Climate Change and Health Outcomes in Sub-Saharan Africa: Linkages and Pathways

Abstract

In Sub-Saharan Africa (SSA), the interplay between climate change and health outcomes poses a significant concern, given the region's susceptibility to environmental shifts. The relationship highlights complex linkages and pathways that necessitate comprehensive understanding and intervention strategies to mitigate adverse consequences. This study investigates this relationship using quantitative analysis based on secondary data from the World Development Indicators and the International Monetary Fund for 21 SSA countries. Employing the Discroll and Kraay, as well as System GMM estimation techniques, the research assesses the effect of climate change on various health indicators in SSA. Results reveal substantial associations, emphasizing the vulnerability of certain populations and potential health risks. The findings underscore the necessity for a comprehensive understanding and intervention strategies. Recommendations focus on enhancing climate resilience, reinforcing health infrastructure, and implementing robust public health policies to effectively address the evolving challenges posed by climate change on health outcomes in SSA.

Keywords: Climate change, Health outcomes, Climate Resilience, Health infrastructure, SSA

JEL Classification: Q54, I10, Q58, I11, I18, O55

1. Introduction

Sub-Saharan Africa (SSA) is considered one of the regions most vulnerable to the adverse impacts of climate change due to its reliance on rain-fed agriculture, limited adaptive capacity, and high prevalence of poverty (Kelly & Radler, 2024). The region experiences a range of climate-related challenges, including increased temperatures, erratic rainfall patterns, and more frequent extreme weather events (Ayanlade et al., 2022). These environmental shifts not only threaten food security and water availability but also have profound implications for public health outcomes in SSA. Understanding the nexus between climate change and health in the context of SSA is crucial for informed decision-making and targeted interventions to safeguard the well-being of its populations.

Among the myriad consequences of climate change, its impact on health outcomes in SSA emerges as a critical challenge with multifaceted dimensions. The region's susceptibility to climate-related health risks, compounded by existing socioeconomic vulnerabilities, underscores the urgency of addressing the linkages and pathways between environmental changes and public health outcomes. Studies have indicated that rising temperatures, altered precipitation patterns, and extreme events in SSA are associated with a higher burden of infectious diseases, malnutrition, and heat-related illnesses (Chersich et al., 2018; WHO, 2020). However, gaps persist in understanding the specific mechanisms through which climate change influences health indicators and the differential effects on diverse populations within SSA. This problematic necessitates a comprehensive and nuanced exploration of the interconnected dynamics between climate change and health outcomes in SSA to inform evidence-based strategies for mitigating health risks and enhancing resilience in the face of a changing climate.

The objective of this study is to investigate the effect of climate change on a range of key health outcome variables in SSA, including but not limited to the Prevalence of Undernourishment, Life Expectancy at birth, Infant Mortality rate, and on the incidence of malaria. By utilizing secondary data from the World Development Indicators (WDI) and International Monetary Fund (IMF) databases spanning the period from 2004 to 2019, this research aims to explore the complex relationships between climate change and various health indicators in 21 SSA countries. Through rigorous quantitative analysis, mainly the Fixed effect Discroll and Kraay and the System Generalized Method of Moments (GMM), this study provides valuable insights into the pathways through which climate change influences public health outcomes in the region, shedding light on vulnerable populations and the differential impacts of environmental shifts on diverse health variables.

The present study makes multifaceted contributions to the field. It significantly enhances the understanding of climate-health linkages in SSA by analyzing a comprehensive dataset spanning 21 countries over 16 periods. To the best of our knowledge, this study is likely the first to examine climate change's effect on health outcome variables in SSA. The few studies on the topic (Patz & Olson, 2006; Woodward et al., 2014) focus principally on the concept that encompasses the overall well-being of individuals. Our study differs from the latter in that, it goes further looking at the effect on specific, measurable indicators that help assess and quantify the impact of various factors on health. The examination of multiple health variables provides a more nuanced assessment of the impacts of environmental shifts on various aspects of public health, offering a holistic view of the complex interplay between climate change and health. Additionally, the research identifies vulnerable populations and regions most at risk from the health effects of climate change, analyzing key indicators such as the prevalence of undernourishment, life expectancy, infant mortality, neonatal health, etc. This identification allows for a targeted approach in interventions and resource allocation. Moreover, the findings are expected to have crucial policy implications for climate change adaptation and health resilience efforts in SSA. By elucidating the pathways through which climate change influences health outcomes, the research informs evidence-based policies and strategies, contributing to the enhancement of climate resilience, improvement of public health infrastructure, and safeguarding of vulnerable populations. Furthermore, the study's contribution extends to academic discourse on the climate-health nexus in SSA. By offering empirical evidence on the relationship between climate change and diverse health indicators, the research enriches the existing body of knowledge and sets the stage for further research and policy development in the field of climate change and public health.

The rest of the manuscript is organized as follows: Section 2 reviews pertinent literature on the connection between climate change and health outcomes. Section 3 outlines the methodology employed for the empirical investigations. Section 4 presents the discovered results and the accompanying discussions. Finally, Section 5 concludes the paper and offers policy implications concerning adaptation strategies for climate change and public health policies.

2. Literature Review

In this section, we present a brief theoretical literature, followed by some transmission channels of climate change to health outcomes, and conclude the section with some empirical review of the concepts.

2.1.Theoretical Underpinnings

The intricate relationship between climate change and health outcomes in SSA is a critical area of study with multifaceted implications for public health and well-being. Climate change, a global challenge poses a range of direct and indirect health risks, particularly in vulnerable regions such as SSA. The region's susceptibility to climate-related hazards, including extreme weather events, changing rainfall patterns, and temperature fluctuations, underscores the urgency of understanding the complex linkages between environmental changes and health outcomes. As highlighted by the World Health Organization (WHO, 2018), the impacts of climate change on health are manifold, affecting morbidity, mortality, nutrition, water-borne diseases, and overall health system resilience.

At the core of the climate-health nexus lies a theoretical framework that elucidates the pathways through which environmental shifts influence public health outcomes. The concept of "Planetary Health" (Whitmee et al., 2015) emphasizes the interconnectedness of human health, environmental sustainability, and climate resilience. Within this framework, climate change is recognized as a determinant of health, shaping disease patterns, nutrition, access to clean water, and the spread of vector-borne illnesses. The "EcoHealth" approach (Charron, 2011) further delves into the complex interactions between ecosystems, human health, and social dynamics, emphasizing the need for interdisciplinary strategies to address the health impacts of environmental change. These theoretical foundations underscore the importance of adopting a holistic view of the climate-health relationship and considering the multiple pathways through which climate change influences health outcomes in SSA.

Studies have documented a range of health impacts of climate change (Chersich et al., 2018), underscoring the urgent need for targeted interventions and adaptive strategies. Rising temperatures and prolonged heatwaves have been associated with an increased prevalence of heat-related illnesses and cardiovascular conditions (Gasparrini et al., 2017). Changes in precipitation patterns and water availability have amplified the risk of waterborne diseases, negatively impacting sanitation and hygiene practices in vulnerable communities (Lim et al., 2012). Moreover, extreme weather events, such as floods and droughts, have been linked to food insecurity, malnutrition, and the spread of infectious diseases (WHO, 2018). These health risks highlight the interconnected nature of climate change and public health outcomes, necessitating a comprehensive understanding of the pathways through which environmental changes affect health in SSA.

Addressing the health effects of climate change in SSA requires many policy approaches that prioritize environmental sustainability, public health resilience, and community adaptation. Policy interventions should encompass climate mitigation strategies, disaster preparedness and response plans, and initiatives to strengthen health systems and infrastructure (Semenza et al., 2016). Furthermore, fostering community engagement, enhancing early warning systems, and promoting sustainable practices can contribute to building climate-resilient health systems in SSA.

2.2.Transmission Channels: How Climate Change Influences Health Outcomes in SSA

Climate change poses a formidable threat to global health, jeopardizing the progress made in achieving universal health coverage (UHC) and broader poverty reduction and development goals. The ramifications of climate change extend across various facets of human life, including agriculture, food production, infrastructure, livelihoods, and overall well-being. This impending challenge is not uniform and intensifies existing inequalities within and between nations. The anticipated impact encompasses climate-related health hazards, such as communicable disease outbreaks, hindrances to healthcare access, and premature deaths due to malnutrition, heat stress, and the proliferation of water-borne and vector-borne diseases. Additionally, disruptions to food and water systems, coupled with extreme weather events like floods, storms, wildfires, and droughts, further compound the complex interplay between climate change and health outcomes in Sub-Saharan Africa. Indeed, exploring these transmission channels becomes imperative to comprehend the intricate linkages and address the multifaceted challenges ahead.

Agricultural Disruptions Channel

Agricultural disruptions induced by climate change pose a significant threat to food security and contribute to the prevailing issue of undernourishment in SSA. According to the Food and Agriculture Organization (FAO, 2018), this region is particularly vulnerable to climate variability, impacting rainfall patterns, temperature regimes, and exacerbating extreme weather events. Changes in climate alter the timing and distribution of planting seasons, leading to crop failures and diminished yields (Lobell et al., 2008). This disruption in agricultural productivity directly influences the availability and accessibility of food resources for the population.

Smallholder farmers, who constitute a substantial portion of SSA's agricultural sector, face heightened risks due to climate-induced disruptions. The dependence on rain-fed agriculture makes these farmers susceptible to irregular and unpredictable precipitation patterns, affecting crop growth and yield consistency (Funk et al., 2015). This vulnerability is further exacerbated by increased frequency and intensity of extreme events such as droughts and floods, which disrupt normal farming practices (Wheeler & von Braun, 2013). These disruptions cascade through the entire food supply chain, from cultivation to distribution, impacting the quantity and diversity of available food.

The relationship between agricultural disruptions and undernourishment becomes pronounced as these challenges persist. Reduced crop yields and diminished agricultural productivity contribute to food scarcity, leading to higher prices and reduced consumer affordability (FAO, 2018). The socio-economic repercussions of climate-induced agricultural challenges disproportionately affect marginalized and vulnerable populations, exacerbating existing inequalities (Wheeler & von Braun, 2013).

Vector-Borne Diseases (VBDs) Channel

Changes in temperature and precipitation patterns significantly influence the distribution and abundance of vectors like mosquitoes and ticks, altering the transmission dynamics of diseases such as malaria, dengue, and other VBDs (Githeko et al., 2000). Rising temperatures create favourable conditions for the proliferation of vectors, expanding their geographic range and elevating the risk of disease transmission. The intricate relationship between climate change and VBDs can have profound implications for various health outcome variables.

Malaria, a prominent VBD, remains a major public health challenge in SSA. The Intergovernmental Panel on Climate Change (McCarthy, 2001) predicts that climate change will contribute to an increase in the geographic spread of malaria, exposing additional populations to the disease. The heightened transmission of malaria has direct consequences on health variables such as morbidity and mortality, particularly among vulnerable groups such as children and pregnant women (Parham et al., 2015).

Dengue fever, another VBD, is on the rise in SSA due to changing climate conditions. The expansion of suitable habitats for the Aedes mosquito, the primary vector for dengue, increases the risk of dengue outbreaks in previously unaffected regions (Messina et al., 2019). Dengue poses health risks such as severe fever, hemorrhagic fever, and shock syndrome, impacting health outcomes through increased hospitalization rates and potential fatalities.

Beyond malaria and dengue, the broader spectrum of VBDs includes neglected tropical diseases that thrive in specific climatic conditions. Climate change influences the transmission cycles of diseases like schistosomiasis and trypanosomiasis, affecting health outcomes such as chronic infections, organ damage, and long-term disability (Lafferty, 2009).

Water Scarcity Channel

Changes in precipitation patterns, increased temperatures, and extreme weather events contribute to shifts in water availability, quality, and accessibility (Water, C. A. R. E., 2019). Diminished water resources, coupled with the growing demand for agriculture, industry, and domestic use, heighten the risk of water scarcity-induced health challenges in the region. Insufficient access to clean and safe water directly affects health outcomes, exacerbating waterborne diseases, malnutrition, and overall well-being.

In many SSA countries, water scarcity often leads to compromised water quality as reduced availability forces communities to rely on unsafe water sources. Contaminated water becomes a breeding ground for waterborne diseases such as diarrheal infections, cholera, and typhoid fever (Hunter et al., 2009). The World Health Organization (WHO & Sanitation, 2019) estimates that diarrheal diseases alone account for a significant proportion of the global burden of water-related illnesses, particularly affecting children under the age of five.

Malnutrition is another health outcome variable exacerbated by water scarcity, as limited water availability hampers agricultural productivity and food security. Crop failure and reduced yields, attributed to inadequate water for irrigation, contribute to food shortages and diminished nutritional diversity (Funk et al., 2015). Malnutrition, in turn, affects various health indicators, including stunted growth, increased susceptibility to infections, and impaired cognitive development, particularly among children (Affoh et al., 2022).

Moreover, water scarcity-induced stressors contribute to mental health issues, affecting the overall well-being of communities. The strain associated with limited access to water resources, compounded by the socio-economic impacts of droughts and water shortages, can lead to heightened levels of stress, anxiety, and mental health disorders (United Nations Economic Commission for Africa (Lisinge-Fotabong, 2023).

Other transmission channels of how climate change may affect health outcomes in SSA include the displacement channel and extreme weather channel. The displacement channel, influenced by rising sea levels, increased frequency of extreme weather events, and gradual environmental degradation, contributes to population movements and migration (McMichael, 2013). These population displacements result in heightened vulnerability to health risks, including inadequate access to healthcare, increased exposure to infectious diseases, and mental health challenges among displaced individuals (Fussell et al., 2014). The extreme weather channel manifests through the intensification of weather events such as hurricanes, floods, and heat waves. Such events pose direct health threats, causing injuries, heat-related illnesses, and disruptions to healthcare infrastructure (Patel et al., 2018).

2.3.Empirical Literature

Climate change stands as a formidable challenge, exerting profound impacts on global ecosystems and human societies. In the context of SSA, a region already grappling with multifaceted health challenges, the relationship between climate change and health outcomes demands careful scrutiny. This empirical literature review aims to navigate the evolving landscape of research, categorizing studies into two groups. The first category delves into studies presenting the direct linkages between climate change and health outcomes variables in SSA. These investigations explore the pathways through which climate-induced shifts influence prevalent health issues. The second category encompasses studies scrutinizing the determinants of health outcomes in SSA, acknowledging the broader socioeconomic, gender-based, and healthcare access factors shaping vulnerability and resilience in the face of climate change. By synthesizing these empirical insights, this review aims to provide a comprehensive understanding of the nuanced dynamics at the intersection of climate change and health in SSA, laying the groundwork for targeted interventions and policy responses.

Looking at the first stand of literature, there is a scarcity of studies addressing the specific relationship. Among the few, Leal Filho et al. (2013) investigated the relationship between rising temperatures and malaria incidence in Sub-Saharan Africa and found a significant positive correlation between increased temperatures and the expansion of malaria transmission zones. Their study highlighted the susceptibility of vulnerable populations to heightened malaria risks as a consequence of climate change-induced temperature changes. A different study on developing countries by Hunter et al. (2009) explored the impact of water scarcity on waterborne diseases. The study revealed a direct correlation between reduced water availability and an increase in waterborne diseases such as cholera and typhoid fever. This underscores the vulnerability of communities to climate-induced changes in water resources, affecting health outcomes in +developing countries. Similarly, Watts et al. (2015) conducted an extensive analysis of the health implications of extreme weather events in SSA. Their findings indicated a heightened vulnerability to injuries, heat-related illnesses, and disruptions to healthcare infrastructure due to events like hurricanes and floods.

On the second stand of literature, a study by Adeyemo et al. (2024) investigated the determinants of maternal health outcomes in SSA, considering socioeconomic factors. The research highlighted the crucial role of economic conditions, education, and access to healthcare in shaping maternal health outcomes, providing insights into addressing disparities in health outcomes in the context of climate change. In exploring determinants of child health outcomes, Beyene (2023) examined the impact of agriculture and nutrition on child health in

SSA. The study identified a complex interplay of factors, including agricultural practices and nutritional patterns, influencing child health. A study by Hakura et al. (2016) explored gender-related determinants of health outcomes in SSA. The research highlighted disparities in healthcare access and outcomes based on gender, emphasizing the need for gender-sensitive approaches in addressing health challenges exacerbated by climate change.

After a critical analysis of the above literature, the present study underscores the intricate interplay between climate change and health outcomes by narrowing the focus to SSA countries and examining the climate change effect on specific health outcome variables, thus sets the stage for a more comprehensive understanding of the complex dynamics in SSA, offering valuable insights for targeted interventions and policy responses.

3. Methodology

This Section presents the data used, the empirical model, and the estimation technique for this study successively.

3.1. Data

The data used are from secondary sources. These were taken from databases maintained by the International Monetary Fund (IMF) and the World Development Indicators (WDI). The data are for 21 SSA countries[1], covering the period 2004–2019. The choice of the study period depends exclusively on the availability of data. The choice of the study area is justified by the fact that Sub-Saharan Africa serves as a crucial study area for investigating the linkages between climate change and health outcomes, given its unique socio-economic, environmental, and health challenges, offering insights that can inform targeted interventions and policies in this vulnerable region.

Table 1

Variables, Source, and Sample Statistic description

Variable	Sources	Obs	Mean	Std. Dev.	Min	Max
SurfaceTemp	IMF database	336	0.919	0.385	-0.505	1.821
Atmospherictemp	IMF database	336	0.989	0.403	-0.418	2.713
Undernourishment	WDI	327	20.415	11.201	3.4	55.4
Infant Mortality	WDI	336	53.874	16.777	27.3	105.9
Incidence of malaria	WDI	336	206.641	143.783	0.156	494.039
Life expectancy	WDI	336	59.076	4.633	44.502	68.526

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[1] Angola, Benin, Botswana, Cameroon, Congo, Dem. Rep., Congo, Rep., Ethiopia, Gabon, Ghana, Kenya, Mozambique, Namibia, Niger, Nigeria, Senegal, South Africa, Sudan, Tanzania, Togo, Zambia, Zimbabwe

DGGHE	WDI	336	1.627	1.133	0.141	5.016
Pop density	WDI	336	51.46	47.033	2.356	223.223
FDI	WDI	336	4.043	5.857	-10.215	38.943
Institutional Quality	WDI	336	-0.624	0.616	-1.736	0.788

Source: *Authors, from the collected data*
Obs, and *Std. Dev* refers respectively to the number of observations and the standard deviation.

The summary statistics of the variables in our model are shown in Table 1, where we notice that the first two moments of the variables lie within an interval suitable for comparability.

3.2. Presentation of Variables

Dependent variable

In this paper, we chose a vector of variables representing Health Outcomes as our dependent variable (Vu, 2020). These variables are Prevalence of undernourishment (% of population), Infant Mortality rate (per 1,000 live births), Incidence of malaria (per 1,000 population at risk) and Life expectancy at birth. Health outcomes refer to the effects and results of healthcare interventions on the health status of individuals or populations.

Independent variables

As the independent variable in this study, we use the surface temperature change (Climate), indicating the variation in Climate (Hansen et al., 2010; Morice et al., 2021). Lean & Rind (2009) employed surface temperature change as a reliable variable to forecast climate change in the future. Alternatively to this variable, the present study employs the Atmospheric temperature change to capture climate change. This choice is justified following the works of Lenderink and Van Meijgaard (2010), who used this variable in measuring climate change.

In addition to the independent variables of interest, we introduce control variables into the model. These are Domestic general government health expenditure (DGGHE) (Ganda, 2021), Population density (McClelland et al., 2018), and Foreign direct investment (FDI) (Nguéda & Kelly, 2022).

3.3. Model and Estimation Strategy

Based on the work of Kelly and Radler (2024), we specify the following empirical model:

$$Health_{it} = \alpha_0 + \alpha_1 Climate_{it} + \delta_k X_{it} + \mu_{it} \qquad (1)$$

Where *Health* is the dependent variable representing the vector of Health outcomes variables for country i at time t. *Climate* stands for the Surface temperature change, X is the vector of control variables, and μ is the stochastic error term.

The literature suggests estimating equation 1 with panel data in order to consider country-fixed effects. These models are unable to address the endogeneity issue pertaining to the explanatory variables and heteroskedasticity, which Baum et al. (2003) claim appears to be ubiquitous in empirical investigations. To address this, we reformulate equation 1 while accounting for the nuances in resolving the aforementioned issues. The following equations in levels (2) and first difference (3) can be used to summarize this:

$$Health_{it} = \alpha_0 + \alpha_1 Health_{i(t-\tau)} + \alpha_2 Climate_{it} + \sum_{h=1}^{k} \delta_h X_{h,i(t-\tau)} + v_i + \theta_t + \mu_{it} \qquad (2)$$

$$Health_{it} - Health_{i(t-\tau)} = \alpha_0 + \alpha_1 \left(Health_{i(t-\tau)} - Health_{i(t-2\tau)}\right) + \alpha_2 \left(Climate_{it} - Climate_{i(t-\tau)}\right) + \sum_{h=1}^{k} \delta_h \left(X_{h,i(t-\tau)} - X_{h,i(t-2\tau)}\right) + (\theta_t - \theta_{t-\tau}) + \mu_{i(t-\tau)} \qquad (3)$$

Two estimation methods are applied to ensure valid statistical inference and robust standard errors in the panel: The fixed effects of Driscoll and Kraay’s estimator, and the two-step GMM estimator.

First of all, Driscoll and Kraay's estimator allows for the control of all time-invariant variations between the study participants, eradicating significant sources of bias. This method is used to address the cross-sectional dependence issue. The Driscoll-Kraay technique works best for addressing corrections for cross-sectional dependence (Hoechle, 2007). Both balanced and unbalanced panels can be used with this technique, and it can deal with missing values. The size of the cross-sectional dimension in finite samples does not represent a constraint on feasibility, even if the individuals of a panel are much larger than the time dimension, because this method of estimating standard errors does not restrict the limiting behavior of the number of panels. Nevertheless, one should be somewhat cautious about applying this estimator to panels that contain a large cross-section but only a very short time dimension (Driscoll & Kraay, 1998).

Second, we use the two-step system GMM, which outperforms the one-step estimator, per Roodman (2009b). This model was initially presented by Arellano and Bond (1991), and it was subsequently improved by Arellano and Bover (1995), followed by Blundell and Bond (1998). The proliferation of instruments, which weakens Hansen's statistics as a result, is a prevalent issue with the system GMM (Ketu et al.,, 2024). A potential option would be to set a ceiling for instrumentation that is either below (Roodman, 2009a) or just above the total number of panels. The instruments used for the GMM estimation are all exogenous by design. Although there is no set formula for selecting the most suitable instrument, the instruments kept after the exercise should be exogenous. According to the body of literature that already exists on the subject of instrument selection, we kept the second lag of the explanatory variables as an instrument in this regard (Kiviet, 2023). Nchofoung et al. (2023) used the conventional approach to further collapse these instruments. As per Roodman's (2009a) recommendation, this is done to make sure there are fewer instruments maintained in the regression than there are cross-sections.

According to Roodman (2009a), using the GMM technique is sufficient for the cross-sectional dimension to exceed the time dimension. The first prerequisite for implementing the GMM technique described in Roodman (2009b) is confirmed by the fact that the number of cross-sections (21 nations) is more than the number of time series (16 years). Additionally, the GMM is an instrumental strategy that attacks the issue of endogeneity from two directions, first by addressing reverse causality and second by accounting for time-invariant omitted variables through the control of unobserved heterogeneity (Blundell & Bond, 1998). Since cross-country variance is inherent to panel data studies, the GMM is an approach that is frequently used for data that has been organized in a panel form. 21 cross sections for 16 years make up the panel nature of our data. This model's validity depends on (i) the exogeneity criterion for instrument validity and overidentifying restrictions, for which the Hansen test's P-value should be negligible (i.e., larger than 10%), and (ii) the absence of order 2-order autocorrelation. The following Section contains the estimation findings.

4. Findings

This Section encompasses a comprehensive exploration of Preliminary Results, Baseline Results, and Discussion followed by robustness checks and sensitivity analysis.

4.1. Preliminary Results

It's important to run a few preliminary experiments before estimating the aforementioned equations. Because of the linkages between nations, a cross-sectional dependence test must be carried out. Indeed, biased conclusions may emerge from disregarding this issue in panel data (Kengdo et al., 2020). The cross-sectional dependence test (CD) developed by Pesaran (2015) is therefore used for this study with the following hypothesis:

H0: No cross-sectional dependence.

H1: Has cross-sectional dependence.

Table 2

Pesaran (2015) tests for cross-sectional dependence

Variable	**CD-test**	**p-value**
Surface Temp	30.450***	0.000
Undernourishment	7.490***	0.000
Infant Mortality Rate	52.600***	0.000
Malaria Incidence	15.980***	0.000
Life expectancy	54.820***	0.000
DGGHE	-2.360**	0.018
Population Density	57.660***	0.000
FDI	-3.990**	0.021

Source: *Authors, from the collected data.*

Notes: CD refers to the Cross-sectional Dependence test associated with Pesaran (2015)

It appears from Table 2 that the null hypothesis can be rejected at the threshold of 5%. This shows that the sample dataset we used contains cross-sectional dependency. Therefore, baseline regressions are estimated using the Discroll and Kraay technique proposed by Driscoll and Kraay (1998).

4.2. Baseline Results

Table 3 demonstrates that the findings are generally robust and that the p-values are significant at the 1% level. It suggests that Health outcomes variables (Undernourishment, Infant Mortality Rate, and Malaria Incidence) are positively and significantly affected by Climate change while Life expectancy at birth is negatively and significantly affected by Climate change. However, Driscoll and Kraay's estimator is unable to adequately capture the dynamic nature of the model under discussion. This is due to the likelihood that the lag-dependent variable in Equation 3 will correlate with specific effects, creating an endogeneity bias (Gnangnon, 2019). Furthermore, the model contains many regressors that may cause a bidirectional issue. We employ the two-step system GMM in order to handle this possible endogeneity as apparent in Table 4.

Table 3

Effect of Climate change on Health Outcomes variables (Discroll & Kraay)

	(1) Undernourishment	(2) Infant Mortality	(3) Incidence of malaria	(5) Life expectancy
SurfaceTemp	4.845***	10.70***	38.42***	-5.781***
	(1.385)	(2.196)	(12.83)	(0.988)
DGGHE	-2.074***	-7.918***	-76.45***	0.292**
	(0.572)	(0.600)	(6.927)	(0.233)
Pop density	0.995***	0.158*	0.430**	-0.198***
	(0.0159)	(0.0110)	(0.157)	(0.00314)
FDI	-0.236**	-0.197	-4.180***	0.198**
	(0.0826)	(0.0187)	(1.406)	(0.0432)
Constant	32.49***	76.57***	327.4***	54.23***
	(3.135)	(4.872)	(31.23)	(1.563)
Observations	327	336	336	336
R-squared	0.235	0.298	0.454	0.228
Number of groups	21	21	21	21

Source: *Author's construction*

*Notes: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.*

The baseline findings utilizing the system GMM estimator are presented in Table 4. The outcomes that follow are as follows:

Column (1) presents the bivariate link between Climate change, Prevalence of undernourishment, and a set of control variables. Column (2) shows the climate change effect in relation to the Infant mortality rate while Columns (3) and (4) present the latter in relation to the Incidence of Malaria and Life expectancy at birth respectively. The results show that, at the 1% significance level, climate change captured by Surface temperature change has a positive effect on the Prevalence of undernourishment, Infant mortality rate, and Incidence of Malaria respectively, but has a negative effect on life expectancy at birth. With everything being equal, Undernourishment, Infant Mortality rate, and Malaria incidence rise by 0.183, 0.363, and 9.658 with every unit increase in the Surface temperature change (or Climate change) in SSA. Similarly, a Unit increase in Surface temperature change results in a 0.129 decrease in Life expectancy at birth.

This finding implies that higher surface temperatures can negatively affect agricultural productivity, leading to lower crop yields and food shortages thereby contributing to undernourishment as food becomes scarcer and more expensive. Also, elevated temperatures may create favourable conditions for the proliferation of disease vectors, such as mosquitoes carrying malaria. Warmer temperatures can expand the geographical range suitable for these vectors, increasing the incidence of diseases like malaria. Conversely, extreme heat events can lead to heat-related illnesses and fatalities. Increased prevalence of diseases (as observed in malaria incidence) and food scarcity may contribute to a decline in overall health, affecting life expectancy. In a broad sense, our results are compatible with the findings of Leal Filho et al. (2013), Hunter et al. (2009), and Watts et al. (2015).

The introduction of control variables in our model does not influence the sign and statistical significance of our interest variables. The findings suggest that health expenditure is associated with reduced undernourishment, infant mortality, and malaria incidence, while simultaneously increases life expectancy at birth. This result align with economic theories emphasizing the importance of healthcare as a productive investment in human capital (Schultz, 1961). Increased health spending often leads to better healthcare infrastructure, improved access to medical services, and enhanced preventive measures. The positive effect on life expectancy reflects the long-term benefits of a healthier population, potentially contributing to a more productive and economically active workforce. Moreover, by addressing specific health challenges such as undernourishment and infectious diseases, health expenditure can break the cycle of poverty and promote economic development.

The findings equally suggest that an increase in foreign direct investment is linked to a reduction in undernourishment, infant mortality, and malaria, along with an increase in life expectancy at birth. FDI can contribute to economic development and improved living standards. Foreign investments often bring in resources, technology, and expertise, fostering the development of healthcare infrastructure and overall well-being (Luo et al., 2010). The positive correlation between FDI and health outcomes emphasizes the interconnectedness of economic and health indicators, highlighting the potential for globalization and international investments to positively impact public health in developing regions.

Contrarily, our results indicate that an increase in population density is associated with higher rates of undernourishment, infant mortality, and malaria, coupled with a reduction in life expectancy at birth. These findings are consistent with the challenges posed by overcrowding and resource constraints (Kanter et al., 2020). Higher population density can strain healthcare resources, lead to inadequate sanitation, and create conditions conducive to the spread of diseases. This underscores the importance of effective urban planning and healthcare policies to manage population growth sustainably and ensure that the benefits of economic development are equitably distributed.

Table 4

Effect of Climate change on Health Outcomes variables (System GMM)

	(1) Undernourishment	(2) Infant mortality	(3) Incidence of malaria	(4) Life expectancy
L.Undernourishment	0.930***			
	(0.0786)			
L.InfantMortality		0.989***		
		(0.0539)		
L.Incidenceofmalaria			0.262***	
			(0.0197)	
L.Lifeexpectancy				0.980***
				(0.132)
SurfaceTemp	0.183***	0.363***	9.658***	-0.129***
	(0.0156)	(0.0213)	(1.289)	(0.0164)
DGGHE	-0.351***	-3.120***	-32.93	3.068***
	(1.017)	(0.834)	(26.36)	(0.756)
Pop density	0.642***	0.640*	1.460***	-0.186**
	(0.0214)	(0.0695)	(0.492)	(0.0922)
FDI	-0.255***	-0.110**	-2.759**	0.361**
	(0.0750)	(0.0967)	(0.815)	(0.0614)
Constant	4.491***	1.071***	63.8***	2.223***
	(1.150)	(0.422)	(9.153)	(0.998)
Observations	315	326	326	326
Number of id	21	21	21	21
AR(1)	0.0483	0.0101	0.00719	0.0652
AR(2)	0.442	0.135	0.604	0.611
Sargan OIR	0.803	0.899	0.312	0.961
Hansen OIR	0.179	0.962	0.938	0.769
Instruments	14	14	14	14

Source: *Author's construction*

*Notes: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.*

4.3. Robustness Check

We employ an alternative measure of climate change (the independent variable) variable (Atmospheric temperature change) to assess the robustness of our baseline findings.

4.3.1. Using an alternative measure of Climate Change

Previous findings demonstrated that the Prevalence of undernourishment, Infant mortality rate, and Incidence of Malaria are favorably and significantly affected by Surface temperature change while Life expectancy at birth is negatively and significantly affected by Surface temperature change. When we evaluate the results' robustness using Atmospheric temperature change as a substitute for Surface temperature change, the baseline results hold true. Table 5 provides a summary of the findings. We see once more that the relationship between health indicators and temperature changes remains consistent when assessing the robustness of the results using Atmospheric temperature change as an alternative measure. The prevalence of undernourishment, infant mortality rate, and incidence of malaria continue to exhibit favorable and significant associations with changes in atmospheric temperature. This underscores the resilience of the observed patterns and reinforces the notion that temperature variations, whether at the surface or in the atmosphere, play a pivotal role in influencing health outcomes. On the flip side, life expectancy at birth maintains its negative and significant correlation with both Surface and Atmospheric temperature changes, emphasizing the enduring effect of temperature fluctuations on overall population health.

Table 5

The alternative independent variable in the Health-Climate change Nexus (System GMM)

	(1) Undernourishment	(2) Infant Mortality	(3) Incidence of malaria	(4) Life expectancy
L.undernourishment	0.926***			
	(0.0791)			
L.Infant Mortality		0.986***		
		(0.0554)		
L.Incidenceofmalaria			0.310***	
			(0.0191)	
L.Lifeexpectancy				0.977***
				(0.135)
Atmospherictemp	0.171***	0.352***	9.284***	-0.127***
	(0.0159)	(0.0217)	(2.297)	(0.0166)
DGGHE	-0.281*	-3.163***	-27.97**	3.086***
	(1.056)	(0.848)	(5.292)	(0.783)
Pop density	0.633***	0.581***	1.374***	-0.471***
	(0.0214)	(0.0707)	(0.512)	(0.0943)
FDI	-0.259***	-0.106*	-2.543*	0.357**
	(0.0755)	(0.0969)	(0.803)	(0.0619)
Constant	4.279***	0.487***	22.426***	2.203**

	(0.202)	(0.0614)	(8.408)	(0.0271)
Observations	315	326	326	326
Number of id	21	21	21	21
AR(1)	0.0458	0.0104	0.00675	0.0696
AR(2)	0.434	0.136	0.588	0.612
Sargan OIR	0.818	0.902	0.324	0.960
Hansen OIR	0.188	0.964	0.932	0.763
Instruments	14	14	14	14

Source: *Author's construction*

*Notes: Standard errors in parentheses; *** p<0.01, ** p<0.05, * p<0.1.*

5. Conclusion and Policy Recommendations

This research aims to illustrate the connection between Health Outcomes and climate change in SSA. We used a sample of 21 SSA nations from 2004 to 2019 for this purpose, and we applied a variety of robust methodologies, including the Driscoll-Kraay fixed effect and Generalized Method of Moments, to address the issues of cross-sectional dependency, heteroscedasticity, and endogeneity. The econometric analysis revealed that Health outcomes variables (Undernourishment, Infant Mortality Rate, and Malaria Incidence) are positively and significantly affected by Climate change while Life expectancy at birth is negatively and significantly affected by Climate change. These results are robust when using an alternative measure of climate change variable.

In light of the econometric analysis demonstrating the significant effect of climate change on health outcomes, policymakers should prioritize the development and implementation of comprehensive climate-resilient healthcare strategies. Firstly, investments in healthcare infrastructure and capacity building should be directed towards regions most vulnerable to the adverse effects of climate change, ensuring that communities have the resources and adaptive measures to cope with increased health risks. Secondly, there is a critical need for the integration of climate change considerations into public health policies, emphasizing preventive measures and early interventions to mitigate the rising incidence of undernourishment, infant mortality, and malaria incidence. Additionally, targeted efforts should focus on improving access to healthcare services and education, particularly in regions where climate change exacerbates existing health disparities. A broader commitment to global climate action is essential, as reducing greenhouse gas emissions and adopting sustainable practices can contribute to mitigating the adverse health effects outlined in the analysis, ultimately safeguarding life expectancy at birth.

Regarding the role played by control variables, governments should prioritize and increase allocations to healthcare spending, recognizing its dual role in reducing undernourishment, infant mortality, and malaria incidence while simultaneously enhancing life expectancy at birth. This involves not only financial investments but also strategic planning to ensure equitable healthcare access. Again, measures should be implemented to address the challenges posed by increasing population density. Urban planning initiatives and policies promoting sustainable population growth, alongside improved healthcare infrastructure, can help mitigate the adverse effects on undernourishment, infant mortality, malaria incidence, and life expectancy. Lastly, fostering an environment conducive to foreign direct investment is crucial. Governments should create a business-friendly atmosphere, streamline regulations, and invest in education and healthcare to attract and retain foreign investors. This multifaceted approach will not only boost economic growth but also contribute to positive health outcomes, reducing undernourishment, infant mortality, and malaria incidence while increasing life expectancy at birth.

While the research provides valuable insights specific to SSA, the generalizability of findings to all developing countries may be constrained by the limited sample size and data timeframe. Future research endeavors could enhance the robustness of the study by extending the investigation to encompass a more comprehensive array of developing nations, allowing for a more representative analysis. Furthermore, conducting analyses at both macro and micro levels could address potential variations in climate variations and its effect on health across different scales, contributing to a more nuanced understanding of the complex relationship under consideration.

References

Adeyemo, Q. E., Yahaya, H., Esther, A. O., Aboagye-Mensah, P., Blessing, A. J., & Ikome, T. E. (2024). A Scoping Review on Influence of Socioeconomic Status on Antenatal Care Utilization and Pregnancy Outcomes in Sub-Saharan Africa. *medRxiv*, 2024-01.

Affoh, R., Zheng, H., Dangui, K., & Dissani, B. M. (2022). The impact of climate variability and change on food security in sub-saharan africa: Perspective from panel data analysis. *Sustainability*, *14*(2), 759.

Arellano, M., & Bond, S. (1991). Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations. *The Review of Economic Studies*, *58*(2), 277-297.

Arellano, M., & Bover, O. (1995). Another look at the instrumental variable estimation of error-components models. *Journal of Econometrics*, *68*(1), 29-51.

Ayanlade, A., Oluwaranti, A., Ayanlade, O. S., Borderon, M., Sterly, H., Sakdapolrak, P., ... & Ayinde, A. F. (2022). Extreme climate events in sub-Saharan Africa: A call for improving agricultural technology transfer to enhance adaptive capacity. *Climate Services*, *27*, 100311.

Baum, C. F., Schaffer, M. E., & Stillman, S. (2003). Instrumental variables and GMM: Estimation and testing. *The Stata Journal*, *3*(1), 1-31.

Beyene, S. D. (2023). The impact of food insecurity on health outcomes: empirical evidence from sub-Saharan African countries. *BMC Public Health*, *23*(1), 338.

Blundell, R., & Bond, S. (1998). Initial conditions and moment restrictions in dynamic panel data models. *Journal of Econometrics*, *87*(1), 115-143.

Charron, D. F. (2011). Ecohealth research in practice. In *Ecohealth research in practice: innovative applications of an ecosystem approach to health* (pp. 255-271). New York, NY: Springer New York.

Chersich, M. F., Wright, C. Y., Venter, F., Rees, H., Scorgie, F., & Erasmus, B. (2018). Impacts of climate change on health and wellbeing in South Africa. *International journal of environmental research and public health*, *15*(9), 1884.

Driscoll, J. C., & Kraay, A. C. (1998). Consistent covariance matrix estimation with spatially dependent panel data. *Review of Economics and Statistics*, *80*(4), 549–560.

Fao, I. F. A. D., & UNICEF. (2018). WFP and WHO (2017) The state of food security and nutrition in the world 2017: building resilience for peace and food security. *Rome: Food and Agriculture Organization of the United Nations (FAO)*.

Funk, C., Peterson, P., Landsfeld, M., Pedreros, D., Verdin, J., Shukla, S., ... & Michaelsen, J. (2015). The climate hazards infrared precipitation with stations—a new environmental record for monitoring extremes. *Scientific data*, *2*(1), 1-21.

Fussell, E., Hunter, L. M., & Gray, C. L. (2014). Measuring the environmental dimensions of human migration: The demographer's toolkit. *Global Environmental Change*, *28*, 182-191.

Ganda, F. (2021). The impact of health expenditure on environmental quality: the case of BRICS. *Development Studies Research*, *8*(1), 199-217.

Gasparrini, A., Guo, Y., Sera, F., Vicedo-Cabrera, A. M., Huber, V., Tong, S., ... & Armstrong, B. (2017). Projections of temperature-related excess mortality under climate change scenarios. *The Lancet Planetary Health*, *1*(9), e360-e367.

Githeko, A. K., Lindsay, S. W., Confalonieri, U. E., & Patz, J. A. (2000). Climate change and vector-borne diseases: a regional analysis. *Bulletin of the World Health Organization*, *78*(9), 1136-1147.

Gnangnon, S. K. (2019). Tax Reform and Trade Openness in Developing Countries. *Journal of Economic Integration*, *34*(3), 498-519.

Hakura, M. D., Hussain, M. M., Newiak, M. M., Thakoor, V., & Yang, M. F. (2016). *Inequality, gender gaps and economic growth: Comparative evidence for sub-Saharan Africa*. International Monetary Fund.

Hansen, J., Ruedy, R., Sato, M., & Lo, K. (2010). Global surface temperature change. *Reviews of Geophysics*, *48*(4).

Hoechle, D. (2007). Robust standard errors for panel regressions with cross-sectional dependence. *The Stata Journal*, *7*(3), 281–312.

Hunter, P. R., Zmirou-Navier, D., & Hartemann, P. (2009). Estimating the impact on health of poor reliability of drinking water interventions in developing countries. *Science of the total environment*, *407*(8), 2621-2624.

Kanter, G. P., Segal, A. G., & Groeneveld, P. W. (2020). Income Disparities In Access To Critical Care Services: Study examines disparities in community intensive care unit beds by US communities' median household income. *Health Affairs*, *39*(8), 1362-1367.

Kelly, A. M., & Radler, R. D. N. N. (2024). Does energy consumption matter for climate change in Africa? New insights from panel data analysis. *Innovation and Green Development*, *3*(3), 100132.

Kengdo, A. A. N., Nchofoung, T., & Ntang, P. B. (2020). Effect of external debt on the level of infrastructure in Africa. *Economics Bulletin*, *40*(4), 3349-3366.

Ketu, I., Kelly, A. M., & Tchapchet Tchouto, J. E. (2024). Does economic complexity reduce the size of the shadow economy in African countries?. *SN Business & Economics*, *4*(1), 1-27.

Kiviet, J. F. (2023). Instrument-free inference under confined regressor endogeneity and mild regularity. *Econometrics and Statistics*, *25*, 1-22.

Lafferty, K. D. (2009). The ecology of climate change and infectious diseases. *Ecology, 90*(4), 888-900.

Leal Filho, W., May, J., May, M., & Nagy, G. J. (2023). Climate change and malaria: some recent trends of malaria incidence rates and average annual temperature in selected sub-Saharan African countries from 2000 to 2018. *Malaria Journal*, *22*(1), 248.

Lean, J. L., & Rind, D. H. (2009). How will Earth's surface temperature change in future decades? *Geophysical Research Letters, 36*(15)

Lenderink, G., & Van Meijgaard, E. (2010). Linking increases in hourly precipitation extremes to atmospheric temperature and moisture changes. *Environmental Research Letters, 5*(2), 025208.

Lim, S. S., Vos, T., Flaxman, A. D., Danaei, G., Shibuya, K., Adair-Rohani, H., ... & Pelizzari, P. M. (2012). A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. *The Lancet*, *380*(9859), 2224-2260.

Lisinge-Fotabong, E. (2023). Health in Climate Change Diplomacy in Africa. In *Health Diplomacy in Africa: Trends, Challenges, and Perspectives* (pp. 167-179). Cham: Springer International Publishing.

Lobell, D. B., Burke, M. B., Tebaldi, C., Mastrandrea, M. D., Falcon, W. P., & Naylor, R. L. (2008). Prioritizing climate change adaptation needs for food security in 2030. *Science*, *319*(5863), 607-610.

Luo, Y., Xue, Q., & Han, B. (2010). How emerging market governments promote outward FDI: Experience from China. *Journal of world business*, *45*(1), 68-79.

McCarthy, J. J. (Ed.). (2001). *Climate change 2001: impacts, adaptation, and vulnerability: contribution of Working Group II to the third assessment report of the Intergovernmental Panel on Climate Change* (Vol. 2). Cambridge University Press.

McClelland, G. T., Altwegg, R., Van Aarde, R. J., Ferreira, S., Burger, A. E., & Chown, S. L. (2018). Climate change leads to increasing population density and impacts of a key island invader. *Ecological Applications, 28*(1), 212-224.

McMichael, A. J. (2013). Globalization, climate change, and human health. *New England Journal of Medicine, 368*(14), 1335-1343.

Messina, J. P., Brady, O. J., Golding, N., Kraemer, M. U., Wint, G. W., Ray, S. E., ... & Hay, S. I. (2019). The current and future global distribution and population at risk of dengue. *Nature Microbiology, 4*(9), 1508-1515.

Morice, C. P., Kennedy, J. J., Rayner, N. A., Winn, J. P., Hogan, E., Killick, R. E., ... & Simpson, I. R. (2021). An updated assessment of near-surface temperature change from 1850: the HadCRUT5 data set. *Journal of Geophysical Research: Atmospheres, 126*(3), e2019JD032361.

Nchofoung, T. N., Nkemgha, G. Z., Fokam, D. N. D. T., & Njamen, K. A. A. (2023). Achieving the Sustainable Development Goals Through Water and Sanitation: Do Information and Communication Technologies (ICTs) Matter for Africa? *Journal of the Knowledge Economy*, 1-25.

Nguéda, R. D. N., & Kelly, A. M. (2022). The nexus between economic complexity and foreign direct investment in Sub-Saharan Africa. *South Asian Journal of Social Studies and Economics*, *14*(2), 41-52.

Parham, P. E., Waldock, J., Christophides, G. K., Hemming, D., Agusto, F., Evans, K. J., ... & Michael, E. (2015). Climate, environmental and socio-economic change: weighing up the balance in vector-borne disease transmission. *Philosophical Transactions of the Royal Society B: Biological Sciences, 370*(1665), 20130551.

Patel, V., Saxena, S., Lund, C., Thornicroft, G., Baingana, F., Bolton, P., ... & UnÜtzer, J. (2018). The Lancet Commission on global mental health and sustainable development. *The Lancet, 392*(10157), 1553-1598.

Patz, J. A., & Olson, S. H. (2006). Climate change and health: global to local influences on disease risk. *Annals of Tropical Medicine & Parasitology, 100*(5-6), 535-549.

Pesaran, M. H. (2015). Testing weak cross-sectional dependence in large panels. *Econometric reviews, 34*(6-10), 1089-1117.

Roodman, D. (2009a). A note on the theme of too many instruments. *Oxford Bulletin of Economics and Statistics, 71*(1), 135-158.

Roodman, D. (2009b). How to do xtabond2: An introduction to difference and system GMM in Stata. *The Stata Journal, 9*(1), 86-136.

Schultz, T. W. (1961). Investment in human capital. *The American economic review, 51*(1), 1-17.

Semenza, J. C., Tran, A., Espinosa, L., Sudre, B., Domanovic, D., & Paz, S. (2016). Climate change projections of West Nile virus infections in Europe: implications for blood safety practices. *Environmental Health*, *15*(1), 125-136.

Vu, T. V. (2020). Economic complexity and health outcomes: A global perspective. *Social Science & Medicine, 265*, 113480.

W. H. O., & Sanitation, H. (2019). Health: A Primer for Health Professionals. *World Health Organization: Geneva, Switzerland*, 36.

Water, C. A. R. E. (2019). Leaving no one behind. *The United Nations World Water Development Report*, *507*.

Watts, N., Adger, W. N., Agnolucci, P., Blackstock, J., Byass, P., Cai, W., ... & Costello, A. (2015). Health and climate change: policy responses to protect public health. *The lancet, 386*(10006), 1861-1914.

Wheeler, T., & Von Braun, J. (2013). Climate change impacts on global food security. *Science, 341*(6145), 508-513.

Whitmee, S., Haines, A., Beyrer, C., Boltz, F., Capon, A. G., de Souza Dias, B. F., ... & Yach, D. (2015). Safeguarding human health in the Anthropocene epoch: report of The Rockefeller Foundation–Lancet Commission on planetary health. *The Lancet, 386*(10007), 1973-2028.

Woodward, A., Smith, K. R., Campbell-Lendrum, D., Chadee, D. D., Honda, Y., Liu, Q., ... & Haines, A. (2014). Climate change and health: on the latest IPCC report. *The Lancet, 383*(9924), 1185-1189.

World Health Organization. (2018). COP24 special report: health and climate change.