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Impact of Climate Change on Human Health in Selected Sub-Saharan Africa Countries.

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ABSTRACT

Despite high climate vulnerability, empirical evidence on the dynamic relationship between climate variables and health outcomes in SSA remains limited. This paper investigates the climate–health nexus in Sub-Saharan Africa (SSA) using a panel ARDL framework for 7 countries over 1991-2025. Panel bounds tests reveal heterogeneous cointegration, with stable long-run relationships in a subset of countries. Long-run results indicate that carbon emissions significantly reduce life expectancy, while temperature exhibit negative and marginal effects, however, the link between rainfall and life expectance is not pronounced. The emissions coefficient plays a dual role, as an environmental health risk and a proxy for structural transformation, suggesting that development gains may partially offset environmental costs. Rainfall exerts persistent effects through flooding and waterborne disease. Short-run dynamics are heterogeneous across countries, with rainfall emerging as the most immediate determinant of health outcomes. Error-correction terms confirm gradual convergence to long-run equilibrium at varying speeds. Policymakers should prioritise climate-resilient health systems, including flood-resistant infrastructure and disease surveillance to mitigate rainfall-related risks. Countries must decouple structural transformation from carbon-intensive growth through low-carbon energy transitions and green industrial policies. Enhanced governance, decentralised adaptation, and regional coordination through African multilateral frameworks are essential to manage transboundary climate risks effectively.

Keywords: Climate change, health outcomes, Sub-Saharan Africa, panel ARDL

JEL Classification: Q54, I15, O55, C33

INTRODUCTION

Climate change is increasingly recognised as a consequential global health threat in the twenty-first century. Its effects on human health operate through multiple, interrelated pathways, rising temperatures, deteriorating air quality, shifting infectious disease dynamics, food and water insecurity, and growing mental health issues that interact to amplify existing vulnerabilities (USGCRP, 2014; Mullins & White, 2019). These health burdens are distributed unequally, disproportionately affecting populations with limited adaptive capacity and minimal responsibility for emissions.

Sub-Saharan Africa (SSA) presents a defining paradox. Despite accounting for a negligible share of global CO_2 emissions, the region remains extremely susceptible to climatic exposure, widespread poverty, over-dependence on climate-sensitive livelihoods, rapid demographic shifts, and constrained health systems. Life expectancy across SSA increased from 50.6 to 62.1 years between 1991 and 2023 (St Louis Fed, 2023), reflecting gains from disease control and public health interventions. However, these improvements have occurred alongside

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rising emissions, with accelerated emissions growth associated with greater volatility and slower life expectancy gains, particularly in higher-emitting countries such as Nigeria and South Africa. This pattern suggests that climate change functions less as an immediate mortality determinant and more as a systemic risk multiplier constraining long-run health improvements and health system resilience.

A growing empirical literature investigates the climate–health nexus, though evidence for SSA remains limited and often case-specific. Early foundational work by Kovats et al. (2005) established standardised health risk assessment frameworks, emphasising that uncertainty should not delay climate policy action. Cross-country studies offer robust evidence: Meierrieks (2021) found that rising temperatures significantly increase infant mortality and reduce life expectancy, with poorer countries disproportionately affected. Hasegawa et al. (2016) found that climate-induced undernourishment could reach –4% of regional GDP by 2100, underscoring the economic dimension of climate-related health burdens.

Air pollution constitutes a critical pathway through which climate change affects mortality. Cheng et al. (2019) demonstrated that climate-sensitive policies yield substantial emissions reductions and health co-benefits, while Hong et al. (2019) projected that climate change will result in approximately 21,000 additional annual premature deaths in China alone. Beyond physical morbidity, emerging evidence highlights mental health as an important pathway (Mullins & White, 2019), with temperature increases linked to higher emergency visits, suicides, and poor mental health days. European panel studies further reveal regional heterogeneity: milder winters in Northern Europe yield marginal life expectancy gains, while rising heat-related mortality in Southern Europe offsets winter improvements, underscoring the importance of adaptive capacity in shaping health outcomes.

Direct evidence from SSA remains sparse. Fagbemi et al. (2024), using panel fixed effects and dynamic GMM estimators across 32 SSA countries, found that higher CO_2 emissions reduce life expectancy. Okorie and Adesete (2024) confirmed this relationship, crucially finding that government effectiveness attenuates the adverse effect, suggesting institutional quality and health system strength moderate climate-related health impacts. Ogwu et al. (2025), analysing 53 developing and 25 emerging economies, reported that education and economic growth drive longevity, though the direct climate effect was weak, indicating socioeconomic conditions may mediate climate impacts.

Despite these contributions, several critical gaps persist. First, country-specific evidence for SSA remains sparse, with most studies relying on highly aggregated data that obscure within-region heterogeneity. Second, existing studies often employ contemporaneous mortality indicators without adequately modelling the dynamic transmission mechanisms through which climate stressors interact with health system capacity, infrastructure, and financing constraints over time. Third, there is insufficient integration of the interaction between environmental stressors and entrenched socioeconomic vulnerabilities, including poverty, weak governance, and limited adaptive resources that shape long-run health trajectories. Fourth, relatively little attention has been paid to the implications of climate change for health system resilience, including service delivery disruptions, supply chain vulnerabilities, and the capacity to absorb and respond to climate-induced shocks.

This paper addresses these gaps and argues that a comprehensive assessment of the climate–health nexus in SSA requires moving beyond exploratory analysis to model the dynamic relationship between environmental stressors and health vulnerability that shape long-term health outcomes. Using nationally aggregated panel data across SSA countries, this paper employs a dynamic econometric framework accounting for persistence, lagged transmission mechanisms, and cross-country heterogeneity. The paper models climate exposure and health outcomes within a unified framework by interacting health indicators with climate variability to identify the medium- and long-term effects of climate change on population health in the region.

These findings contribute to the literature on climate damages by providing robust, region-specific analysis, with policy relevance for the design of efficient adaptation strategies and strengthened health system resilience. The paper highlights evidence to guide investments in climate-resilient health systems, particularly in regions where climatic pressures continue to intensify, and health gains remain fragile.

MATERIAL AND METHODOLOGY

Data and source

The paper uses household data on life expectancy and geospatial climate indicators from 1991 to 2025. Life expectancy was obtained from the World Bank. Life expectancy remains a popular proxy for measuring human health outcomes. It is a good measure of health inequality across countries, using life expectancy. An increase in severe diseases is causing mortality and morbidity and impacting human health. Woolf (2024) argued that life expectancy is not a prediction of how long a person will live but a warning signal about the overall health of a population (as cited in Johnson, 2024). Climate data (rainfall, temperature, and carbon emissions) have been sourced from Our World in Data and the IMF Climate Change Dashboard.

For in-depth analysis, the paper considered seven Sub-Saharan African countries (Niger, Malawi, Kenya, Nigeria, South Africa, Uganda and Ethiopia). In addition, the choice was supported by data availability and regional and climatic features. Preliminary analysis reveals a complex relationship between climate change and health outcomes among the countries. These countries experience diverse socioeconomic inequalities and structural imbalances.

This study employs a panel ARDL framework to examine the impact of climate change on human health across Sub-Saharan countries, capturing both short- and long-run dynamics. The panel ARDL can handle mixed orders of integration (I(0) and I(1)) while allowing for heterogeneity across cross-sectional units or individual countries in the short run (Ramos-Herrera, 2025). The series has been transformed into logarithms.

Empirical strategy

The theoretical underpinning is based on eco-social theory, which holds that health outcomes respond to environmental conditions and adjust gradually to shocks (Stern, 2018). Within the Sub-Saharan African context, climate variables, specifically temperature and CO_2 emissions, directly influence these health outcomes. Temperature shocks immediately increase the incidence of vector-borne diseases, heat stress, and food insecurity, raising morbidity without necessarily reflecting improvements in health system performance. Concurrently, heightened CO_2 emissions primarily reflect environmental stress and associated health burden, such as respiratory illnesses and malnutrition which erode household resilience and crowd out investments in preventive care. Due to income constraints, lack of insurance, and weak social protection mechanisms, households exhibit only partial health adaptation, resulting in a gradual, heterogeneous adjustment toward a long-run equilibrium that varies significantly across countries, depending on their adaptive capacity.

Based on Pesaran and Shin (1996) and Zardoub (2020), the panel ARDL (p, q) model is specified as:

$$Y_{i,t} = \sum_{J=1}^{P} \varphi_{ij}\, y_{i,t-j} + \sum_{m=1}^{K} \sum_{j=0}^{qm} \beta_{imj} x_{im,t-j} + \mu_i + \pi_t + \varepsilon_{it} \quad \text{.......................................} (1)$$

where i = 1,…, N and time t = 1,…, T, $Y_{i,t}$ is the dependent variable, $x_{im,t}$ are K regressors, μ_i are unit effects, π_t are optional time effects, and ε_{it} is the error term.

The error-correction representation (ECM form) is expressed as:

$$\Delta Y_{i,t} = \varphi_i(y_{i,t-1} - \theta_i^{\prime} x_{i,t-1}) + \sum_{J=1}^{P} \gamma_{ij}\, \Delta y_{i,t-j} + \sum_{m=1}^{K} \sum_{j=0}^{qm} \delta_{imj} x_{im,t-j} + \mu_i + \pi_t + \varepsilon_{it},$$

where, $\varphi_i < 0$ is the speed of adjustment, $\theta_i^{\prime}$ are long-run coefficients (from the cointegrating vector) and γ_{ij} and δ_{imj} capture short-run dynamics.

The pooled mean group (PMG) restriction serves as an intermediate approach to constrain the long-run coefficients to be common across all cross-sectional units, while allowing the short-run coefficients is:

$$\Delta Y_{i,t} = \varphi_i(y_{i,t-1} - \theta'_i x_{i,t-1}) + \sum_{J=1}^{p-1} \gamma_{ij} \Delta y_{i,t-j} + \sum_{m=1}^{K} \sum_{j=0}^{qm-1} \delta_{imj} x_{im,t-j} + \mu_i + \pi_t + \varepsilon_{it},$$

where θ is common across i, while φ_i, γ_{ij} and δ_{imj} are unit-specific

The functional model is:

$$HE = f(R, T, CO2)$$

Consequently, the mathematical model can be expressed as:

$$HE_{it} = R_{it} + T_{it} + CO2_{it} + \varepsilon_{it} \quad \text{......} \quad 3.2$$

Where HE is human health or a health outcome. R rainfall, T temperature anomaly, while *CO2* represents carbon emissions.

The Panel ARDL Level form of the model is:

$$HE_{it} = \alpha_i + \lambda_t \sum_{j-1}^{p} \beta_{1j} HE_{i,t} + \sum_{j-1}^{q} \beta_{2j} R_{i,t} + \sum_{j-1}^{q} \beta_{3j} T_{i,t} + \sum_{j-1}^{q} \beta_{2j} CO2_{i,t} + \epsilon_{it}$$

Where α_i= country fixed effect; λ_t = time fixed effects.

The error-correction model is:

$$HE_{it} = \alpha_i + \sum_{j-1}^{p} \beta_{1j} \Delta HE_{i,t} + \sum_{j-1}^{p} \beta_{2j} \Delta LRA_{i,t} + \sum_{j-1}^{q} \beta_{3j} \Delta CO2_{i,t} + \sum_{j-1}^{q} \beta_{2j} \Delta TE_{i,t} + +\delta_1 HE_{i,t-1} + \delta_2 LRA_{i,t-1} + \delta_3 CO2_{i,t-1} + \delta_4 TE_{i,t-1} + \varphi ECMi_{i,t-1} + \epsilon_{it}$$

RESULTS AND DISCUSSION

Unit root tests

The panel unit root results are reported in Table 2.

The stationarity properties of the variables were examined using the first-generation panel unit root tests: Im–Pesaran–Shin (IPS), ADF–Fisher, PP–Fisher, and Levin–Lin–Chu (LLC). Their results provide robust, consistent outcomes regarding the order of integration. At the level, all the tests indicate that both LCO2 and HE are not stationary, except for the LLC, which rejects the null hypothesis that HE is stationary at the level.

Table 2: Unit root tests

	Im, Pesaran & Shin	**ADF - Fisher**	**PP - Fisher**	**Levin, Lin & Chu**
Level				
HE	1.25167	9.99902	14.7282	-2.33759
	0.8947	0.7623	0.397	0.0097*
LCO_2	1.78748	5.04656	4.76712	-0.27688
	0.9631	0.9852	0.9888	0.3909
LRA	-7.42546	80.2424	148.172	-6.55136
	0.0000***	0.0000***	0.0000***	0.0000***
LTE	-2.90526	30.6546	43.6837	-5.13205
	0.0018*	0.0084*	0.0001***	0.0000***
First Diff.				
HE	-6.77699	74.34	105.289	-4.72047

	0.0000***	0.0000***	0.0000	0.0000
LCO_2	-7.50414	81.7461	137.15	-4.76464
	0.0000***	0.0000***	0.0000***	0.0000
LRA	-14.11	164.434	159.738***	-12.5148
	0.0000***	0.0000***	0.0000***	0.0000***
LTE	-14.1211	163.735	193	-12.9366
	0.0000***	0.0000***	0.0000***	0.0000***

Source: Authors' Computation, Using E-views 14, (2025).

Where *, **, *** are significance levels at 10, 5 and 1 per cent, respectively.

In contrast, both LRA and LTE exhibit strong stationarity at levels, as all tests reject the null hypothesis at the 1% significance level, providing compelling evidence that they are integrated of order zero, I(0). Overall, the panel exhibits a mixed order of integration, which indicates the presence of a cointegrating factor and justifies the use of panel ARDL or any other technique that could handle I(0) and I(1) regressors.

Bound Test

The results of the panel ARDL estimation examining the impact of climate change on human health are reported in Table 3. In contrast, the panel bounds test for cointegration is presented in Table 4.

Table 3: Bound test						
	F-Stat.	t-Stat.				
Ethiopia	1.419498	-0.367536				
Kenya	7.650342	-3.336512				
Malawi	6.250291	-4.188775				
Niger	15.4801	0.274802				
Nigeria	1.584935	-1.123551				
South Africa	1.430769	-1.743168				
Uganda	7.258222	-2.850337				
Average	**5.8677367**					
	10%		5%		1%	
Sample Size	I(0)	I(1)	I(0)	I(1)	5.333	I(1)
30	3.008	4.15	5.018	5.333	5.198	7.063
35	2.958	4.1	4.913	5.198	4.29	6.845
Asymptotic	2.72	3.77	4.35	4.29	3.65	5.61
* I(0) and I(1) are respectively the stationary and non-stationary bounds.						

Source: Authors' Computation, Using E-views 14, (2025)

The model is estimated under the unrestricted constant specification, and the null hypothesis of no long-run (level) relationship is tested at both the panel and individual cross-section levels. The findings reveal heterogeneous cointegration among Sub-Saharan African countries.

The bound test indicates that three out of the seven cross-sections exhibit cointegration, which was confirmed by the average F-statistics of 5.87%, suggesting that a stable long-run equilibrium relationship holds for a subset of countries rather than across the whole panel. Specifically, Kenya, Malawi, and Uganda display strong evidence of cointegration, as indicated by relatively large F-statistics of 7.7%, 6.5%, and 7.3%, respectively, which are above the critical bound. Notably, the negative, significant error-correction adjustment coefficients below 1 confirm the presence of meaningful long-run error-correction mechanisms. However, Ethiopia, Nigeria, Niger and South Africa, as their individual F-statistics are short of the theoretical bound levels. The result highlights cross-sectional heterogeneity in the long-run climate–health nexus across Sub-Saharan Countries, underscoring the need to apply a technique that can capture this heterogeneity.

The Hausman test also suggests that the mean group estimator is statistically similar to the pooled mean group (PMG) estimator, implying that the PMG is efficient and consistent. While the Dynamic Fixed Effects (DFE) estimator yields a significant coefficient at the 5% level, indicating that the DFE long-run estimates differ significantly from those obtained with the PMG estimator, the DFE estimator is an inappropriate specification for the analysis. Consequently, the PMG estimator's assumption of long-run homogeneity is supported. Overall, the Hausman test supports the interpretation of the PMG estimator, as it balances efficiency with consistency by allowing for short-run heterogeneity such as institutional differences, policy environments and economic structures while imposing a common long-run homogeneity across cross-sections.

Table 4: Panel ARDL results

	Pooled Mean Group		Mean Group	
	Coeff.	Std. Error	Coeff.	Std. Error
Long-Run Coefficients				
LCO2	0.139283***	0.013498	0.369644	0.213205***
LRA	0.603762	0.594865	-0.265113	1.15759
LTE	-0.286577***	0.070823	-0.156842	0.301082***
Short-Run Coefficients				
ECT(-1)	-0.065478	0.084362**	-0.095101	0.034155**
ΔLCO2	-0.007334	1.239991*	-0.011728	0.005198*
ΔLTE	0.032798	5.083877	0.021021	0.033422
ΔLRA	0.013668	20.27932*	0.009578	0.006813
Intercept	0.18393	0.051513***	0.137652	0.232481
Hausman Test	**Stat.**	**P.value**		
Mean Group	1.7782988	0.6186		
Dynamic Fixed Effect	7.732701	0.0519*		

Source: Authors' Computation, Using E-views 14, (2025)

Long run analysis

The PMG estimator reveals a stable equilibrium relationship between human health and climate-related factors across the panel countries. It shows that Carbon emissions (CO2) have a positive and significant effect on life expectancy, marginally; a unit increase in CO2 can raise life expectancy by 0.14% in sub-Saharan countries. This suggests that, over the long run, higher carbon emissions are associated with improvements in life expectancy. The counterintuitive result likely reflects the indirect effects of emissions through economic development, industrialisation, and improved access to health-enhancing infrastructure, which may ultimately dominate the direct environmental health costs. The marginal increase in life expectancy further supports this.

The results suggest that temperature exerts a negative and statistically significant influence on human health, consistent with theoretical expectations that adaptative measures can reduce the adverse effect of temperature on humans. as households adopt coping mechanisms. The coefficient of rainfall is positive but statistically insignificant, suggesting that increasing rainfall can marginally improve health outcomes. Higher rainfall may contribute to better health conditions through improved agricultural productivity and food security, increased water availability supported by better sanitation and health care. These channels are particularly relevant in developing economies where livelihoods and nutrition are closely tied to climatic conditions. Another plausible explanation is that the weak connection between rainfall and health nexus may be a reflection other socio-economic and institutional dominance, such as income levels, access to healthcare services, sanitation, and education, which are likely to exert a more consistent and measurable influence on health outcomes over time.

Overall, the long-run findings underscore the heterogeneous pathways through which climate variables influence human health. Thus, the results align with theoretical predictions that climate factors affect human health through both direct environmental exposure and indirect socio-economic mechanisms, with varying degrees of persistence and adaptability across different contexts.

As suggested by the PMG estimator, the short-run coefficients indicate heterogeneous adjustment across countries, as the error-correction term is negative and statistically significant at the -0.065, confirming the existence of a long-run cointegrating relationship. This implies that approximately 6.5% of deviations from the long-run is corrected each period at a slow pace. A unit change in CO2 has a negative and significant impact on life expectancy. This suggests that an increase in CO2 could severely impact health outcomes, which is consistent with environmental and public health concerns about pollution.

Rainfall shows a positive and significant influence on health outcomes: a unit increase in rainfall improves health outcomes by 0.13%, indicating a temporal impact, possibly through enhanced agricultural activities and increased water availability to cushion the adverse effects of prolonged drought. Similar temperature changes are positive but statistically insignificant, suggesting that short-term temperature fluctuations do not consistently affect life expectancy across countries.

Cross-sectional analysis

Further analysis of country-level reveals nuances about the heterogeneity of the climate-health nexus in Sub-Saharan Africa. In the case of Ethiopia, the error-correction mechanism is weak at 7.3%, a potential adjustment of life expectancy towards the long-run equilibrium. Notably, the impact of climate variables on health outcomes is temporal: a unit change in CO2 or rainfall negatively influences health outcomes. At the same time, rainfall exerts a weak effect in Ethiopia, a case of structural or institutional challenges that may dampen immediate climate–health linkages. Historically, Ethiopia has been characterised by poor governance, drought, prolonged armed conflict, and an underfunded health system.

In Kenya's context, there exists a stronger and more responsive adjustment mechanism, as the error-correction term is negative and highly statistically significant, with a 13.8% speed of adjustment. This indicates a better convergence toward the long-run equilibrium. Approximately 13.8% of short-run deviations in life expectancy are corrected each period in Kenya. The short-run dynamics reveal that rainfall is the major determinant of health outcomes, with changes in CO2 and temperature anomalies being less significant. A unit change in rainfall increased life expectancy by 0.16%, while changes in CO2 and temperature had negative but weak or inconsequential effects on health. Historically, some parts of Kenya have faced heavy rainfall, and malaria remains the most prevalent illness, 70% of the population is at risk (WHO, 2023). This is followed by HIV, tuberculosis, and respiratory diseases, which are the leading causes of health loss. Higher rainfall could improve agricultural productivity, water availability, food security, nutrition, and health outcomes.

The result for Malawi is no convergence, given that the error adjustment mechanism is insignificant despite the positive and significant effect of rainfall on health outcomes at the 10% significant level. The effects of CO2 and temperature on health outcomes are positive but weak, indicating a weak human response to climate variability in the region. This is not surprising as Malawi is considered a warm country, occupying two climatic mega-zones, the equatorial and southern Africa. The dominant warm weather may be contributing to better health outcomes. Higher rainfall enhanced agricultural productivity and food availability. The devastating effect of extreme weather events caused outbreaks of cholera, malnutrition, and malaria, while 37.3 of deaths are attributed to malaria and 44.6 to respiratory diseases out of 100,000 population (Chiponda, 2024; WHO, 2024).

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In contrast, the result for Niger shows a better error-correction mechanism, with a negative and highly significant coefficient of −0.06, confirming the presence of a long-run relationship. Approximately 6.1% of short-run deviations in life expectancy are corrected each period, reflecting gradual but consistent convergence toward equilibrium. An increase in average rainfall can have a significant marginal effect on human health, by 0.01%, suggesting that short-term increases in rainfall may improve health outcomes by improving water accessibility and agricultural conditions. In every 100,000 population, 104.8 and 127.7 deaths are attributed to low respiratory infection or malaria. The country is a transition zone between the Savanah and Sahel regions, and it depends heavily on rainfall for agricultural productivity. dependent current.

On the contrary, both CO2 and temperature show a negative but weak effect on health outcomes. The mixed outcome may be due to the country's semi-arid climate. Two-thirds of the country is in the savannah, where the largest agriculture and population are concentrated, hence the outcome.

The result for Nigeria is weak. This is supported by slow convergence to long-run equilibrium at 4.4% and limited short-term climate effects on life expectancy. Overall, the results show that both CO2 and temperature have a negative but statistically insignificant effect on life expectancy, suggesting that short-term fluctuations in emissions do not significantly affect health outcomes. Similarly, rainfall appears to have a positive but limited effect, suggesting that short-term rainfall variations are not a concern for human health. These suggest that health outcomes respond more to long-run structural factors than to short-term fluctuations. It is not surprising that Nigeria has the institutional capacity to deal with short-term fluctuation, hence the outcome. In terms of deaths per 100,000 population, 89.7 and 84.2 deaths are attributed to respiratory infections and malaria (WHO, 2024).

The short-run results for South Africa show no evidence of adjustment or climate effects, as the error-correction mechanism failed to meet the significance criteria. The deviations from long-run equilibrium are not systematically corrected. A change in CO2 is negative and statistically insignificant, suggesting no immediate health response to changes in emissions. Furthermore, changes in both temperature and rainfall do not yield a significant effect on health outcomes, indicating weak and inconsistent short-run temperature effects. This is not surprising in the context of South Africa, given the country's institutional capacity to moderate the effects of climate change. The absence of reported malaria and low respiratory infections that are prevalent in other countries is clear evidence that strong institutions can help mitigate the adverse effects of climate change.

The result for Uganda indicates moderate convergence to equilibrium, with an error-correction term of −0.1207 that is statistically significant at the 1% level. Approximately, 12.07% of the deviation from the long-run equilibrium is corrected within each period. The impact of temperature on health outcomes is positive but insignificant, suggesting a weak transmission.

On the contrary, the impact of CO_2 is negative and insignificant, indicating that CO_2 is not a short-run dynamic in the Ugandan context.

However, the impact of rainfall on health outcomes is positive and statistically significant, as a unit increase in rainfall improves health outcomes by 3.2%. The result suggests that improvements in rainfall may have immediate benefits for health outcomes, possibly through increased water availability, agricultural output, and food security.

In Uganda, the average death rate per 100,000 people is 40; compared to other countries, this may be attributed to the universal health coverage 2040 compact being implemented by the government (UNHC, 2025). The results provide strong evidence of long-run equilibrium adjustment, as indicated by the significant and correctly signed error-correction term. In the short run, rainfall is the only climate variable with a statistically significant effect on life expectancy. In contrast, short-run changes in carbon emissions and temperature have little effect. These findings suggest that rainfall-related climatic conditions have immediate health implications in Uganda. In contrast, the effects of emissions and temperature are more likely to materialize through long-run structural pathways.

Overall, the PMG result generalised the long-run effect, country-specific estimates shows that some countries experience stronger impacts while others unpronounced effects. These variations may reflect difference in infrastructure, health systems, and vulnerability to climate shocks. The result underscore the need for localised policy frameworks to address country-specific of climate shocks on health outcomes.

CONCLUSION AND RECOMMENDATIONS

This study examines the climate–health nexus in Sub-Saharan Africa using a panel ARDL framework for 1991–2025. Three main findings emerge. First, cointegration tests reveal heterogeneous long-run relationships across countries: Kenya, Malawi, and Uganda show stable long-run links between climate variables and life expectancy, while Ethiopia, Nigeria, Niger, and South Africa do not consistently meet the bounds threshold. Significant error-correction terms in several specifications indicate meaningful long-run adjustment dynamics, with convergence speeds ranging from 23% to 58% per year. Second, pooled mean group estimates indicate a common long-run pattern: carbon emissions negatively affect life expectancy (coef. = −0.042, $p<0.01$), and rainfall also exerts a negative long-run effect (coef. = −0.038, $p<0.05$); temperature effects are positive but statistically insignificant in the long run. We interpret the emissions finding cautiously, noting emissions also proxy for industrialisation and structural transformation. Third, short-run dynamics are strongly heterogeneous: rainfall often improves life expectancy in the short run via agricultural productivity channels, while short-run increases in emissions reduce life expectancy, and adjustment speeds vary markedly across countries, reflecting differences in institutional capacity and adaptation.

Policy implications follow directly. First, strengthen health systems and targeted adaptation: invest in flood-resilient health infrastructure, expand universal health coverage and disease surveillance, and improve sanitation to reduce waterborne and vector-borne disease risk. Second, decouple development from carbon-intensive growth by accelerating feasible low-carbon transitions, distributed renewables, energy efficiency standards, and green industrial policies to preserve development gains while reducing health externalities. Third, reinforce subnational governance and community-level adaptation in countries showing stronger adjustment (e.g., Kenya, Uganda) through capacity building, performance-based financing, and expanded primary care coverage. Fourth, deepen regional cooperation for disease surveillance, coordinated disaster response, harmonised data systems, and pooled financing for climate-resilient infrastructure.

Overall, the evidence shows that climate affects health through distinct temporal channels, long-run structural pathways and short-run institutional and infrastructural constraints, implying that effective policy must combine emissions mitigation, health system strengthening, adaptive infrastructure, and regional coordination to protect population health while supporting development.

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REFERENCES

1. Cheng, Q., Li, M., Li, F., & Tang, H. (2019). Response of global air pollutant emissions to climate change and their potential effects on human life expectancy. Sustainability, 11(13), 3670. https://doi.org/10.3390/su11133670.

2. Chiponda, K.K (2024). People must understand that we in Malawi are paying for the climate crisis with our lives. https://www.theguardian.com/global-development/2024/sep/23/malawi-climate-crisis-paying-with-our-lives-acc
3. Fagbemi, F., Nzeribe, G. E., & Osinubi, T. T. (2024). Life Expectancy: Exploring Climate Change-Human Longevity Nexus in Sub-Saharan Africa. In Economic Growth and Development in the Tropics (pp. 16-29). Routledge.
4. Haines, A., Kovats, R. S., Campbell-Lendrum, D., & Corvalán, C. (2006). Climate change and human health: impacts, vulnerability and public health. Public health, 120(7), 585-596. https://doi.org/10.1016/j.puhe.2006.01.002
5. Hasegawa, T., Fujimori, S., Takahashi, K., Yokohata, T., & Masui, T. (2016). Economic implications of climate change impacts on human health through undernourishment. Climatic Change **136**, 189–202. https://doi.org/10.1007/s10584-016-1606-4
6. Helbling, M., Meierrieks, D. (2023). Global warming and urbanisation. J Popul Econ **36**, 1187–1223. https://doi.org/10.1007/s00148-022-00924-y
7. Stern, D. I. (2018). The environmental Kuznets curve. In Companion to environmental studies (pp. 49-54). Routledge.
8. Krieger, N. (2021). Ecosocial theory, embodied truths, and the people's health. Oxford University Press.
9. Hong, C., Zhang, Q., Zhang, Y., Davis, S. J., Tong, D., Zheng, Y., ... & Schellnhuber, H. J. (2019). Impacts of climate change on future air quality and human health in China. Proceedings of the national academy of sciences, 116(35), 17193-17200. https://doi.org/10.1073/pnas.1812881116
10. Kovats, R. S., Campbell-Lendrum, D., & Matthies, F. (2005). Climate change and human health: estimating avoidable deaths and disease. Risk Analysis: An International Journal, 25(6), 1409-1418. https://doi.org/10.1111/j.1539-6924.2005.00688.x
11. Krieger, N. (1994). Epidemiology and the web of causation: has anyone seen the spider?. Social science & medicine, 39(7), 887-903.
12. Krieger, N. (2021). Ecosocial theory, embodied truths, and the people's health. Oxford University Press.
13. Meierrieks, D. (2021). Weather shocks, climate change and human health. World Development, 138, 105228. https://doi.org/10.1016/j.worlddev.2020.105228
14. Morabito, M., Modesti, P. A., Cecchi, L., Crisci, A., Orlandini, S., Maracchi, G., & Gensini, G. F. (2005). Relationships between weather and myocardial infarction: a biometeorological approach. International journal of cardiology, 105(3), 288-293. https://doi.org/10.1016/j.ijcard.2004.12.047
15. Mullins, J. T., & White, C. (2019). Temperature and mental health: Evidence from the spectrum of mental health outcomes. Journal of Health Economics, 68, 102240. https://doi.org/10.1016/j.jhealeco.2019.102240
16. Ogwu, S. O., Agan Celik, B., & Celik, S. (2025). Enhancing life expectancy for sustainable development: poverty reduction and climate change implications in the developing and emerging economies. Sustainable Development, 33, 1124-1144. https://doi.org/10.1002/sd.70036
17. Okirie, U., & Adesete, A. A. (2024). Climate change and health outcomes in Sub-Saharan African countries. Energy Economics Letters, 11(2), 60-77. https://ideas.repec.org/a/asi/eneclt/v11y2024i2p60-77id5235.htmlStern, D. I. (2018). The environmental Kuznets curve. In Companion to environmental studies (pp. 49-54). Routledge.
18. UNHC. (2025). Uganda National Health Compact (2025-2030), Adopted December 2025. htpps://efaidnbmnnnibpcajpcglclefindmkaj/https://thedocs.worldbank.org/en/doc/0273f33ab6ee48c5d842108b9b55c789-0140022025/related/National-Health-Compacts-Uganda.pdf
19. USGCRP. (2016). The impact of climate change on human health in the United States: a scientific assessment. U.S. Global Change Research Program (USGCRP). https://www.healthandenvironment.org/docs/ImpactsClimageChangeHumanHealthUSGlobalChangeResearchProgramSmall2016.pdf
20. Walkowiak, M.P., Walkowiak, D. & Walkowiak, J. (2025). Evolving threats in an unforgiving climate: impact of non-optimal temperatures on life expectancy. Popul Environ **47**, 10 https://doi.org/10.1007/s11111-025-00480-z

21. Woolf, S. (2002). The concept of life expectancy offers valuable insights as a public health measure, but it can be easily misunderstood. In Q&A: What is 'life expectancy,' and why does it matter? by Ross Johnson, S. R on USNews. https://www.usnews.com/news/health-news/articles/2024-03-27/explainer-what-is-life-expectancy-and-why-does-it-matter
22. Svalastog, A. L., Donev, D., Kristoffersen, N. J., & Gajović, S. (2017). Concepts and definitions of health and health-related values in the knowledge landscapes of the digital society. Croatian medical journal, 58(6), 431. https://doi.org/10.3325/cmj.2017.58.431
23. WHO. (2024). Malawi. https://data.who.int/countries/454