−22,304[a] (0,000)
Unadjusted Dickey-Fuller t	−13,605[a] (0,000)	−5972[a] (0,000)	−15,048[a] (0,000)

[a] p<1 %; value in (.) are p-values.
Source: Author's computation.

Table 6
Long-run elasticity outcomes applying the FMOLS approach.

Variables	Dependent: Log Maize yield		
Floods (FLO)	−0.066[a] (0.014)		−0.038[b] (0.014)
Droughts (DRO)		−0.453[b] (0.215)	−0.590[b] (0.201)
Agricultural labour force (PAGRI)	0.005[c] (0.003)	0.005[b] (0.003)	0.005[c] (0.003)
Fertilizer (FERTI)	0.005[a] (0.001)	0.005[a] (0.001)	0.005[a] (0.001)
Financial development (FD)	0.004 (0.005)	0.006 (0.004)	−0.002 (0.002)
FLO (−1)	0.041[b] (0.019)		−0.039[b] (0.019)
DRO (−1)		0.055[c] (0.030)	−0.002[b] (0.001)
FLO × PAGRI	−0.002[b] (0.001))		−0.001[a] (0.0003)
FLO × FERTI	−0.001 (0.003)		0.001 (0.003)
FLO × FD	0.004[b] (0.002)		−0.004[b] (0.002)
DRO × PAGRI		−0.007[c] (0.004)	−0.010[c] (0.006)
DRO × FERTI		−0.005[c] (0.003)	−0.006[b] (0.003)
DRO × FD		−0.009 (0.015)	0.008 (0.014)
Constant	8.946[a] (0.231)	8.994[a] (0.207)	8.932[a] (0.232)
Number of groups	34	34	34
Observations	855	855	855

[a] p<1 %.
[b] p<5 %.
[c] p<10 % value in (.) are Std. deviation.
Source: Authors' own computation.

Table 7
Long-run elasticity outcomes applying the FMOLS approach.

Variables	Dependent: Log Rice yield		
Floods (FLO)	−0.119[b] (0.051)		−0.087[b] (0.037)
Droughts (DRO)		−0.395[b] (0.135)	−0.146[b] (0.069)
Agricultural labour force (PAGRI)	0.007 (0.005)	0.007[c] (0.004)	0.008[b] (0.004)
Fertilizer (FERTI)	0.006[b] (0.003)	−0.004 (0.003)	0.006[b] (0.003)
Financial development (FD)	0.022[b] (0.009)	0.018[b](0.007)	0.020[b] (0.009)
FLO (−1)	−0.025[b] (0.010)		−0.042[b] (0.018)
DRO (−1)		−0.027[c] (0.014)	−0.006[b] (0.003)
FLO × PAGRI	−0.0002 (0.004)		−0.0002 (0.004)
FLO × FERTI	−0.008[b] (0.004)		−0.011[b] (0.005)
FLO × FD	−0.003 (0.008)		−0.007 (0.008)
DRO × PAGRI		−0.009[a] (0.003)	−0.006[a] (0.002)
DRO × FERTI		−0.015 (0.016)	−0.029[c] (0.017)
DRO × FD		−0.027[a] (0.007)	−0.045[c] (0.027)
Constant	9.390[a] (0.345)	9.344[a] (0.306)	9.354[a] (0.343)
Number of groups	31	31	31
Observations	776	776	776

[a] p<1 %.
[b] p<5 %.
[c] p<10 % value in (.) are Std. deviation.
Source: Author's computation.

Similarly, the lags values of floods and droughts negatively impact maize, rice and sorghum yields in SSA, reflecting that the impacts of floods and droughts are not limited to one season but can have consequences on the next ones. This outcome is also supported by Ref. [1] who claimed that disasters' influence on agricultural growth is not limited to a single season, but it can have serious repercussions on local food shortages in the years after the disaster. Concerning indirect impact, our outcomes revealed that

Table 8
Long-run elasticity outcomes applying the FMOLS approach.

Variables	Dependent: Log Sorghum yield		
Floods (FLO)	−0.029[a] (0.007)		−0.098[b] (0.036)
Droughts (DRO)		−1.707[c] (0.885)	−1.133[b] (0.576)
Agricultural labour force (PAGRI)	−0.001 (0.004)	−0.002 (0.003)	−0.001 (0.004)
Fertilizer (FERTI)	0.001 (0.005)	0.005 (0.004)	0.001 (0.004)
Financial development (FD)	0.015[b] (0.007)	−0.007[b] (0.003)	0.013[b] (0.006)
FLO (−1)	0.047[b] (0.023)		−0.065[b] (0.031)
DRO (−1)		−0.201[b] (0.093)	−0.247[c] (0.132)
FLO × PAGRI	−0.001 (0.003)		−0.0002 (0.003)
FLO × FERTI	−0.007[c] (0.004)		−0.008[b] (0.004)
FLO × FD	0.005 (0.006)		0.003 (0.006)
DRO × PAGRI		−0.016[c](0.009)	−0.008[b] (0.004)
DRO × FERTI		−0.002 (0.010)	−0.009 (0.010)
DRO × FD		−0.022 (0.016)	−0.022 (0.016)
Constant	9.298[a] (0.0002)	9.340[a] (0.251)	9.332[a] (0.294)
Number of groups	31	31	31
Observations	768	768	768

[a] $p<1$ %.
[b] $p<5$ %.
[c] $p<10$ % value in (.) are Std. deviation.
Source: Author's computation.

agricultural labour force, fertilizer consumption and financial development are the transmission channels through which floods and droughts reduce maize, rice and sorghum yields, respectively. Our outcome is consistent with [25] who think that climate-related disruptions have affected farmers' investment choices, resulting in decreased expenditures on machinery, seeds, and pesticides and [26] who estimate that fluctuations in weather conditions influence agricultural assets such as land, livestock, and farming equipment. Indeed, while floods or droughts occur, this made agricultural activities difficult for farmers and to survive, they are forced to leave their villages for the cities to engage in non-agricultural activities, this leads to yields reduction. On other hands, they used migration as adaptation strategy to face floods or droughts.

For example [59], found that migration rates rise during drought years, particularly in the drier regions of Mexico and that this response is more pronounced in states and seasons where agricultural production is highly sensitive to precipitation. Similarly, floods and droughts can make fertilizers application difficult for farmers as found by Ref. [58] who revealed that while weather shocks have a minimal impact on farmers abandoning inorganic fertilizers altogether, they do significantly decrease the overall amount of fertilizer used but floods and severe shocks exert a more pronounced influence compared to droughts and moderate shocks. Finally, floods and droughts can increase farmers' credit constraints because according to Ref. [60], the impacts of droughts lead to lower income from crop and livestock sales, this can make farmers who experience droughts unable to repay credit, which discredits them to credit managers.

5. Conclusion and policy recommendations

Agriculture is a sector that provides resources to other sectors and its development is a prerequisite for the economic development of nations. Thus, the agricultural sector is one of the priorities of African countries. However, climatic risks, particularly floods and droughts, are one of the major obstacles to agricultural development and they threaten food security. To find an adequate solution to this problem, governments, technical and financial partners, and researchers are finding ways to find optimal conditions under which African agricultural sector development could occur. This paper's main goal is to analyse the direct and indirect mechanisms through which climate extreme events influenced selected food crop yield in SSA while focusing also on the effect of the previous climate extreme events on current agricultural production. To do so, a database of 34 SSA nations was built for the period 1990 to 2020 and estimated using the FMOLS approach. Overall, climate extreme events effects were negative, highlighting the role of climate extreme events in worsening the agricultural performance of SSA nations. Also, the findings showed that floods and droughts in past years negatively influence current yields of maize, rice and sorghum yields. Moreover, agricultural labour force, fertilizer and financial development are the main transmission channels through which floods and droughts can affect maize, rice and sorghum yields.

Our results support the argument that the agricultural sector needs sustainable solutions such as adaptation strategies for better agricultural performance due to its dependence on climatic hazards which are at the root of its poor performance in developing countries. Thus, the establishment of an enabling framework for agricultural development is the result of a combination of several policy instruments put together. Thus, Sub-Saharan African countries should focus on policies to operationalize adaptation plans, which will help achieve the desired level of agricultural production and generate productivity gains for the economy. Thus, adaptation strategies implementation could help cope with climatic risks' negative effects and thus strengthen crops production through risk management which is very essential in adaptation of the agricultural system to climate and climate extreme events. In addition, policies to improve the quality of the agricultural labour force through the development and capacity building of agricultural research institutions and quality education that enhance the capacity of farmers to innovate, cope with new agricultural challenges and use good agricultural practices are essential to improve agricultural productivity.

The implementation of its recommendations, on the economic level, will allow the countries of sub-Saharan Africa to increase their agricultural productivity and thus generate enough wealth to develop their nation. Socially, beyond ensuring food security, it will help achieve Sustainable Development Goals 1, 2 and 13. Social protection notably reinforcement of agricultural insurance could be important to put in place programme which can protect farmers with are most vulnerable to climate extreme events. Another limitation of this studies is that we assume that droughts or floods occurrence in any region of the country negatively impacted national agricultural yield. This study did not consider the role that can play social protection in the effects of climate extreme events on agriculture. Further studies can explore the effects of climate and climate extreme events on agriculture with focus on social protection.

Data availability statement

Data will be made available on reasonable request.

CRediT authorship contribution statement

Armand Fréjuis Akpa: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

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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