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RESEARCH ARTICLE

Exploring the effects of climate change and government stability on internal conflicts: evidence from selected sub-Saharan African countries

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Abstract
Climate change has been linked to water scarcity, land degradation, and food insecurity, exacerbating existing tensions and creating new conflicts in countries with weak political institutions. Despite the critical need for effective conflict management and climate adaptation measures, prior studies failed to emphasize the role climate change plays in civil clashes in conflict-affected countries. In this research, we undertake a comprehensive investigation of the effects of climate change and government stability on internal conflicts in 14 selected SSA nations between 1996 and 2016. The study embraces contemporary heterogeneous panel techniques to address heterogeneity and cross-sectional dependence issues that usually appear in panel data estimates. We employed second-generation unit root tests, such as CADF and CIPS, to determine the order of integration of the variables. In addition, Pedroni and Westerlund cointegration tests confirmed the long-run relationship among the variables. Although temperatures were insignificant, the long-run results of the pooled mean group (PMG) approach suggested that civil conflicts decline when precipitation increases. In addition, the outcomes indicate that environmental degradation and population growth are long-run aggravators of social unrest. The short-run results suggest that rising temperatures exacerbate civil conflicts in the selected SSA countries. However, the study found that government stability lessens internal conflicts in the short run, but not in the long run. The DOLS technique validated the long-run outcomes of the PMG technique. Based on the findings of the study, conflict-prone SSA countries should integrate climate change adaptation and conflict prevention strategies, implement sustainable water resource management practices, and endorse climate-related conflict resolution.

Keywords Climate change · Conflicts · Political stability · Environmental degradation · Migration · Sub-Saharan Africa

Introduction

The deterioration of climatic conditions and the depletion of natural resources wreaked havoc on individual well-being and social order. Over the past few years, the discussions surrounding the security implications of environmental issues have grown as climate change has triggered directly or indirectly about 20–30% of the conflicts (Ryan 2019). According to the Intergovernmental Panel on Climate Change (IPCC 2022), the global temperature has risen about 1 °C compared to the pre-industrial level, adversely damaging climate-susceptible industries such as agriculture, tourism, fisheries, energy, and forestry. Such an effect is expected to continue and harm sub-Saharan African (SSA) countries unless climate adaptation measures are implemented (Ritchie 2022). In addition, conflicts are unpredictable and hard to handle as they occur in unforeseeable directions. Although climate change is a universal issue that countries must contend with, a primary concern is the prospect of conflict in the most vulnerable regions with a history of social unrest, including Somalia, Sudan, Mali, and Chad (Cappelli et al. 2023; United Nations 2021). In SSA, the climate change effect is severe because of their population density, fragile ecosystems, and dependence on the climate sensitivity sectors. It is predicted that less developed countries would be most

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affected by the consequences of climate change, where sub-Saharan Africa is home to the majority of climate refugees (Sofuoğlu and Ay 2020).

Conflict is more likely to arise due to environmental changes such as dramatic precipitation variations, temperature swings, and water scarcity, which can diminish economic well-being as well as societal welfare (Bernauer et al. 2012; Koubi 2019). Along with influencing economic performance, environmental stresses, such as increasing sea levels and extreme weather conditions, force afflicted people to migrate (Homer-Dixon 1994; Raleigh and Urdal 2007). Primarily, the oscillating environmental conditions have adversely influenced human lives through frequent and severe droughts, famines, and floods, which have caused millions of people to be displaced. High water stress is expected to affect over 250 million people in Africa, potentially displacing up to 700 million people by 2030 (United Nations 2022). Environmentally driven migration can result in violence in receiving locations because of competition for limited resources and racial tensions when migrants come from various ethnic groups (Bernauer et al. 2012). The empirical evidence considers climate change a "threat multiplier" that puts more pressure on scarce resources and aggravates existing violent events, poverty, and unemployment (Froese and Schilling 2019; Koubi 2019; Price 2017). Climate change generates, hastens, and deepens the current civil conflicts in MENA countries (Sofuoğlu and Ay 2020). In some regions, the evidence underlines that more significant potential risks exist with rainfall abundance than drought (Gleditsch 2012).

During the past few decades, the controversy about the scientific evidence that climate change affects social stability has raged unabated. Although some studies reveal that climate change directly influences civil conflicts, most literature emphasizes the indirect effects of environmental changes. Current and continuing debate points out that climatic changes are correlated with conflict risk, with rising temperatures and declining precipitation often leading to armed conflict (Hendrix and Salehyan 2012; Raleigh and Kniveton 2012). The empirical evidence shows that temperature variations and rainfall patterns are related to social instability (Dell et al. 2014). On the other hand, the focus of the indirect pathways is how climate change affects instability through economic repercussions and migration. The IPCC (2022) has reported that weather extremes have displaced millions due to reduced water security and food insecurity, with the most significant impacts observed in vulnerable regions, primarily in Africa. Furthermore, environmental changes cause the destruction of fisheries, forests, freshwater availability, agricultural land, and patterns of human habitation, eventually resulting in resource scarcity (Raleigh and Urdal 2007). Likewise, the shrinking supplies of environmental resources, such as clean water and fertile land, and the deterioration of weather patterns cause resource competition that triggers armed tensions, leading to displacement and migration (Daccache et al. 2015; Homer-Dixon 1994; Hsiang et al. 2011). This implies that while natural disasters brought on by climate change do not directly contribute to civil unrest indicators like conflict, terrorism, and violence, they play a significant role in the process that eventually leads to social instability in already vulnerable countries (Sofuoğlu and Ay 2020).

Countries with deficient government institutions are more susceptible to climate change. Environmental changes pose a danger to social stability by destroying livelihoods and employment as well as impairing governmental capacity (Sofuoğlu and Ay 2020). It is noteworthy that adverse environmental conditions might cause decreased agricultural income, higher food prices, and declining crop yields. Moreover, climatic variations impact the ability of some developing countries to produce food because they reduce crop production in some areas (Raleigh and Urdal 2007). The increases in food costs trigger the beginning of low-intensity political violence, including rallies, protests, and riots (Koubi 2019). Nevertheless, the unfavorable impacts of environmental scarcity also weaken social institutions, leading to increased violence (Homer-Dixon 1994). Bernauer et al. (2012) pointed out that the likelihood of environmentally induced economic hardship and migration resulting in violent conflict is higher in nations with fragile political institutions. Since 1960, civil war has occurred in more than two-thirds of the SSA nations (Blattman and Miguel 2010). According to the African Peace and Security Architecture Roadmap 2016–2020, climate change is one of the components influencing peace and security on the continent. Moreover, Aribigbola et al. (2013) disclosed that natural disasters have caused the food chain in several SSA nations to be disrupted, leading many people to move in search of employment and food, which has increased ethnic conflict. This endorses the findings that climate change worsens social instability in already unstable countries (Nzeadibe et al. 2012; Sofuoğlu and Ay 2020).

In the bargain, climate change escalates the ongoing conflicts and humanitarian crises in some of the poorest countries, which are the most vulnerable to climate change risks worldwide (Scheffran et al. 2012). Regarding this, the SSA countries highly depend on rain-fed farming for income and food provision, which increases their likelihood of experiencing civil conflicts during extreme climatic events (Burke et al. 2009; von Uexkull 2014). Farmers and herders clash over pasture and water resources, damaging crops, raising killings, forcing displacement, and leading to starvation (Vanger and Nwosu 2020). Socioeconomic conditions, such as ethnic divisions and cultural diversity, influence the association between climate change and armed conflicts in the region (Schleussner et al. 2016; von Uexkull 2014). Contrarily, the empirical investigation of SSA countries reveals that even increased precipitation leads to clashes (Salehyan and Hendrix 2014; Theisen 2012). The African continent, accounting for only 4% of global greenhouse gas emissions (GHGs), is highly susceptible to climate-related catastrophes vis-à-vis its low adaptive capacity and institutional fragility (Ifejika Speranza 2010; Nzeadibe et al. 2012). The primary reason for this is the lack of technological and infrastructure resources in developing nations to reduce climate change vulnerability (Sofuoğlu and Ay 2020). Studies reveal that these countries will likely lose a third of their GDP in 2050 unless climate change susceptibility is tackled and effective strategies are implemented (Lenshie et al. 2022).

The body of knowledge about the security implications of precipitation and temperature anomalies is growing quickly. The incidence and pattern of climate-induced conflict and population migration in SSA present contrasting and critical discourse (Lenshie et al. 2022; Lenshie and Jacob 2020; Madu and Nwankwo 2021). However, the implications of location-specific factors and geopolitics contributing to climate-induced conflict are underexplored in many parts of Africa (Cappelli et al. 2023; Lenshie et al. 2022). Despite some quantitative empirical studies investigating the linkage between climatic variations and conflict, the mechanisms connecting the two phenomena need to be clarified in the selected conflict-affected countries. Several scholars have stated that location characteristics alter the risk of violence, but the empirical studies on the various locations present weak and inconclusive results that also suffer from methodological ambiguity (Buhaug 2015). As cross-country research in the SSA is scarce in the available literature, this study focuses on selected SSA economies, which have fast-growing, rapidly rising populations and land degraded by droughts and desertification. This research aims to identify the impacts of climate change, deforestation, population growth, and political stability on internal conflicts in the selected nations using panel data analysis between 1996 and 2016. Additionally, the chosen countries have a historical background of armed conflicts and social unrest exacerbated by institutional fragility. Climate change not only increases conflict risks but also hinders the achievement of SDG17 in the region—promoting peace, justice, and strong institutions.

Accordingly, this study contributes to the expanding literature and policymakers in the following forms. Firstly, this study considers deforestation, a measure of environmental degradation, to identify whether it contributes to the internal conflicts of the 14 selected SSA countries. Deforestation is regarded as a driving factor in soil fertility loss, crop yield reduction, employment losses, and forced migration (Ali Warsame and Hassan Abdi 2023). Human activities like increasing agricultural fields, misusing water resources, building new settlements, urbanization, and charcoal production cause land degradation that exacerbates droughts and floods in some SSA economies (Warsame et al. 2023). Consequently, conflicts between farmers and herders over pasture and water supplies are increasing due to land degradation (Moritz 2010; Vanger and Nwosu 2020). Secondly, the study selected 14 countries in SSA that had active conflicts in 2019 to estimate the role of climate change in their tensions. Thirdly, the present study applies contemporary heterogeneous panel approaches, such as the pooled mean group (PMG), mean group (MG), and dynamic ordinary least squares (DOLS), to estimate the long-run and short-run effects of temperature variations, precipitation patterns, environmental degradation, and government stability on internal conflicts. In addition, the causality path of the selected variables has been unclear in past studies. Hence, this study employs the panel causality test developed by Dumitrescu and Hurlin (2012) to establish the direction of the causative association between the explanatory factors and internal conflicts. Fourthly, the empirical studies that may inform the development and implementation of climate change policies toward conflict resolution are very limited in the SSA context. Regarding this, it is challenging to design effective policy interventions when uncertainty hinders efforts to reduce the adverse repercussions of climate change (Burke et al. 2009). Policymakers need the information to establish policies to avert climate-related conflicts, and this study complements the search for policies that prevent conflicts and the instabilities linked to climate change. In addition to the repercussions of change, decision-makers must consider both the direct and indirect risks connected with climate change mitigation and adaptation strategies.

The rest of the paper will be organized as follows. The "Literature review" section displays the relevant literature. In the "Methods" section, the data and econometric approach of the study are illustrated. The "Empirical results and discussion" section delivers the empirical results, robustness, and discussion of the findings. The final section concludes and offers the appropriate policy implications from the results.

Literature review

Studies on the impacts of climate alteration on conflicts have increased due to the increasing global recognition of its detrimental effects on the livelihoods of societies. In emerging economies, Harari and Ferrara (2018) highlighted a robust short-run relationship between climate change and conflicts. Climate change is attributed to be a direct or indirect driver of intrastate conflicts in some sub-Saharan African countries (Almer et al. 2017; Koubi 2019; Mack et al. 2021). Many studies have related the deterioration of living conditions to environmental changes, vicious violence, and social instability in many parts of Africa. The empirical literature on violent conflict and climate change presents an inconclusive debate that gives little help to policymakers. This section presents the relevant studies that examined climate change and conflict.

The evidence from developing and less developed countries supports that climatic variations contribute to internal conflicts. These countries are the most susceptible to varying environmental circumstances, including water scarcity, diminishing crop productivity, and rising sea levels (Raleigh and Urdal 2007). For instance, Adams et al. (2018) and Levy et al. (2017) exhibited that temperature and precipitation variations are associated with violence as they lead to crop reduction, although the individual cases are hard to validate. Using the Dumitrescu and Hurlin (2012) panel causality test, Sofuoğlu (2021) investigated the causal linkage between climate change and civil unrest in the Mediterranean, Middle East, and North African regions. Although there was no causality between precipitation and civil instability in any given nation, they found a causality from temperature to civil unrest in most of the countries. Using a similar technique, Sofuoğlu and Ay (2020) support that climatic variations cause political unrest and conflicts in MENA countries. Additionally, the empirical results support the notion that environmental change acts as a threat multiplier in MENA nations. Similarly, Abel et al. (2019) tested the causal relationship between climate, conflict, and forced migration by adopting bilateral data from 157 countries. The findings suggest that climate change substantially impacted asylum seeking between 2011 and 2015 by influencing the severity of drought and the risk of armed conflict. Despite the fact that the Syrian conflict, which started in 2012, has many causes, including historical conflicts over politics, religion, and social ideologies, as well as economic factors, water scarcity and climatic conditions have contributed to the country's economic downturn (Gleick 2014).

There is strong evidence that climatic fluctuations contribute to conflict in some circumstances and via particular paths (Koubi 2019). For instance, the Sahel has traditionally been characterized by severe climatic change and social instability, which limited the region's ability to reduce poverty and provide food security (Benjaminsen et al. 2012). The authors discovered that violent conflict might be explained more by reasons other than those directly connected to environmental circumstances and resource constraints. Many studies focusing on SSA reveal that climate change affects violent conflicts over water scarcity and declining agricultural output. In East Africa, Abdi et al. (2022) modeled the impacts of climate change on crop output between 1990 and 2018. The study found that crop output increases with precipitation levels and decreases due to temperature anomalies. Moreover, Shimada (2022) examined the effects of climate-related natural disasters on economic and social factors using panel data from African nations. They discovered that environmental catastrophes brought on by climate change impacted economic growth and farm output, which led to violent conflicts in the region. Additionally, the decline of water resources and extreme weather incidents are linked to food insecurity and human rights violations (Schaar 2017). Besides, Almer et al. (2017) investigated the connection between water scarcity and the riots and found that diminishing of water resources are linked to the violence in SSA.

In sub-Saharan Africa, Burke et al. (2009) investigated the impacts of global climatic variability on civil conflicts. They discovered solid historical linkages between temperature and violence, with warmer years considerably increasing the likelihood of conflicts. While transhumant pastoralism is prevalent in many African nations, Morello and Rizk (2022) discovered that climate-related conflicts have affected mobility. They also estimate that 65% of cultivable land was degraded, potentially affecting access to traditional sustenance due to inadequate natural resource management. Moreover, changes in rainfall patterns could potentially limit water resources, intensifying pastoral conflicts in Kenya (Scheffran et al. 2012). Similarly, Madu and Nwankwo (2021) investigated the spatial pattern of climatic variations and farmer-herder conflict vulnerabilities in Nigeria and found that climate change exposure is the best predictor of conflicts. This study indicated that high climate change vulnerability is linked to farmer-herder conflicts in Nigeria. The undertaking of Mack et al. (2021) discloses that rainfall variability increases the likelihood of conflict in sub-Saharan Africa. Furthermore, Cappelli et al. (2023) examined climate change and the armed conflict in Africa between 1990 and 2016. The study confirmed that climate fluctuations influenced the probability of civil violence. They suggested that climate adaptation policies should account for spatial interaction and that climate strategies should support peacekeeping initiatives. In Somalia, Mohamed and Nageye (2019) examined the connection between environmental degradation, resource scarcity, and civil conflicts. They found that declining water availability increases the likelihood of civil conflicts in Somalia.

The studies have asserted that the consequences of climate change on social stability are worse in countries with poor institutional quality. Wischnath and Buhaug (2014) argue that climate change is a significant factor in conflicts, with political and economic factors being the prime drivers. According to several other studies, deforestation and demographics may also impact society's propensity to engage in violent conduct. For instance, Ali Warsame and Hassan Abdi 2023 indicate that environmental degradation hampers agricultural production in Somalia. Accordingly, there was a consensus among studies that climate change and environmental degradation reduce the livelihoods of rural societies, which induces communal conflicts as migration behavior aggravates the conflicts (Daccache et al. 2015; Maystadt et al. 2014). Some researchers embrace the neo-Malthusian conflict theory, which claims that population expansion puts pressure on the supply of renewable resources from natural sources such as cropland and freshwater availability, increasing the possibility of a low-intensity civil war. Similarly, Lenshie et al. (2022) explored the geopolitics of climate-related conflict and migration in West Africa from 2008 to 2019. The findings showed that droughts and desertification are leading factors in the armed conflicts in West Africa and that failure to curb the effects of climate change increases the threats to human security. However, Urdal (2005) evaluated this hypothesis using cross-national time series data from 1950 to 2000. The findings show that nations with high rates of population expansion, urbanization, or refugees do not have higher probabilities of internal armed conflict. Recently, Van Hout et al. (2023) underscored the urgent need for international and regional cooperation to effectively implement climate-related and conflict-related adaptation and resilience policies in Africa.

The literature presented evidence that rising temperatures and the changing rainfall pattern trigger violence and civil conflicts in Africa, with little consideration of location differences. Most previous studies omitted key predictors and assumed that climatic factors and conflicts have a linear relationship, which is unlikely regarding sub-Saharan Africa's nature. In a systematic review, Nagano and Sekiyama (2023) identified the absence of pertinent components, such as land degradation, in prior studies on climate risks and conflicts. Little is known about the factors driving internal conflicts in the SSA countries with active conflicts. By adopting heterogeneous panel techniques, this study contributed to the literature by examining the relationship between temperature variations, precipitation, government stability, and internal conflicts by considering the role of deforestation in the selected countries.

Methods

Data

The study adopts annual panel data from 1996 to 2016 to investigate the effects of climate change and government stability on internal conflicts in 14 selected sub-Saharan African nations. According to the Stockholm International Peace Research Institute, SSA was home to at least 15 nations with active armed conflicts in 2019. These countries include Burkina Faso, Burundi, Cameroon, the Central African Republic (CAR), Chad, the Democratic Republic of the Congo (DRC), Ethiopia, Kenya, Mali, Mozambique, Niger, Nigeria, Somalia, South Sudan, and Sudan. However, the unavailability of data limits the study to select 11 countries alongside 3 other countries with a recent history of conflicts, i.e., Côte d'Ivoire, the Republic of Congo, and Uganda. The dependent variable is internal conflict, a measure comprising threats of civil war, coup, terrorism, political violence, and social instability. The explanatory variables are average rainfall, measured as the mean annual precipitation (mm); average temperature, measured as the mean annual temperature in °C; deforestation, measured as millions of hectares of arable land; population growth, measured as the annual population growth rate; and government stability, measured as government cohesion, legislative strength, and popular support. The data were retrieved from the International Country Risk Guide dataset, Climate Change Knowledge Portal (CCKP), and World Development Indicators (WDI). Detailed descriptions of data sources, symbols, and measurement units are listed in Table 1.

Model formulation

Various factors, including environmental, demographic, and governance, can directly or indirectly affect the occurrence of internal conflicts. Upon an inspection of the literature, many studies identified that climatic aspects, such as temperature and precipitation, environmental degradation, population growth, and political stability, are related to conflicts (Koubi 2019; Raleigh and Urdal 2007; Sofuoğlu and Ay 2020; Urdal 2005). By following the model specification of Sofuoğlu and Ay (2020), the econometric model that contained the variables mentioned above was formulated as follows:

$$CONF_{it} = \alpha_0 + \beta_1 ARF_{it} + \beta_2 AT_{it} + \beta_3 DFO_{it} + \beta_4 PG_{it} + \beta_5 GS_{it} + \mu_{it} \quad (1)$$

Table 1 Symbols, measurement, and sources of variables

Variable	Symbol	Measurement	Source
Internal conflicts	CONF	It is an evaluation made up of three parts: threats of civil war/coup, terrorism/political violence, and civil unrest	ICRG
Average rainfall	AR	Mean annual precipitation (mm)	CCKP
Average temperature	AT	Mean annual temperature (°C)	CCKP
Deforestation	DFO	Arable land (hectares)	WDI
Population growth	PG	Population growth (annual %)	WDI
Government stability	GS	It is a risk rating in three subcomponents: government cohesion, legislative strength, and popular support	ICRG

where *CONF* denotes internal conflicts, which is the explained variable; *ARF* represents average rainfall; *AT* signifies average temperature; *DFO* indicates deforestation; *PG* stands for population growth; and *GS* represents government stability. All the variables in Eq. (1) were log-transformed to reduce the heterogeneity issues that commonly occur in heterogeneous panel data and confirm that the series can be understood as percentages. The modified form is as follows:

$$lnCONF_{it} = \alpha_0 + \beta_1 lnARF_{it} + \beta_2 lnAT_{it} + \beta_3 lnDFO_{it} + \beta_4 lnPG_{it} + \beta_5 lnGS_{it} + \mu_{it} \tag{2}$$

where α_0 is the intercept, β_1 and β_5 are the coefficients of average precipitation and government stability, which are predicted to have a detrimental effect on internal conflicts. However, β_2, β_3, and β_4 are the coefficients of average temperature, deforestation, and population growth, which are projected to cause internal disputes to worsen. In addition, μ signifies the white noise error term. Using a panel dataset with several different individual units, $i = 1, 2, 3..., N$ represents the investigated 14 nations, while $t = 1, 2, 3..., T$ captures the time period.

Econometric approach

Cross-sectional dependence

In panel data models, there is a significant attestation that cross-sectional dependence repeatedly exists in the regression framework (Appiah et al. 2018). In a cross-sectional dataset, assuming that the errors are independent across countries can adversely affect test statistics and estimation efficiency, leading to inconsistent outcomes (Sarkodie and Owusu 2020). Nevertheless, a conceivable cross-sectional dependence occurs among SSA nations due to their interdependence in terms of trade, topography, and culture (Abdi 2023). In addition, the test of cross-sectional dependence could navigate us in the suitable panel econometric approach of the study. To account for the potential cross-sectional dependence, we initially test the cross-sectional reliance between the cross-sections considered in this study. Mixed tests are performed to ensure whether the individual units suffer from cross-sectional dependence, such as the Lagrange multiplier (LM) statistic by Breusch and Pagan (1980), the bias-corrected LM test, the Pesaran (2004) scaled LM, and the Pesaran (2015) CD test. The null hypothesis of cross-sectional independence against the alternative hypothesis could be stated as follows:

$$H_0 : \rho_{ij} = \rho_{ji} = \text{cor}\left(e_{it}, e_{jt}\right) = 0, i \neq j$$

$$H_1 : \rho_{ij} = \rho_{ji} \neq 0, \text{for some } i \neq j$$

In addition, Pesaran (2004) presented a simple alternative test for constant values of either *N* or *T* based on normal product-moment correlation coefficients with a mean of precisely 0. Pesaran CD offers reliable ways to cope with any unobserved shared characteristics or spillover effects that may arise between the nations. In the context of balanced panel data, the CD statistic of Pesaran could be computed as shown in Eq. (3).

$$\text{CD} = \sqrt{\frac{2\text{T}}{\text{N}(\text{N}-1)}}\left(\sum_{\text{i}=1}^{\text{N}-1}\sum_{\text{j}=\text{i}+1}^{\text{N}}\hat{\rho}_{\text{ij}}\right) \xrightarrow{d} \text{N}(0,1) \tag{3}$$

where *N* and *T* are observations and the time, respectively, and $\hat{\rho}_{\text{ij}}$ is the sample values shared between country *i* and *j* given as

$$\hat{\rho}_{ij} = \hat{\rho}_{ji} = \frac{\sum_{t\in T_i\cap T_j}\left(\hat{e}_{it}-\overline{e}_i\right)\left(\hat{e}_{jt}-\overline{e}_j\right)}{\sqrt{\sum_{t\in T_i\cap T_j}\left(\hat{e}_{it}-\overline{e}_i\right)^2}\cdot\sqrt{\sum_{t\in T_i\cap T_j}\left(\hat{e}_{jt}-\overline{e}_j\right)^2}} \tag{4}$$

where

$$\overline{e}_i = \frac{\sum_{t\in T_i\cap T_j}\left(\hat{e}_{it}\right)}{\#\left(T_i\cap T_j\right)} \tag{5}$$

Slope heterogeneity

After conducting a cross-sectional dependence test, it is essential to ascertain whether the slope coefficients are homogeneous. According to Bedir and Yilmaz (2016), ignoring the homogeneity of the data might result in unaccounted-for country-specific characteristics. The Pesaran and Yamagata (2008) test is employed in most investigations to assess if the slope coefficients are heterogeneous. The null hypothesis of the test states that all slopes are homogeneous, which implies that each slope coefficient is constant for all cross-sectional units. The following normalized dispersion statistic is employed to evaluate homogeneity:

$$\tilde{\Delta} = \sqrt{\text{N}}\left(\frac{\text{N}^{-1}\tilde{\text{S}}-\text{k}}{\sqrt{2\text{K}}}\right) \tag{6}$$

where *k* denotes the number of regressors and $\tilde{S}$ presents the modified Swamy test. When the error terms are normally distributed under the null hypothesis with the condition of $(N, T) \to \infty$, the $\tilde{\Delta}$ test has an asymptotic standard normal distribution. When small samples are being addressed, like in our case, the following adjusted $\tilde{\Delta}$ test is used:

$$\tilde{\Delta}_{adj} = \sqrt{N}\left(\frac{N^{-1}\tilde{S} - E\left(\tilde{Z}_{iT}\right)}{\sqrt{Var\left(\tilde{Z}_{iT}\right)}}\right) \tag{7}$$

where $E\left(\tilde{Z}_{iT}\right) = k$ and $Var\left(\tilde{Z}_{iT}\right) = 2k(T - k - 1)/(T + 1)$.

Second-generation unit root tests

Succeeding the cross-sectional dependence test, it is necessary to thoroughly investigate the stationarity of the variables and the order of integration. First-generation unit root tests, which rely on the assumption of cross-section independence in the series, are invalid in the presence of cross-sectional dependence (Breitung and Das 2008). In order to ensure the fitness and reliability of the findings when individual panel units are interdependent, Pesaran (2007) suggested second-generation panel unit root tests, such as the cross-sectional ADF (CADF) and the enhanced cross-sectional IPS (CIPS). The usage of both unit root test techniques is equivalent, with the exception that CIPS utilizes the cross-sectional average of the CADF test, represented mathematically as

$$\Delta y_{it} = a_i + \delta_i y_{i,t-1} + \theta_1 \overline{y}_{t-1} + \sum_{j}^{k} \theta_{ij} \Delta \overline{y}_{i,t-j} + \sum_{j=0}^{k} \Delta y_{i,t-j} + \varepsilon_{it} \tag{8}$$

where $\overline{y}_{t-1} = \left(\frac{1}{N}\right) \sum_{i=1}^{N} y_{i,t-1}, \Delta\overline{y}_t = \left(\frac{1}{N}\right) \sum_{i=1}^{N} y_{it}$ and t_i (N, T) are the t-statistic of the estimate. Using the CADF statistic data for each cross-sectional unit, the CIPS statistic is derived as follows:

$$CIPS = \frac{1}{N}\sum_{i=1}^{N} CADF \tag{9}$$

Panel cointegration tests

It is essential to determine the cointegration relationship between the variables prior to the long-run estimates of the variables. Pedroni (1999, 2004) is employed in the study to explore potential cointegrating relationships between the variables. In the cointegrating regression model, the Pedroni test permits panel-specific fixed effects and panel-specific time trends where the AR coefficient differs across panels. The Pedroni panel cointegration test can be expressed as

$$Y_{it} = \alpha_i + \delta_{1i} X_{it} + \delta_{2i} X_{2it} + \ldots \ldots \delta_{pi} X_{pit} + \varepsilon_{it} \tag{10}$$

where α_i and δ_i are the intercepts and slope coefficients that can vary across cross-sections, Y, X, and p are assumed to be integrated of the same order, i.e., I(1). Under the null hypothesis of no cointegration, the residuals ε_{it} will be I(1). Moreover, to confirm the findings of the Pedroni cointegration test, we implement the Kao (1999) cointegration test, which takes heterogeneity and cross-sectional dependency into account when testing whether there is cointegration between the series. The null hypothesis claims that there is no cointegration between climatic conditions, environmental degradation, population growth, government stability, and civil conflicts in SSA nations, while the alternative hypothesis demonstrates the presence of cointegration among the series. Therefore, if the probability value is significant at 1%, 5%, or 10%, respectively, the null hypothesis of no cointegration connection would be rejected.

Panel autoregressive distributed lag (ARDL) technique

The study implemented the mean group (MG) and pooled mean group (PMG) techniques originated by Pesaran et al. (1999) and Pesaran (2004) to assess the long-run and short-run estimates of the study. The PMG estimator enables the short-run dynamics coefficients, intercepts, and error correction term coefficients to vary among countries. It also provides homogeneous long-run estimates across nations. However, the mean group (MG) estimator is more reliable when slope and constants can vary only in the short-run between nations. The error correction term (ECT) of the PMG and MG estimators demonstrates the cointegration linkage and the short-term disturbance adjustment mechanism. However, the Hausman (1978) test is typically used to determine whether the null hypothesis of homogeneity in the long-run coefficients should be accepted. The analysis used a panel ARDL technique to estimate the role of climate change and government stability on internal conflicts in SSA countries. According to Pesaran et al. (1999), the panel ARDL framework of the study (p, q, q, q, q, q) is as follows:

$$\begin{aligned}\Delta lnCONF_{it} = &\alpha_0 + \varphi_1 lnCONF_{it-1} + \varphi_2 lnARF_{it-1} \\ &+ \varphi_3 lnAT_{it-1} + \varphi_4 lnDFO_{it-1} + \varphi_5 lnPG_{it-1} \\ &+ \varphi_6 lnGS_{it-1} + \sum_{i=1}^{p} \delta_1 \Delta lnCONF_{it-k} + \sum_{i=1}^{q} \delta_2 \Delta lnARF_{it-k} \\ &+ \sum_{i=1}^{q} \delta_3 \Delta lnAT_{it-k} + \sum_{i=1}^{q} \delta_4 \Delta lnDFO_{it-k} \\ &+ \sum_{i=1}^{q} \delta_5 \Delta lnPG_{it-k} + \sum_{i=1}^{q} \delta_6 \Delta lnGS_{it-k} + \mu_i + \varepsilon_t\end{aligned} \tag{11}$$

where α_0 is the intercept, φ is the long-run coefficient, δ indicates the coefficient of short-run variables, p and q

Table 2 Descriptive statistics and correlations analysis

	lnCONF	lnAR	lnAT	lnDFO	lnPG	lnGS
Panel A: Descriptive statistics summary						
Mean	0.856	2.868	1.417	0.916	0.458	0.908
Std. Dev.	1.041	3.270	1.473	1.609	0.619	1.064
Maximum	0.243	2.147	1.358	0.145	0.196	0.477
Minimum	0.123	0.321	0.034	0.400	0.070	0.099
Skewness	−1.546	−0.699	0.092	−0.300	−0.418	−1.099
Kurtosis	7.372	2.049	1.669	2.453	3.774	5.135
Jarque-Bera	351.292	35.039	22.114	8.065	15.894	115.047
Probability	0.000	0.000	0.000	0.018	0.000	0.000
Panel B: Pairwise correlations						
lnCONF	1.000					
lnAR	0.213	1.000				
lnAT	−0.045	−0.609	1.000			
lnDFO	0.209	0.152	0.041	1.000		
lnPG	0.107	−0.236	0.056	−0.096	1.000	
lnGS	0.492	0.287	−0.189	0.081	−0.057	1.000

represent the number of lags, Δ is the first difference operator, ε_t is the error term, and μ_i captures country-specific effects.

Dumitrescu–Hurlin panel causality test

In a heterogeneous panel data framework with constant coefficients, the causality test developed by Dumitrescu and Hurlin (2012) is employed to identify the causal relationship between the variables adopted for the study. The test assumes that there may be causation for some cross-sections in the panel but not necessarily for all (Lopez and Weber 2017). In order to determine whether average rainfall, mean temperature, deforestation, population growth, political stability, and internal conflicts are causally connected, the present study applies the Dumitrescu–Hurlin panel causality test. It is noteworthy that Dumitrescu–Hurlin panel causality for heterogeneous panels holds for both $N > T$ and $N < T$. Equation (12) represents the mathematical structure of the test:

$$y_{it} = \alpha_i + \sum_{i=1}^{k} \theta_i^{(k)} y_{i,t-k} + \sum_{i=1}^{k} \delta_i^{(k)} x_{i,t-k} + \varepsilon_{it} \quad (12)$$

where $\theta_i^{(k)}$ and $\delta_i^{(k)}$ demonstrate lag and slope parameters that vary across groups, k signifies the lag orders and is considered to be the same for all cross-sectional units, and α_i denotes individual effects that are intended to be fixed in the time dimension. Moreover, the null hypothesis of the test suggests that there is no homogeneous causation throughout the whole cross-sections, while the alternative hypothesis verifies that there is evidence of at least one causal link between the variables.

Empirical results and discussion

Descriptive statistics and correlations analysis

The descriptive statistics highlight the key features of the variables from the selected sub-Saharan African nations. In Panel A of Table 2, the mean, standard deviation, maximum and minimum values, skewness, Kurtosis, and normality of the data are presented. The mean value of climate change series, such as rainfall and temperature, demonstrated the highest average value and standard deviation, whereas the mean and volatility of population growth had the lowest values. Moreover, the average values of conflicts, government stability, and deforestation were 0.856, 0.908, and 0.916, respectively. Additionally, the descriptive analysis of the study firmly demonstrates that all the variables have negative skewness (long-left tail), except average temperature. Besides, Kurtosis quantifies how many data clusters in a frequency distribution's tails or peak, indicating that all the variables exhibit a platykurtic distribution. Also, the findings of the Jarque-Bera test statistic demonstrate that all the variables are normally distributed at the 1% and 5% significance levels, respectively. On the other hand, we assessed how much two variables moved together or away from one another. The results of the correlation between the variables are presented in Panel B of Table 2.

Cross-sectional dependence and slope heterogeneity test

Prior to estimating the factors responsible for internal conflicts in SSA, it is crucial to examine cross-sectional dependence and slope heterogeneity. As illustrated in Table 3, several cross-sectional dependence tests have been implemented, including the Breusch and Pagan (1980) LM test, the bias-corrected LM test, the Pesaran (2004) scaled LM, and the Pesaran (2015) CD test. The CD findings demonstrate significant evidence of cross-sectional reliance among the nations since the null hypothesis of cross-sectional independence was rejected at the 1% significance level for all series. This implies that all the investigated variables have a cross-sectional dependence.

In addition, the homogeneity of the slope coefficients was checked using Pesaran and Yamagata (2008). The slope heterogeneity findings displayed in Table 4 indicate that we reject the null hypothesis that the coefficient slopes are homogeneous based on the estimated values of the delta tilde $\tilde{\Delta}$ and adjusted delta tilde $\tilde{\Delta}$ as well as their accompanying probability values. The findings indicate that the null hypothesis of homogeneous slope coefficients was rejected at the 1% significance level. This suggests that the slope coefficients are heterogeneous across different cross-sections, which demonstrates that applying heterogeneous panel estimators to our study is appropriate. Taking into consideration slope homogeneity and cross-sectional dependence in panel data assists policymakers in establishing well-structured policies that handle the consequences of climate change and government stability on conflicts.

Panel unit root test results

Panel unit root analysis was carried out to investigate the stationarity level and the integration order of the series. As presented in Table 6, the findings of the CADF and CIPS unit root tests reveal various orders of integration. The findings of the CIPS test reveal that all variables are stationary at level except lnDFO, which became stationary at the first difference. Also, the CADF test demonstrates that lnCONF, lnAR, lnPG, and lnGS are only stationary at a level, while lnDFO and lnAT became stationary after the first difference. However, the outcomes indicate various orders of integration, i.e., stationary at levels I(0) and first difference I(1). Hence, our panel unit root tests propose to proceed with the panel cointegration analysis suggested by Pesaran et al. (1999) to investigate the long-run and short-run relationship between the dependent variable and the regressors.

Table 4 Results of slope heterogeneity

H_0: coefficient slopes are homogeneous	Statistic	*p*-value
$\tilde{\Delta}$	5.317	0.000
$\tilde{\Delta}$ adjusted	6.512	0.000

Panel cointegration test

We adopted Pedroni and Kao cointegration tests to evaluate the long-run relationship between climate change variables, i.e., average precipitation and mean temperature, deforestation, population growth, and government stability. As presented in Table 4, the analyzed results of the Pedroni test indicate that the null hypothesis of no cointegration is rejected for the Modified Phillips–Perron test at the 1% significance level. Moreover, the outcome of the Kao cointegration test, which takes into account the heterogeneity and cross-sectional dependence under the null hypothesis of no cointegration relationship between the variables, strengthened the Pedroni results of the cointegration relationship between the series. Hence, as shown in Table 5, the results of the modified Dickey-Fuller (DF), DF, ADF, unadjusted modified DF, and unadjusted DF tests reveal that the null

Table 3 Test of cross-sectional dependence

H_0: No cross-sectional dependence				
Variable	Breusch-Pagan LM	Pesaran scaled LM	Bias-corrected scaled LM	Pesaran CD
lnCONF	328.501	17.605	17.255	3.958
	(0.000)	(0.000)	(0.000)	(0.000)
lnAR	181.897	6.738	6.388	5.256
	(0.000)	(0.000)	(0.000)	(0.000)
lnAT	882.588	58.676	58.326	29.022
	(0.000)	(0.000)	(0.000)	(0.000)
lnDFO	981.070	65.976	65.626	26.751
	(0.000)	(0.000)	(0.000)	(0.000)
lnPG	465.083	27.729	27.379	0.465
	(0.000)	(0.000)	(0.000)	(0.641)
lnGS	507.192	30.850	30.500	17.670
	(0.000)	(0.000)	(0.000)	(0.000)

hypothesis of no cointegration is rejected at the 1% significance level. In this context, both tests conclude that there is a cointegration linkage between mean rainfall, average temperature, deforestation, population growth, and government stability.

Long-run and short-run estimates

The estimated outcomes of the short-run and long-run effects of average precipitation, mean temperature, deforestation, population growth, and government stability on internal conflicts in SSA countries are presented in Table 6. In this sense, the study utilized the PMG and MG estimators to analyze the relationship between the variables. The Hausman test was used to determine the appropriate estimator of the study. The test was run to decide whether the null hypothesis of homogeneous long-term coefficients should be rejected. Table 7 exhibited that the null hypothesis of homogenous long-run coefficients across the nations was accepted based on the chi^2 statistic of 0.60 and its corresponding *p*-value of 0.988. As a result, the PMG estimator is more accurate and efficient for this undertaking than the MG method. Therefore, the results of the study will be based on the findings of the PMG estimator.

The long-run findings of the PMG technique indicate that all explanatory variables are statistically significant except for the average temperature. The results disclose that an increase in average rainfall reduces internal conflicts in the selected SSA nations at a 1% significance level. Interpretively, a percentage rise in average precipitation reduces conflicts by 0.48% in the long run. However, average temperatures did not significantly explain internal conflicts in the long run. This indicates that, other things being equal, the mean temperature is not a pushing factor in civil disputes in the selected SSA countries over the long run. Furthermore, the findings suggest that environmental degradation escalates internal conflicts in the long run since a 1% rise in deforestation raises internal conflicts by 0.33% at the 1% threshold level. This suggests that environmental degradation significantly influences social unrest in the selected SSA countries. The rural population in SSA heavily depends on forest land for their livelihoods and as a safety net in times of disaster. Also, our outcomes reveal that population growth in the selected SSA countries raises the likelihood of civil unrest at the 1% significance level. A percentage increase in the population of these countries increases internal conflicts by 0.202%. Surprisingly, the long-run outcomes reveal that government stability has a positive linkage with internal conflicts at the 1% significance level. In the long run, a 1% increase in government stability induces internal conflicts to increase by 0.73%.

On the other hand, the short-run results of the study illustrate that only average temperature and government stability

Table 5 Panel unit root test outcomes

	CIPS		CADF	
	Level	*Δ*	Level	*Δ*
lnCONF	−2.687***	−4.474***	−3.316***	−4.232***
lnAR	−3.921***	−5.689***	−2.893***	−3.841***
lnAT	−2.903***	−5.443***	−1.683	−3.888***
lnDFO	−1.869	−3.938***	−1.615	−2.800***
lnPG	−2.213**	−2.988***	−2.527***	−3.470***
lnGS	−2.376**	−4.126***	−2.469***	−3.541***

Notes: *** and ** represent significance levels at 1% and 5%. Δ stands for stationarity at the 1st difference

Table 6 Panel cointegration tests

	Statistic	*p*-value
Pedroni cointegration test		
Modified Phillips–Perron t	4.007	0.000
Phillips–Perron t	0.462	0.322
Augmented Dickey–Fuller t	0.347	0.364
Kao cointegration test		
Modified Dickey–Fuller t	−5.787	0.000
Dickey–Fuller t	−7.144	0.000
Augmented Dickey–Fuller t	−2.760	0.003
Unadjusted modified Dickey–Fuller t	−6.883	0.000
Unadjusted Dickey–Fuller t	−7.409	0.000

Table 7 Results from the PMG estimator

	PMG		MG	
	Coef.	Std. Err.	Coef.	Std. Err.
Long-run outcomes				
lnAR	−0.483***	0.158	−1.188	1.133
lnAT	−1.695	1.358	16.082	16.132
lnDFO	0.331***	0.073	3.073	2.744
lnPG	0.202*	0.113	1.711	1.320
lnGS	0.726***	0.082	3.371	2.691
Short-run outcomes				
ECT_{t-1}	−0.452***	0.093	-0.590***	0.124
ΔlnAR	0.111	0.101	−0.012	0.184
ΔlnAT	1.185**	0.581	0.140	0.993
ΔlnDFO	0.160	0.302	0.259	0.354
ΔlnPG	−0.130	0.422	−0.361	0.562
ΔlnGS	−0.155*	0.088	−0.158	0.145
Constant	0.743***	0.160	−1.544	2.665
Observations	280			
No. of countries	14			
Hausman χ^2	0.60	*p*-value	0.988	

Note: ***, **, * denote significance levels at 1%, 5%, and 10%, respectively were statistically significant. The findings point out that the average temperature aggravates internal conflicts in the short run. Interpretively, a 1 °C rise in mean temperature can raise social unrest by 1.18%. This implies that temperature is a short-run driving factor in social unrest in SSA. Moreover, the short-run results reveal that government stability reduces internal conflicts in the selected SSA countries. A percentage increase in government stability hampers social unrest by 0.1555. This displays that the improved quality of the institutions reduces the tendency for civil unrest in the selected SSA countries. The error correction term (ECT) illustrates how quickly any short-run shock in the investigated variables adjusts to long-run equilibrium. The ECT coefficient is negative and significant, indicating that the relevant variables will modify short-run variations by around 43.4% yearly.

Discussion of the results

A considerable number of quantitative research investigated the connection between climatic factors and internal conflicts, although the directions were inconsistent (Theisen 2017). However, several studies from various countries and regions reinforce our findings that increased precipitation reduces the incidence of conflicts in SSA nations in the long run. For instance, von Uexkull (2014) contends that drought significantly raises the risk that civil war events will occur in SSA regions with rain-fed croplands. They also provide credence to the idea that regions with persistent droughts are more likely to experience war. According to Shimada (2022), droughts have a detrimental impact on cereal output, raising the number of casualties from battles. Since rainfall availability affects natural and agricultural resources, they reveal that community (small scale) violence in East Africa will be more common in highly wet weather, while rebel conflict will be more common in unusually dry weather (Raleigh and Kniveton 2012). Moreover, the short-run findings of the study that increased temperatures are associated with raised conflicts are consistent with several other studies in the literature. In SSA, Burke et al. (2009) discovered substantial historical correlations between civil conflict and temperature, with warmer years significantly increasing the chance of war. Given the significant impact of precipitation on rural African lives, the significant short-term effects of temperature relative to precipitation is surprising. The temperature signal is in line with mounting research showing that increasing temperatures have a direct detrimental impact on agricultural output (Abdi et al. 2022; Schlenker and Lobell 2009). In addition, some studies have observed that temperature substantially correlates with conflict incidence. Due to the dependence of agricultural production on the climate, Zhang et al. (2011) discovered the existence of unidirectional causation from temperature fluctuations to actual grain prices. This implies that temperature variations are a significant element that first damage the agro-economy and, subsequently, people's well-being.

Furthermore, the long-run findings of the study that internal conflicts eventually occur because of deforestation are equivalent to several other investigations. According to Froese and Schilling (2019), anthropogenic interventions, such as forest degradation for agricultural expansion or urbanization on formerly agricultural land, can also contribute to the scarcity of land. Moreover, the empirical evidence indicates that when scarcity of agricultural land combines with rapid population growth, the probability of internal conflict rises (Urdal 2005). However, Raleigh and Urdal (2007) discovered that the impacts of land degradation and water shortages on internal conflicts are marginal, although population density is linked to higher risks of violence. In addition, climate change typically aggravates the scarcity of natural resources and may cause large-scale population shifts due to severe weather conditions (Koubi et al. 2012). This outcome aligns with our long-run findings that population growth contributes to internal conflicts in SSA. Notably, the neo-Malthusian conflict argument demonstrates that, as a result of climate change, population growth puts pressure on scarce environmental resources such as food and freshwater, increasing the likelihood of societies engaging in low-intensity civil war. However, findings do not strongly support the neo-Malthusian conflict explanation. They observed that nations with high rates of population growth, urbanization, or refugees do not always have higher incidences of conflicts compared to nations that experience low rates of population growth. However, society may be compelled to leave the region and cause further shortages when people infringe on the territory of others who may also be resource constrained (Theisen et al. 2013).

The preceding studies support the findings of this study that governmental capabilities are crucial in reducing the possibility of civil conflicts. Raleigh and Urdal (2007) found that political and economic issues have a far more significant impact than demographic and environmental factors. Moreover, Shimada (2022) found that government effectiveness is vital to diminishing the number of people killed by climate-related catastrophes. Additionally, Koubi et al. (2012) found that due to their vulnerability to climate change, non-democratic nations are more prone to face civil unrest as economic conditions worsen, although the evidence is weak. Nations with inclusive political structures, great administrative competence, and low levels of corruption suffer less violent conflict (Koubi 2019). The likelihood of social unrest is very low when governments can offer economic aid, infrastructural improvements, and social services to their population to mitigate climatic hardships. In line with the previous evidence, the results of our study suggest that enhancing sub-Saharan African countries' ability to adapt to climate change may decrease the chance of conflict.

Robustness analysis of the long-run estimates

The study adopted the DOLS approach as a sensitivity analysis to confirm the long-run coefficients of the PMG technique. As presented in Table 7, the sign and significance of the long-run coefficients of climatic factors, environmental degradation, population growth, and government stability on internal conflicts in SSA countries found using the DOLS estimator are in line with the conclusions of the PMG estimator. Hence, this proposes that the long-run findings of the PMG approach are suitable for establishing sound policies that address the issue raised by this study (Table 8).

Dumitrescu–Hurlin causality test

The PMG approach estimates the long-run and short-run relationships between the series, although it does not explain the causal direction of the scrutinized variables. Hence, the study adopts the Dumitrescu and Hurlin (2012) causality test, frequently used for heterogeneous panel data. The causality results of the Dumitrescu–Hurlin test are illustrated in Table 9. The outcomes reveal that the null hypothesis that the average precipitation does not homogeneously cause internal conflicts was rejected at the 10% significance level. This suggests that variations in civil unrest are essentially affected by changes in average precipitation. However, no evidence supports that internal conflicts homogeneously cause average rainfall. On the other hand, we fail to refute the null hypothesis that temperature does not homogeneously cause internal conflicts in the selected SSA countries. Similarly, we do not have evidence to reject the null hypothesis that internal conflicts do not homogeneously cause the average temperature in SSA nations. This implies that changes in temperature levels do not induce variations in social unrest in SSA countries. Moreover, the evidence suggests a bidirectional causality between deforestation and internal conflicts in SSA countries at the 5% significance level. This implies that variations in internal conflicts are considerably influenced by changes in deforestation. Similarly, changes in deforestation are influenced by changes in internal conflicts. Furthermore, the evidence supports the null hypothesis that population growth does not homogeneously affect internal conflicts and vice versa. This result proposes that population growth does not affect alterations in internal conflicts in selected SSA countries. Moreover, we reject the null hypothesis that government stability does not homogeneously cause internal conflicts at the 1% threshold level. This implies that changes in internal conflicts are influenced by changes in the stability of public institutions. Similarly, the analysis indicates evidence to reject the null hypothesis that internal conflicts do not homogeneously cause government stability at the 1% significance level. This proves that the patterns of government stability in the selected SSA countries are affected by variations in internal conflicts.

Table 8 The long-run estimates of DOLS

Variable	Coefficient	Std. Error	*t*-Statistic
lnAR	−0.274**	0.141	−1.935
lnAT	−0.551	1.184	−0.466
lnDFO	0.018	0.076	0.242
lnPG	0.222***	0.067	3.287
lnGS	0.128**	0.063	2.040
R^2	0.637		
Adjusted R^2	0.613		

Table 9 Dumitrescu–Hurlin causality test outcomes

Null hypothesis	*W*-Stat.	Zbar-Stat.	Direction of causality
lnAR → lnCONF	2.573***	3.030	Unidirectional
lnCONF → lnAR	1.418	0.598	
lnAT → lnCONF	0.793	−0.715	No causality
lnCONF → lnAT	1.288	0.325	
lnDFO → lnCONF	2.059**	1.949	Bidirectional
lnCONF → lnDFO	2.100**	2.034	
lnPG → lnCONF	1.359	0.476	No causality
lnCONF → lnPG	1.123	−0.022	
lnGS → lnCONF	3.859***	5.735	Bidirectional
lnCONF → lnGS	3.794***	5.599	

→ signifies that variable *X* does not homogenously cause variable *Y*. ***, **, and * denote a 1%, 5%, and 10% significance level

Conclusion and policy recommendations

Climate change and environmental degradation have severe social and economic implications for vulnerable local communities in sub-Saharan Africa. There is a consensus among researchers that environmental scarcity and extreme weather are strongly related to social instability in many poor economies. It is necessary to quantify the magnitude of the effects of climate change on civil unrest to implement comprehensive policies that tackle its adverse repercussions. Correspondingly, this study aims to investigate the effects of climatic variability and environmental degradation on internal conflicts in selected sub-Saharan African countries between 1996 and 2016. The study used a PMG cointegration method to scrutinize the short-run and long-run parameters. The study disclosed the presence of cross-sectional dependence and rejected the null hypothesis of the homogeneity of the slope coefficients. Due to this, the study employed second-generation unit root tests such as CADF and CIPS to determine the order of integration of the variables. Both tests revealed a mixed order of stationarity, i.e., I(0) and I(1). Also, the long-run cointegration connection between average rainfall, mean temperature, deforestation, population growth, political stability, and internal conflicts was confirmed by Pedroni and Westerlund cointegration tests. The study further employed the Dumitrescu–Hurlin test to determine the direction of the causal association between the variables.

The long-run outcomes of the PMG technique presented that a rise in precipitation reduces civil conflicts in the selected SSA countries, although temperatures were insignificant. In addition, the empirical evidence discloses that environmental degradation is a contributing factor that escalates the social instability of the selected SSA countries. This indicates that the scarcity of environmental resources, such as shortages in rainfall patterns and land degradation brought on by extreme weather conditions, influences the incidence of internal conflicts among the communities in sub-Saharan Africa. Moreover, the study discovered that the rising population is contributing to the internal conflicts of the selected SSA countries. This supports previous studies that indicate climate change contributes to the risk of climate-induced migration and displacement, exacerbating competition over scarce resources and increasing civil conflicts. However, the study found that government stability reduces internal conflicts in the short run but not in the long run. This implies that when governments have the adaptive capacity to reduce the negative consequences of climate change, the possibility of internal conflicts is moderate. The short-run findings also indicate that temperatures increase internal conflicts in the selected SSA nations. As the ECT coefficient is negative and significant, the relevant variables are anticipated to alter short-run fluctuations by around 43.4% annually. Notably, the DOLS verified the robustness of the long-run results of the PMG technique. Furthermore, Dumitrescu–Hurlin causality outcomes reveal unidirectional causation from precipitation to internal conflicts. The results also suggest that internal conflicts have a bidirectional causal association with deforestation and government stability. However, the study found that internal conflicts had no causal link with temperature or population growth.

Tackling climate change and its effects, including conflicts in sub-Saharan Africa, requires robust, comprehensive, people-, and planet-centered policy interventions in the mitigation of climate-related conflicts. We can draw the following recommendations from the findings of the study. Firstly, the governments of the conflict-affected countries should integrate climate change adaptation and conflict prevention strategies into national and regional governance frameworks, emphasizing the need for adaptive, flexible policies. Since climate-related conflict is a multifaceted issue that cannot be approached in a linear manner, this can be achieved by promoting cross-sectoral coordination to ensure climate considerations are incorporated into key policy areas, including security, agriculture, and resource management. Secondly, the authorities should implement sustainable resource management practices that prioritize equitable access to natural resources and minimize resource-driven conflicts. It is essential to implement regulatory measures to prevent illegal resource exploitation, land encroachments, and deforestation, which can exacerbate conflicts. Thirdly, sub-Saharan African policymakers should establish sustainable water management initiatives. Water is a critical resource but also scarce, resulting in conflict over sharing it efficiently. Poor water management also triggers inequalities, poverty, and climate-induced crises, including hunger, drought, and displacement. Therefore, developing effective water management can help prevent water scarcity conflicts. Fourthly, governments should endorse conflict resolution approaches that effectively tackle the underlying factors contributing to climate-related conflicts, including resource scarcity and displacement. It is advisable to allocate resources towards peacebuilding initiatives that aim to foster reconciliation and establish enduring stability in places impacted by violence.

Furthermore, the study highlights several limitations and proposes future research directions. The limitations include issues with data availability in some of the countries as well as the sample size. Since the study focused on low-income countries in the SSA, future studies should investigate the impact of climate change on social stability by increasing the sample period and using data from countries with divergent income levels. This might shed light on whether climate-related violence is an issue for developing economies or not. Future studies should also explore the role of integrating climate adaptation and conflict prevention strategies in reducing climate-related conflicts.

Author contribution AHA handled the study's conception, design, development, data collection, analysis, interpretation, and writing of the first draft and reviewed and edited the entire manuscript. AAM wrote some parts of the introduction and the literature review. MOS wrote the conclusion, and policy implications.

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

Declarations

Ethical approval This study follows all ethical practices during writing. We declare that this manuscript is original, has not been published before, and is not currently being considered for publication elsewhere.

Consent to participate Not applicable.

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