Climate Change and Human Capital Accumulation in Sub-Saharan Africa : Effects on health inegalities.

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Abstract

Sub-Saharan Africa is one of the most affected regions by climate change. This paper examines the effects of climate change on population health inegalities in 45 countries located in the south of the Sahara over the period 1960 to 2019. After estimating an ARDL model, the findings reveal that temperature variation is associated with long-term health losses. The results also indicate significant and negative effects of rainfall on health status. These losses are reflected in lower life expectancy at birth, increased adult mortality rates and years of life lost due to mortality and morbidity. These findings show that climate change can increase health inequalities and degrade human quality of life.

Keywords : Climate change ; health ; human capital ; Sub-Saharian Africa.

JEL classification : I14, I15, Q54, O15.

1. Introduction

The rapid increase in the frequency of climate shocks has drawn the attention of the scientific community and policy makers to its effects on infrastructure, agricultural production, and, most importantly, human development and human lives (IPCC, 2012 ; Tol, 2018 ; Park et *al*., 2020). The worsening socioeconomic conditions of households resulting from these effects, may affect their ability to invest in human capital and improve their living standards (Maccini & Yang, 2009 ; Randell & Gray, 2016 ; Fishman et *al*., 2019 ; Park et *al*., 2020). Thus, they are likely to fall below the poverty line and remain there (World bank, 2013). This will reinforce social inequalities, especially health inequalities.

Existing studies have shown that climate change, which is accompanied by an increase in temperature, could lead to an increase in extreme weather events. This could have effects on infectious and chronic diseases, including chronic respiratory disorders, heat- or cold-related diseases such as cardiovascular disease, injuries, and psychological disorders (McMichael et *al*,, 2001 ; Basu & Samet, 2002 ; Deschênes & Greenstone, 2011 ; Deschenes, 2014 ; Geruso & Spears, 2018 ; Meierrieks, 2021). The burden of disease and mortality from these chronic diseases is trending upward in populations of developing countries, particularly those in sub-Saharan Africa. This region is one of the most affected by climate change (IPCC, 2007). Indeed, the region's vulnerability can be explained in part by its strong dependence on agricultural activities, which are dependent on rainfall. In this region, the vast majority of employment is located in the agricultural sector, accounting for more than half of the workforce, or 15% of the region's GDP (OCDE & FAO, 2016). In addition, the low adaptive capacity of these countries makes them more fragile to climate change (IPCC, 2014).

This study contributes to the literature on climate change and health in several ways. The majority of existing studies have focused on the effects of climate change on population health without considering health inequalities and quality of life. In addition, these studies have focused on the effects of a single climate variable, which may bias the estimated effects of climate change (Auffhammer et *al*., 2013). To address this gap, we combine temperature and precipitation data with health data from 45 sub-Saharan African countries over the period 1960 to 2019. We use health indicators on women and men, namely disability-adjusted life years (DALYs), life expectancy at birth, and adult mortality rate. Thus, this study differs from existing studies in three ways. First, our study, unlike others, takes into account health inequalities and quality of life in the analysis of the effects of climate change on population health. These are measured by disability-adjusted life years. Second, it highlights the effects of climate change on gender disparities in health over the short and long run. These short and long term estimates allow us to make meaningful predictions about health losses that may be associated with climate change. Finally, we study the effects of two climate variables, namely temperature and precipitation. This allows us to obtain unbiased estimates of the effects of changes in precipitation and temperature, since the two variables are historically correlated (Auffhammer et *al*., 2013). In addition, the inclusion of these two variables will allow us to capture the majority of the effects of climate change.

The remainder of the paper is organized as follows. In Section 2, we discuss the theoretical links between climate change and health status. Section 3 presents our data on climate and population health. In Section 4, we present and discuss our results.

2. Climate Change and Human Health

Health, being an important component of human capital, is a key driver of long run productivity gains and economic development (Barro, 1996 ; Strauss & Thomas, 1998 ; Bhargava et *al*., 2001). The production of this input requires the combination of medical inputs with time spent on activities to improve health (Becker, 1965 ;Goodman et *al*., 1999 ; Zweifel et *al*., 2009). This durable capital stock depreciates over time, but investments in health compensate for the losses (Grossman, 1972 ; Muurinen, 1982). Among the factors deteriorating the health stock is climate change. In this section, we present the theoretical basis for linking climate change to health status. To do so, we will study the effects of temperature and precipitation on population health.

2.1 Temperature and Health

The extension of endogenous growth models to negative externalities related to the quality of the environment implies that the deterioration of environmental conditions negatively affects household welfare (Greiner, 2005 ; Economides & Philippopoulos, 2008). Indeed, climate shocks can affect well-being through the deterioration of health and economic conditions, which compromises the accumulation of human capital.

Very high temperatures can increase mortality through the physiological, income, and conflict/crime mechanisms. The physiological mechanism is based on epidemiological theory, which establishes a negative relationship between exposure to abnormal temperatures and health status (Kunst et *al*., 1993 ; Basu & Samet, 2002 ; Curriero et *al*., 2002). Excessive temperature-related mortality results from the failure of the body's thermoregulatory mechanism. Thermoregulation is the process of maintaining a normal body temperature. In fact, extreme temperatures trigger an increase in heart rate to increase the flow of blood from the body to the skin, which can result in sweating in hot temperatures or shivering in cold temperatures. These responses allow individuals to continue physical and mental activities in certain temperature ranges. However, hot temperatures cause an increase in blood viscosity and cholesterol levels, which are the cause of cardiovascular, respiratory and cerebrovascular diseases (Keatinge et *al*., 1986 ; Kunst et *al*., 1993). Similarly, exposure to cold temperatures results in cardiovascular stress due to changes in blood pressure, vasoconstriction and increased blood viscosity (causing clotting), as well as increases in red blood cell count, plasma cholesterol and plasma fibrinogen Huynen et *al*., 2001).

In terms of the income channel, Burgess et *al.* (2017) find that extreme heat leads to lower agricultural yields and employment opportunities. In this context, labor demand and farm wages are low (Desbureaux & Rodella, 2019). This income shock combined with low food storage and rising food prices, leads to malnutrition and morbidity (Kudamatsu et *al*., 2012 ; FAO, 2016 ; Blom et *al*., 2019). In addition, consumption smoothing will force the household to reduce its investments in health-enhancing goods and adaptive tools (Randell & Gray, 2016). Furthermore to these channels, high temperatures can also increase mortality through increased incidence of conflict and crime (Hsiang & Burke, 2014 ; Dell et *al*., 2014 ; Breckner & Sunde, 2019 ; Abrahams, 2020). This is because extreme weather events cause production to decline, potentially reducing the opportunity cost of engaging in violence or protest against the government (Dell et *al*., 2014). Moreover, the state budget deficit associated with the loss of economic output could limit the state's ability to maintain security. Similarly, rising food prices may lead to riots that spill over into broader political instability, and migration related to climate shock could potentially lead to conflict (Dube & Vargas, 2013 ; Dell et *al*., 2014 ; Breckner & Sunde, 2019). From a biological perspective, high temperatures influence impulsivity and aggression by affecting serotonin neurotransmission in the brain. This makes people more aggressive and more likely to commit violent crimes (Hsiang et *al*., 2013 ; Dell et *al*., 2014).

Using a 2 x 2 Heckscher-Ohlin model of international trade, Dal Bó & Dal Bó (2011) describe the mechanism through which a variation in food prices affects conflict. For this purpose, the authors consider an economy composed of two productive sectors, one of which is labor-intensive and the other capital-intensive. A change in commodity prices affects factor returns. For example, an increase in the price of the capital-intensive good expands the capital-intensive sector while the labor-intensive sector contracts. The latter sector releases more labor per unit of capital than the first sector can absorb at initial factor prices. This availability of labor lowers wages and the opportunity cost of conflict. This income shock increases inequality and incite social conflict (Collier & Hoeffler, 2004 ; Dube & Vargas, 2013).

Faced with these direct (physiological mechanism) and indirect (income channel) effects of weather shocks, economic agents will seek to minimize the impact of these negative effects on their well-being. To do so, they must make investments in goods and adaptation measures (Becker, 2007 ; Deschênes & Greenstone, 2011). As such, Burgess et *al*. (2017) developed a model in which agents' health status is endogenous but can potentially depend on weather shocks. They consider an economy with a large number of agents that value both consumption and health status. In particular, each agent seeks to maximize its utility. They assume that agents offer their labor power in exchange for a wage and that they purchase goods to improve their health status. Each agent has access to a means of saving and borrowing that allows them to smooth their consumption and health status over time. For the authors, a climate shock such as very high temperatures negatively affects the health stock.

Faced with this situation, agents can react by adopting two coping strategies. The first is the purchase of goods to strengthen health status. This health good may include traditional health products such as medicines or health care. It can also be a component of food consumption such as the use of cooling technologies (electric fans, air conditioning). More broadly, this health good could also represent any leisure or rest that the agent might decide to purchase in order to improve their health. This might include a decision to work indoors rather than outdoors when it is hot, or to take a lower-paying job in order to avoid working outside on a hot day. However, there are limitations on the effects of these measures since spending on health-enhancing goods in period t reduces what is left to spend on other components of utility (consumer goods).

The second form of adaptation relies on the reallocation of resources between periods. This requires agents to borrow or reduce savings during the decision period. That is, when income is temporarily low or health status is temporarily deteriorated. The ability of agents to borrow and save will allow them to smooth their consumption and health status. This is consistent with the lessons of savings and capital accumulation models, which state that access to the asset market allows consumers to smooth fluctuations in their income (Huggett, 1993 ; Aiyagari, 1994). However, borrowing and saving constraints may limit this smoothing. In such cases, the resulting impact of a weather shock on health could be substantial.

2.2 Precipitation and Health

Variation in precipitation can also have significant effects on health. The effects are manifested through nutritional status and infectious diseases. In terms of nutrition, the channel is as follows: higher levels of rainfall are associated with better harvests, stable or increased income, and therefore better access to food at lower prices. This denotes an ability of parents to provide food and medical inputs to household members (Rose, 1999 ; Maccini & Yang, 2009 ; Rabassa et *al*., 2012 ; Skoufias & Vinha, 2012 ; Cornwell & Inder, 2015). As for the transmission of infectious diseases, numerous studies have linked extreme weather events to increased incidence of these diseases (Weiss & McMichael, 2004 ; Rabassa et *al*., 2012 ; Cornwell & Inder, 2015). Climate change by altering the natural habitat of pathogens, could affect the transmission of many infectious diseases including vector-borne (malaria, hemorrhagic fever, yellow fever) and water-borne (cholera, typhoid fever) (IPCC, 2001 ; McMichael et *al*., 2003 ; 2006 ; Levy et *al*., 2016).

Rainfall anomalies can also increase mortality through crime and conflict (Miguel et *al*., 2004 ; Miguel, 2005 ; Sekhri & Storeygard, 2014). Extreme rainfall causes crop and income losses. This shock deteriorates the socioeconomic conditions of households and increases social inequalities. This situation increases resentment and generates tensions between social classes or with the state. These tensions can be at the origin of irrational behavior such as civil conflicts or the formation of armed groups perpetrating theft and crime (Sambanis, 2002 ; Miguel et *al*., 2004). Hirshleifer (1995) explains violence in terms of three interacting determinants: preferences, opportunities and perceptions. According to his model of conflict, divergent preferences and capabilities of the parties create opportunities for conflict. The perception of the likelihood of a favorable outcome in a conflict enters into the calculation of the expected net benefits of the conflict and may lead a party to choose to use violence as a strategy to satisfy their preferences. This theory emphasizes information (and perception) problems in explaining violence and foreshadows the rational choice theory of war (Fearon, 1995).

There are also studies in the literature examining the effects of rainfall shocks experienced during early childhood (Rose, 1999 ; Rabassa et *al*., 2012 ; Cornwell & Inder, 2015 ; Sivadasan & Xu, 2021 ; Le & Nguyen, 2021). The findings of these studies indicate a negative relationship between rainfall variation and children's health. It is within this framework that Cornwell & Inder (2015) developed a simple conceptual model to examine the mechanisms through which rainfall shocks affect child health. To do so, they assume that health is a function of nutrition levels in the early stages of life and negative health shocks (diseases). They consider an economy with two districts, one of which has a comparative advantage in the production of a staple food (e.g. rice) because it has relatively high levels of rainfall. For this purpose, any differences in rainfall levels between the districts may lead to higher or lower levels of production, but this would be compensated for by costless trade or movement between the districts.

On the other hand, in a situation of imperfect information with transaction costs, the variability of rainfall would have differential impacts on consumption in each district, and thus on health. This difference is explained by the inability of agents to respond immediately to the production deficit. This observation reinforces the hypothesis formulated by Maccini & Yang (2009), which states that high levels of rainfall improve nutrition and health.

In considering the pathological effect of rainfall, the authors note that rainfall levels that exceed the zone norm will potentially have an effect on disease prevalence, as normal protections (child physiological and immune systems) are insufficient. However, this positive rainfall shock can have an effect on children's health, as the availability of food at harvest time and in the following months promotes child development (Moore et *al*., 1997). This effect becomes significant during the key stages of child development, namely gestation and the first months after birth.

Also fitting into the framework of the channels through which weather shocks affect child health, Rabassa et *al*. (2012) identify two channels of transmission: illness and income. Using a health production function, the authors consider child health in a period as a function of early period health endowment, investment in child care, and exposure to the disease environment. Investment in child health is a function of nutritional intake, which is dependent on household consumption, time spent on child care, infrastructure, and the environment. Because of their poorly developed physiology and immune systems, children's exposure to diseases resulting from adverse environmental conditions can lead to deterioration in their health (IPCC, 2007).

According to the authors, the income effect is manifested through consumption and time spent on child health care. Indeed, rainfall generates income changes through its effects on agricultural production (Duflo & Udry, 2004 ; Levine & Yang, 2014). For example, an increase in income induced by a positive rainfall shock promotes consumption and a quality diet. Thus, nutritional intake can improve child health and reduce infant mortality ((Behrman & Deolalikar, 1988). However, rainfall not only causes variation in income, but also in the opportunity cost of agricultural labor time, especially for women (Miller & Urdinola, 2010 ; Kim, 2010). This can have a negative effect on children's health. The increased opportunity cost of parentes time associated with high rainfall encourages mothers to substitute their time for childcare with income-generating activities. This reduces breastfeeding time and consequently deprives children of essential nutrients for effective protection against disease (Bhalotra, 2010 ; Kim, 2010 ; Rabassa et *al*., 2012).

Moreover, the inability of households to smooth consumption in response to a negative shock may affect child health and lead to inequalities in children's human capital investment (Rose, 1999 ; Jensen, 2000 ; Sivadasan & Xu, 2021). Indeed, parental preference resulting from resource constraints (borrowing, credit) imposes a new process of resource allocation among household members. In this case, there is a differential allocation of food and health care by gender, which affects the well-being of girls more than boys (Behrman & Deolalikar, 1990). This observation is consistent with the findings of household behavior models. For example, in the common preference model with a single household utility function, differences in resource allocation arise from preferences (Thomas, 1990 ; Haddad et *al*., 1997). This behavior can lead to discrimination in children's human capital investment, which will depend on each child's ability to transform the allocated resources into the good that the household needs (Becker & Tomes, 1976 ; Akresh et *al*., 2012).

3. Data and descriptive statistics

3.1 Data

Due to the lack of availability of data on daily temperature and precipitation variation and health outcomes at the sub-national level, we choose to link annual temperature and precipitation data to health data measured at the national level.

The data in our study are mainly secondary data, coming from international institutions and organizations. They are mainly collected from the World Development Indicators (WDI) database of the World Bank, the Climate Research Unit of the University of East Anglia[1] and the Global Health Metric. This unit provides meteorological data collected at various weather stations. Global Health Metric's Global Burden of Disease estimates incidence, prevalence, mortality, years of life lost, years lived with disability, and disability-adjusted life years due to 369 diseases and injuries, for both sexes, and for 204 countries and territories. These databases have the advantage of covering the majority (if not all) of African countries on many domains. In contrast, other databases cover only a few African countries (International Country Risk

[1] http://www.cru.uea.ac.uk/data.

Guide database) and focus on a specific area (Transparency International corruption data). Despite these advantages, Williams & Siddique (2008) point out the limitations of governance indicator data. They suggest that the fact that data on institutional quality do not cover a sufficiently long period of time may limit the possibilities for time series studies or the possibility of obtaining a sufficiently large amount of information related to these data. However, this does not detract from the quality of our data. Our scope of study covers 45 countries in Sub-Saharan Africa[2] and the period 1960 to 2019. The choice of countries and time period is based on data availability.

The variables in our study are composed of health indicators (dependent variables), climate variables (variables of interest) and control variables.

- **Population Health Indicators**

The data on population health come from the World Development Indicators (WDI) of the World Bank and the Global Health Metric database[3]. We use three gender-specific health indicators, which represent our explained variables:

1. **Life expectancy at birth**: defines the number of years a newborn would live if the mortality patterns prevailing at the time of birth remained the same throughout his or her life.
2. **Adult mortality rate**: defined as the probability per 1000 individuals of dying between the ages of 15 and 60.
3. **Disability-adjusted life years** (DALYs): indicate the loss of the equivalent of one year of good health. They are calculated as the sum of years of life lost in terms of mortality and years of life lost in terms of morbidity. In this study, we used disability-adjusted life years for all causes (illness, death, injury).

These indicators are measures of general population health and are commonly used in the literature because of their availability and intuitive interpretation. The first indicator measures the general health of the population and is not related to the age structure of a country, and takes

[2] The countries in sub-Saharan Africa are : Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cabo Verde, Central African Republic, Chad, Comoros, Congo, Côte d'Ivoire, Djibouti, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritius, Mozambique, Namibia, Niger, Nigeria, Rwanda, Sao Tome and Principe, Senegal, Sierra Leone, South Africa Sudan, Tanzania, Togo, Uganda, Zambia and Zimbabwe.
[3] www.healthdata.org

into account infant and adult mortality. The second indicator measures the health of a country's working population. The last one is an indicator of health inequalities and quality of life.

- **Climate variables**

In this study, we use two climate variables from the University of East Anglia Climate Research Unit database: temperature in °C and rainfall in 1000 mm. These represent our variables of interest. These weather data are available on a 0.5 x 0.5 degree grid resolution. These variables are weighted by local population size, meaning that variation in temperature and precipitation in more populated areas are more influential when estimating their effects on national health status.

- **Control variables**

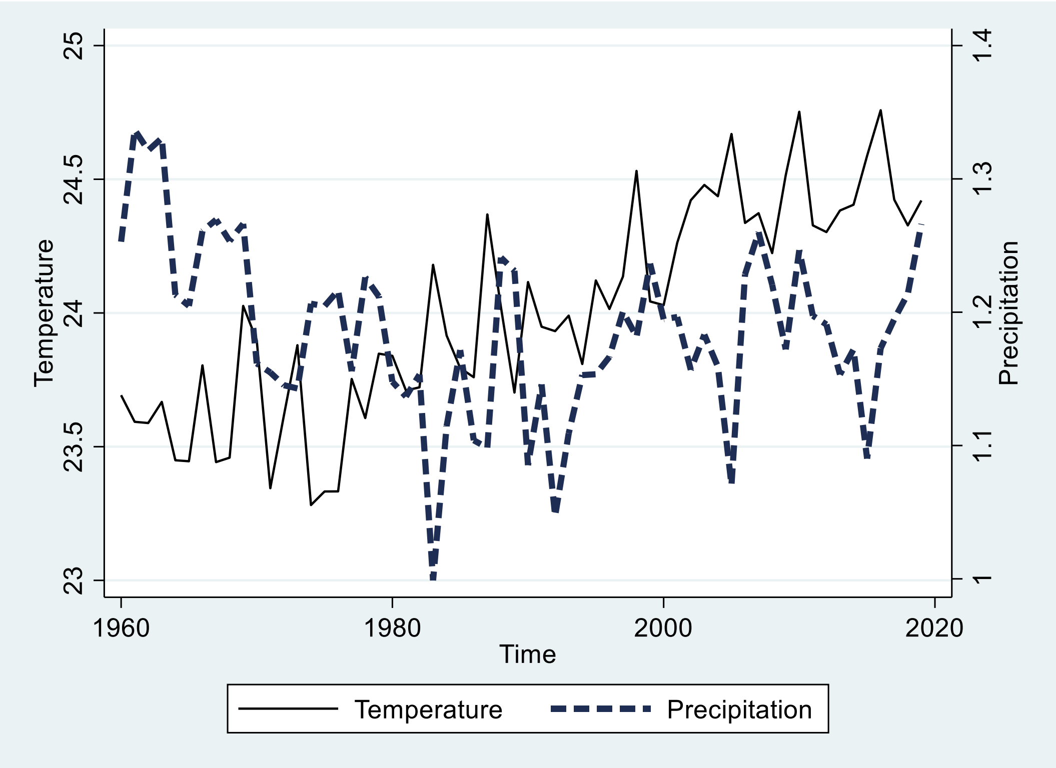
These variables are derived from the literature on the health effects of climate change (Deschênes & Greenstone, 2011 ; Deschênes, 2014 ; Geruso & Spears, 2018 ; Meierrieks, 2021). This is GDP per capita, which measures the level of income of the country. The data for this variable come from World Development Indicators of the World Bank. We also select as an institutional variable: democracy, from the database of Bjørnskov & Rode (2020). These authors consider a country to be democratic if elections have been held, if they have been free and fair, and if there has been a peaceful rotation of legislative and executive offices following these elections. Finally, we have access to public services from the V-DEM Dataset[4]. It refers to equitable access to basic public services, such as law and order, primary education, clean water and health care. The institutional variable and access to public services are used to capture adaptation measures to counter the adverse effects of climate change.

3.2 Descriptive statistics

Figure 1 shows the change in temperature and precipitation between 1960 and 2019. We see that the average temperature has increased from 23.7°C to about 24.4°C. This is consistent with the notion of climate change described by IPCC (2014). In contrast, there is no clear trend in precipitation changes. This observation is consistent with the finding of IPCC (2014), indicates that there is no clear effect of climate change on precipitation.

[4] https://www.v-dem.net/en/data/data-version-10/.

Graph 1 : **Evolution of Temperature and Precipitation, 1960-2019**.



Source: Author based on CRU data (2021)

Table 1 presents the descriptive statistics for our variables over the period 1960-2019. These statistics tell us a number of things. The statistics indicate that women have an average life expectancy of 53.23 with a standard deviation of 8.69. For men, the average life expectancy is 49.80 with a standard deviation of 8.05. This reflects a homogeneous distribution of life expectancy observations around the mean. The average adult mortality rate for women and men is 329.33 and 388.60 respectively. We also observe that women and men have the same mean in terms of disability-adjusted life years (69266.15).

Table 1: **Descriptive statistics of variables**

Variable	N	Mean	Standard deviation	Minimum	Maximum
Life expectancy at birth female	2700	53.23166	8.69145	27.571	77.89
Life expectancy at birth male	2700	49.7976	8.052151	24.834	71.3
Adult mortality female	2700	329.3255	92.14245	84.455	685.026
Adult mortality male	2700	388.6017	94.14712	143.523	753.695
Disability-adjusted life years female	1350	69266.15	29084.09	22990.95	569989.2
Disability-adjusted life years male	1350	69266.15	29084.09	22990.95	569989.2
Temperature	2700	24.0026	3.32537	12.44294	29.74882
Precipitation	2700	1.185834	0.6126265	0.0779409	3.746304
GDP per capita	2254	1698.177	2434.843	164.3366	20532.98
Democracy	2700	0.202963	0.4022797	0	1
Access to public services	2698	1.148999	0.7477819	0	4

Source: Author based on WDI, Global Health Metric and CRU (2021).

3.3 Model specification

To analyse the link between climate change and health, we start with a Becker-Grossman one-period health production function, which highlights the role of adaptation in the context of the effect of climate change on health. We then use the results to derive an expression for the effect of temperature change on health. The model presented here is inspired by Harrington & Portney (1987) and Deschênes & Greenstone (2011). For this purpose, we assume that the utility of the representative individual depends on the consumption of a single consumption good $\boldsymbol{Z_c}$, and health, or more precisely on the survival rate TS. The utility function is of the following form:

$$U = U(Z_c, TS) \qquad (1)$$

The survival rate depends on the ambient temperature $\boldsymbol{T}$ and the consumption of a market good $(\boldsymbol{Z_h})$ that maintains health by increasing the probability of survival. The expenditure of $\boldsymbol{Z_h}$ is also referred to as preventive expenditure. The production function for survival is given by:

$$\mathrm{TS} = \mathrm{TS}(\mathrm{Z_h}, \mathrm{T}) \qquad (2)$$

The good $\boldsymbol{Z_h}$ is only purchased to increase the probability of survival, so its consumption does not directly generate utility. It is defined such that $\frac{\partial \boldsymbol{TS}}{\partial \boldsymbol{Z_h}} > \mathbf{0}$. In this context, adaptation represents a process through which individuals modify their investments in $\boldsymbol{Z_h}$ in response to the climate change that occurs through the variation of $\mathbf{T}$. Thus, this variable allows adaptation to modify the relationship between temperature and health. Temperature is an exogenous variable in this model. For simplicity, we assume that high temperatures are bad for health, so that $\frac{\partial \boldsymbol{TS}}{\partial \boldsymbol{T}} < \mathbf{0}$. The individual's budget constraint is of the form :

$$Z_c + p_h Z_h = R \qquad (3)$$

Where $\boldsymbol{R}$ represents the exogenous income, and the prices of $\boldsymbol{Z_c}$ and $\boldsymbol{Z_h}$ are 1 and $\boldsymbol{p_h}$ respectively. The individual's problem is to choose $\boldsymbol{Z_c}$ and $\boldsymbol{Z_h}$ to maximise his utility under the constraints of equations (1.2) and (1.3).

$Max\ U = U(Z_c, TS)$ S.C. $\mathrm{TS} = \mathrm{TS}(\mathrm{Z_h}, \mathrm{T})$ et $Z_c + p_h Z_h = R$

The first order conditions are : $\frac{\partial U}{\partial Z_c} = \lambda \qquad (4)$

$$\frac{p_h}{\partial TS/\partial Z_h} = \frac{\partial U/\partial TS}{\lambda} \qquad (5)$$

Equation (1.4) shows that the Lagrange multiplier λ is equal to the marginal utility of income. Equation (1.5) shows that purchases of the health good $\boldsymbol{Z_h}$ are made until their marginal cost $\boldsymbol{p_h}$ is equal to the monetised value of the health time it provides. Solving the first-order conditions yields the demand equations for $\boldsymbol{Z_c}$ and $\boldsymbol{Z_h}$which are functions of the exogenous variables prices, income and temperature. In addition, it reveals the indirect utility function, V, which is the maximum utility that can be obtained given p, R, and T.

The indirect utility function $\mathrm{V} = \mathrm{V}(\mathrm{p}, \mathrm{R}, \mathrm{T})$ can be used to obtain the expression for the welfare effect of climate change, holding utility and prices constant. Consider an increase in T since climate change is assumed to increase temperatures. In this case, it is obvious that the consumer must be compensated for changes in T by changes in R when utility is held constant. We denote this function by $\mathrm{R}^*(\mathrm{T})$. The term $\mathrm{dR}^*(\mathrm{T})/\mathrm{dT}$ is the change in income required to hold utility constant for a change in T. In other words, it measures the willingness to pay (accept) for a decrease (increase) in temperatures. Since the indirect utility function is not observable so, it is useful to determine an expression for $dR^*(T)/dT$ that can be measured.

$$\frac{\mathrm{dV}}{\mathrm{dT}} = \mathrm{V}_1 \left[\frac{\mathrm{dR}^*(\mathrm{T})}{\mathrm{dT}}\right] + \frac{\partial \mathrm{V}}{\partial \mathrm{T}} = 0 \quad \text{ou} \quad \mathrm{dR}^*(\mathrm{T})/\mathrm{dT} = -\frac{\partial \mathrm{V}/\partial \mathrm{T}}{\partial \mathrm{V}/\partial \mathrm{R}}$$

Using the derivatives of V and the first order conditions of the above maximization problem, we have : $\frac{\mathrm{dR}^*(\mathrm{T})}{\mathrm{dT}} = -\mathrm{p_h}\frac{\partial \mathrm{TS}/\partial \mathrm{T}}{\partial \mathrm{TS}/\partial \mathrm{Z_H}}$ (6).

In principle, these partial derivatives are measurable. From the first-order conditions, we obtain : $\frac{\mathrm{dTS}}{\mathrm{dT}} = \left(\frac{\partial \mathrm{TS}}{\partial \mathrm{Z_h}}\right)\left(\frac{\partial \mathrm{Z_h}}{\partial \mathrm{T}}\right) + \partial \mathrm{TS}/\partial \mathrm{T} \implies \frac{\partial TS}{\partial T} = \frac{dTS}{dT} - \left(\frac{\partial TS}{\partial Z_h}\right)\left(\frac{\partial Z_h}{\partial T}\right)$ (7)

By replacing (1.7) in (1.6) and combining with $\frac{\partial \mathrm{TS}}{\partial \mathrm{Z_h}} = \lambda \mathrm{p_h} \Big/ \left(\frac{\partial \mathrm{U}}{\mathrm{TS}}\right)$ we have **:**

$$\frac{\mathrm{dR}^*(\mathrm{T})}{\mathrm{dT}} = \left(\mathrm{p_h}\frac{\partial \mathrm{Z_h^*}}{\partial \mathrm{T}}\right) - \frac{\frac{\partial \mathrm{U}}{\partial \mathrm{TS}}}{\lambda}\frac{\mathrm{dTS}}{\mathrm{dT}} \qquad (8)$$

Equation (1.8) shows that the willingness to pay/accept a change in temperature can be inferred from measured changes in $\boldsymbol{TS}$ and $\boldsymbol{Z_h}$. From this equation, we derive the total derivative of the survival function with respect to temperature $\boldsymbol{\frac{dTS}{dT}}$:

$$\frac{\mathrm{dTS}}{\mathrm{dT}} = \frac{1}{(\partial \mathrm{U}/\partial \mathrm{TS})/\lambda}\left[\mathrm{p_h}\frac{\partial \mathrm{Z_h}}{\partial \mathrm{T}} - \frac{\mathrm{dR}^*(\mathrm{T})}{\mathrm{dT}}\right] \qquad (9)$$

The term $^{(\partial U/\partial TS)}/_{\lambda}$ is the monetary value of the disutility of a change in survival rate. The first term is the partial derivative of $\boldsymbol{Z_h}$ with respect to temperature multiplied by its price. The second term is the willingness to pay/accept a change in temperature.

Econometrically, equation (1.9) can be written based on empirical work on the health effects of climate change (Deschênes & Greenstone, 2011 ; Meierrieks, 2021) as follows:

$$\mathrm{Y_{hit}} = \gamma_\mathrm{i} + \alpha_1 \mathrm{X_{it}} + \alpha_2 \mathrm{W_{it}} + \alpha_3 \mathrm{Q_{it}} + \gamma_\mathrm{t} + \gamma_\mathrm{st} + \vartheta_\mathrm{it} \qquad (10)$$

$\boldsymbol{Y_{hit}}$ means the hth measure of population health for country i in year t : is life expectancy at birth, adult mortality and disability-adjusted life years. $\boldsymbol{X_{it}}$ *and* $\boldsymbol{W_{it}}$ represent the temperature and precipitation, respectively, of country i in year t. These variables are weighted by population. $\boldsymbol{Q_{it}}$ is the set of explanatory variables (real GDP per capita, democracy, access to public services). $\boldsymbol{\gamma_t}$ is a variable accounting for common time shocks. $\boldsymbol{\gamma_{st}}$ is a variable accounting for variations in health across regions and over time. $\boldsymbol{\gamma_i}$ is the country fixed effect and refers to annual deviations of temperature and precipitation from country-specific temperature and precipitation averages. $\boldsymbol{\vartheta_{it}}$ is the error term.

- **Estimation technique**

To estimate equation 10, the literature proposes, in the case of a dynamic panel, the generalized method of moments (GMM). This method has the advantage of solving endogeneity problems which may be linked to double causality, the omission of relevant variables or the measurement error of certain variables. However, this method assumes that the coefficients of the variables are homogeneous for all countries. This single coefficient for each of the explanatory variables in the panel could suffer from a heterogeneity bias (Pesaran et *al.*, 1999). In addition, the use of this technique requires that the panel be composed of a small time period and a large number of individuals. Our panel is composed of 60 years and 45 countries.

Given these limitations, this study adopts an estimation method that takes into account the heterogeneity of the adjustment dynamics towards the long-run equilibrium. Thus, an error correction model seems appropriate. It offers three advantages over static models and restricted dynamic specifications: (i) it is easy to distinguish between short-run and long-run behaviour; (ii) we can study the forward error correction and deduce the speed of adjustment to the long-run equilibrium; and (iii) we can test the cointegration in the model by examining more closely the statistical significance of the error correction term.

Consider the following ARDL $(p, q_1, q_2, \dots, q_k)$ distributed shift autoregressive model:

$$y_{it} = \sum_{j=1}^{p} \lambda_{ij}\, y_{i,t-j} + \sum_{j=0}^{q} \delta_{ij}\, X_{i,t-j} + \mu_i + \varepsilon_{it} \qquad (11)$$

With y_{it} : the dependent variable, $X_{i,t-j}$: the vector of explanatory variables for group i, μ_i : the fixed effect, the coefficients of the lagged dependent variable are scalars λ_{ij}, δ_{ij} : vectors of coefficients, ε_{it} : error term. T must be large enough for us to estimate the model for each group, but it need not be the same for each group. If the variables are cointegrated, the error term is stationary. Thus, the error correction model is written as :

$$\Delta y_{it} = \emptyset_i y_{i,t-1} + \beta_i' X_{it} + \textstyle\sum_{j=1}^{p-1} \lambda_{ij}^{*}\, \Delta y_{i,t-j} + \sum_{j=0}^{q-1} \delta_{ij}^{*}\, \Delta X_{i,t-j} + \mu_i + \varepsilon_{it} \quad (12)$$

Where $\emptyset_i$ denotes the speed of adjustment, β_i' represents the vector of long-run coefficients. To validate the cointegration hypothesis, $\emptyset_i$ should be negative and significant. To estimate the error correction model, Pesaran et *al.* (1999) developed the Pooled Mean Group (PMG) method, allowing for heterogeneity of the short-term coefficients and homogeneity of the long-term coefficients. Indeed, the PMG estimator allows the parameters (constant, short-term coefficients and error variances) to differ freely between groups, but forces the long-term parameter to be identical for each group in the panel. In addition, the PMG is also useful for capturing cointegration and long-run relationships between variables while controlling for cross-sectional independence in the panel data. The PMG estimator is most appropriate in dynamic panel models when the period is longer than the number of countries, which is the case in this study (T = 60 > N = 45). Therefore, the PMG estimator seems more accurate for the estimation of our panel data. In order to check the consistency of the results, a comparison is made between the mean group (MG), the pooled mean group (PMG) and the dynamic fixed effects (DFE). The MG estimator does not take into account the homogeneity of certain coefficients between countries. The DFE estimator only allows the intercepts to be different between countries. For this, the Hausman test is used to choose the appropriate method between the three estimation techniques.

4. Empirical results

At this level, we first present the results of the stationarity test and then the interpretation of the results of the econometric estimates.

4.1 Stationarity test on panel

We perform the unit root test on panel data in order to check the stationarity of the variables and to be able to adopt the appropriate regression. In the case of panel data, there are several types of stationarity tests, notably the Fisher-type test, which combines the tests of Maddala & Wu (2000) and de Choi (2002), which are different second-generation tests that can be carried out on unbalanced panels. This test is adapted to our data since we have an unbalanced panel due to the lack of data for certain countries for some years of the study period. We therefore use the Fisher-type test to perform the unit root test.

Table 2 shows that adult mortality for women and men, disability-adjusted life years for women and men, GDP per capita and access to public services are non-stationary in level. These variables become stationary in first difference, hence an order of integration of I(1). However, life expectancy at birth for women and men, temperature, rainfall and democracy are stationary in level. Therefore, these variables are integrated of order I(0). The cointegration test is not performed since it is optional in the case of the PMG, since long-run homogeneity is assumed and the error correction term derived in the results attests to the existence or not of a long-run relationship (Bousmah & Onori, 2016). The results of the panel unit root test indicate that the PMG estimation technique is suitable for our study, since the variables are integrated of order I(0) and I(1).

Table 2: **Unit root test**

Variable	In level	In difference
Life expectancy at birth female	-43.1135***	-38.3135***
Life expectancy at birth male	-43.6749***	-37.8648***
Adult mortality female	10.6963	-4.6557***
Adult mortality male	11.0433	-6.0514***
Disability-adjusted life years female	-2.2954	-6.0518***
Disability-adjusted life years male	-0.1138	-0.1138***
Temperature	-22.3503***	50.0700***
Precipitation	-19.6165***	-46.5394***
GDP per capita	3.3622	-19.6246***
Democracy	-3.9231***	-22.2017***
Access to public services	1.2901	-21.0279***

Note : *** p<0.01

Source: Author based on WDI, Global Health Metric and CRU (2021).

4.2 Results and interpretation

The Hausman test is used to select the most efficient estimator among the three estimator techniques PMG, MG and DFE. This test shows that in all specifications, the PMG estimator is more efficient than the MG estimator for all three models. For comparison purposes, we also present the results obtained with the DFE model. The DFE estimator is more restrictive because it allows heterogeneity between countries only. If the imposed homogeneity is not valid, it produces biased estimates of the speed of (Robertson & Symons, 1992 ; Pesaran & Smith, 1995). Therefore, the results of the PMG estimator will be emphasised in this work, as they offer the best compromise in terms of efficiency and consistency. In all specifications, the coefficient of the error correction term (ECT) is negative and statistically significant. This result validates our error correction model and implies that the coefficients of the long-run explanatory variables are valid.

In what follows, we present the estimated effects of climate change on life expectancy at birth, adult mortality and disability-adjusted life years.

4.2.1 Effects of climate change on life expectancy at birth in sub-Saharan Africa

Our regression results on the effects of climate change on life expectancy at birth are presented in Table 3. The results obtained from the PMG estimator indicate that in the long run, temperatures have negative and significant effects on female life expectancy at birth. We found that a temperature increase of 1°C results in a decrease in female life expectancy of 4.96 years. This result supports the epidemiological hypothesis that ambient temperature is an important determinant of mortality and morbidity. This finding confirms the IPCC (2014) prediction of heavy health losses associated with climate change experienced by women on the African continent. Similarly, Meierrieks (2021) found that high temperatures reduce life expectancy at birth in the long term. The same finding was observed in the United States by Deschênes & Moretti (2009). However, we found no significant effect of temperature on long-term male life expectancy at birth.

The results also show that variations in precipitation have no significant effect on the life expectancy at birth of women and men in the long term. In the short term, however, precipitation only influences the life expectancy at birth of women. This result is consistent with the fact that due to their heavy domestic workload, women focus more on agricultural activities that are dependent on rainfall. Thus, the resulting decrease in output forces them to reduce their expenditure on food consumption and health, which may affect their health and reduce their longevity. Sekhri & Storeygard (2014) found a similar result. These authors find that rainfall shocks lead to increased female mortality, which reduces their life expectancy. Miguel (2005) also found that extreme rainfall causes an increase in murders of older women and therefore affects their life expectancy.

For our control variables, only access to public services significantly improves the long-term life expectancy of women. For men, GDP per capita and democracy contribute significantly to improving their long-term life expectancy. These results suggest that these different factors can be used as measures of adaptation to climate change. They support the hypothesis that access to public services, per capita GDP and democracy are key factors in improving the health status of the population.

Table 3: Effects of climate change on life expectancy at birth

	Life expectancy at birth					
	Female			Male		
	PMG	MG	DFE	PMG	MG	DFE
Long run						
Temperature	-4.957***	-9.425	-21.05*	0.233	18.43	-43.53
	(0.781)	(11.87)	(10.98)	(0.615)	(29.84)	(39.74)
Precipitation	-0.177	-1403	-19.61	0.0766	1.361	-42.44
	(0.449)	(17.44)	(17.00)	(0.625)	(17.98)	(37.20)
GDP per capita	-0.000588	-0.0635	2.11e-05	0.0614***	0.158	0.000519
	(0.000419)	(0.0709)	(0.00234)	(0.00375)	(0.132)	(0.00381)
Democracy	-8.021***	7.701	-6.533	2.261**	0.499	-16.01
	(1.363)	(7.771)	(15.16)	(0.899)	(4.944)	(33.15)
Access to public services	26.85***	-3.485	25.32*	-61.78***	-13.80	39.36
	(1.897)	(2.876)	(15.32)	(5.749)	(17.36)	(36.74)
Short run						
Temperature	-0.0163	-0.0834***	-0.0903***	-0.00187	-0.0927***	-0.0959***
	(0.0110)	(0.0271)	(0.0272)	(0.00942)	(0.0262)	(0.0282)
Precipitation	-0.0431**	-0.0927	-0.105	-0.0334	-0.110	-0.113*
	(0.0215)	(0.0900)	(0.0705)	(0.0213)	(0.0819)	(0.0676)
GDP per capita	0.00165***	0.00117***	6.05e-05	0.00181**	0.00132***	5.98e-05*
	(0.000621)	(0.000393)	(3.91e-05)	(0.000737)	(0.000405)	(3.58e-05)
Democracy	0.0108	0.0538	-0.0175	-0.0151	0.0298	-0.0204
	(0.0282)	(0.0872)	(0.0475)	(0.0270)	(0.0740)	(0.0496)
Access to public services	-0.0374	0.0243	0.0609	0.0213	0.0206	0.0449
	(0.0606)	(0.0519)	(0.0816)	(0.0491)	(0.0423)	(0.0709)
ECT	-0.00478*	-0.00417*	-0.00771*	-0.00221*	-0.00985*	-0.00411*
	(0.00385)	(0.00666)	(0.00441)	(0.00304)	(0.00696)	(0.00402)
Constant	-0.152	-2.982**	-3.900***	0.155	-3.932***	-4.186***
	-0.549	(1.212)	(1.510)	(0.282)	(1.279)	(1.568)
Observations	2208	.	.	2208	.	.
Hausman	PMG & MG Chi2 (4) =570.19 P-value = 0.85	MG & DFE Chi2 (4) =10.58 P-value = 0. 15		PMG & MG Chi2(4)=24.38 P-value=0.45		MG & DFE Chi2 (4) = 19.72 P-value = 0. 015

Note: Numbers in parentheses represent the robust standard errors of the estimated coefficients; *, **, *** represent significance at 10%, 5% and 1%,

Source: Author based on data from WDI, Global Health Metric and CRU (2021)

4.2.2 Effects of climate change on adult mortality in sub-Saharan Africa

Table 4 presents the results of the estimated effects of climate change on adult mortality. The results obtain from PMG show that extreme temperatures have significant effects on long-run adult mortality in SSA. These effects are most significant for men. For instance, a temperature increase of 1°C leads to an increase in the adult male mortality rate of 9.35, while for women the rate increases by 4.77. These results are important in itselves, because they show that weather fluctuations are accompanied by a decline in the working age population. This decline in the working population has socio-economic implications for a country. The decrease in the labour force leads to an increase in the cost of labour, which can, all other things being equal, slow down the productivity of companies and economic growth. These results confirm that found by Meierrieks (2021), who also showed in a sample of 70 developed and developing countries that rising temperatures increase adult mortality rates. Similarly, Burgess et *al*. (2017) find that hot days lead to a substantial increase in mortality in India over the period 1957-2000.

We also find that long-term female deaths increase in response to rainfall shocks. Estimates show that a 1 m per year decrease in rainfall results in a 3.48 increase in adult female mortality. This result can be explained by several mechanisms. The deterioration of household socio-economic conditions resulting from extreme rainfall shocks can increase social inequalities. This can lead to widespread social unrest and lawlessness, which could increase violence and crime. For instance, Sekhri & Storeygard (2014) find in their study on India that rainfall anomalies are associated with increased crimes against women. In addition, the drop in income associated with low rainfall, limits the power of the household to respond to health shocks. Consequently, vulnerable people, especially women, will be the victims. In contrast, we found no significant effect of rainfall on the mortality rate of men.

As for the control variables, the results indicate that democracy has a negative and statistically significant effect on women's mortality in the long run. This means that improved democracy contributes to a reduction in the adult mortality rate of women. It is therefore a determinant of adult mortality in SSA. However, a surprising result is the positive and significant effect of access to public services on women's adult mortality rate. Thus, access to public services does not explain adult mortality in the region. In contrast to this result, Meierrieks (2021) finds that access to public services contributes to a decrease in the adult mortality rate. In the short run, we find that GDP per capita has a significant effect only on female adult mortality.

Table 4: Effects of climate change on adult mortality

	Adult mortality					
	Female			Male		
	PMG	MG	DFE	PMG	MG	DFE
Long run						
Temperature	4.766***	-15.25	160.8	9.35***	131.8	461.5***
	(1.107)	(70.01)	(243.1)	(325)	(81.72)	(143)
Precipitation	3.480**	-419.3	49.76	190.6	37.88	180.7
	(1.673)	(284.8)	(101.7)	(137.7)	(102.1)	(237.7)
GDP per capita	0.00130***	-0.0679	0.00353	-0.00454	-0.353***	-0.00354
	(0.00025)	(0.276)	(0.00822)	(0.0326)	(0.0906)	(0.0336)
Democracy	-10.55***	5.134	-1.81	-70.35	-7.909	-60.65
	(1.806)	(33.47)	(29.12)	(200.1)	(37.11)	(199.6)
Acces to public services	30.28***	-55.28	-100.9	-284	-22.68	-283
	(2.515)	(73.66)	(161.2)	(242)	(33.02)	(231)
Short run						
Temperature	-0.389	0.913	1.917***	2.737**	1.115	1.627**
	(0.488)	(0.641)	(0.683)	(0.867)	(0.825)	(0.778)
Precipitation	-0.0303	0.0199	0.827	0.79	-1.35	0.785
	(0.7)	(1.675)	(1.304)	(1.341)	(1.959)	(1.258)
GDP per capita	-0.0290*	-0.0168***	-0.000557	-0.000732	-0.0255***	-0.000675
	(0.0161)	(0.00645)	(0.000826)	(0.000485)	(0.00942)	(0.000485)
Democracy	-0.339	-1.619	-0.319	-2.26	-1.97	-1.16
	(0.927)	(2.14)	(1.305)	(1.231)	(2.374)	(1.142)
Acces to public services	0.739	-0.741	-1.291	-0.841	-0.756	-0.837
	(1.186)	(1.129)	(1.732)	(2.109)	(1.157)	(2.069)
ECT	-0.0862*	-0.0354**	-0.0273*	-0.00978**	-0.0504***	-0.00916**
	(0.0608)	(0.0158)	(0.0428)	(0.00432)	(0.0189)	(0.00401)
Constant	9.11	48.42*	99.42***	94.32***	47.71	93.90***
	(7.704)	(25.81)	(14.69)	(41.34)	(9.13)	(31.2)
Observations	2208	.	.	2208	.	.
Hausman	PMG & MG Chi2 (4) = 0.06 P-value = 0. 996		MG & DFE Chi2 (4) = 0.08 P-value = 0. 985		PMG & MG Chi2 (4) = 0.05 P-value = 0. 874	MG & DFE Chi2 (4) = 0.07 P-value = 0. 765

Note: Numbers in parentheses represent the robust standard errors of the estimated coefficients;
*, **, *** represent significance at 10%, 5% and 1%,

Source: Author based on data from WDI, Global Health Metric and CRU (2021)

4.2.3 Effects of climate change on disability-adjusted life years in sub-Saharan Africa

The results of the econometric estimates of the effects of climate change on disability-adjusted life years (DALYs) obtained by the PMG estimator are reported in Table 5. Our results show that in the long run, temperatures have a positive and significant effect on DALYs for both women and men. However, the magnitude of the effects is more significant for men. A 1°C increase in temperature leads to an increase of 9.32 and 23.21 in disability-adjusted life years for women and men respectively. This indicates that extreme temperatures increase the years of life lost due to illness and death. All else being equal, these effects will increase health inequalities and worsen the quality of life of the population. This result confirms the one found by Chung et *al*. (2017). These authors observe that DALYs due to high ambient temperature were higher for men. The WHO (2008) study is in line with this finding. It reveals that in 2000, the burden of disease from climate change caused about 5.5 million disability-adjusted life years lost worldwide. Similarly, Zhang et *al*. (2007) find that the DALYs lost due to climate change worldwide are very high, especially in developing countries.

For our second climate variable, the results indicate a positive and statistically significant effect of precipitation on the DALYs of women and men in the long term. We found that a decrease in precipitation of 1 m per year increases the DALYs for women by 14.70. The same decrease in rainfall increases the DALYs for men by 17.20. This result shows that rainfall shocks increase years of life lived with disability or years of life lost due to death. This finding corroborates epidemiological theory which states that exposure to extreme weather conditions leads to significant reductions in health (McMichael et *al*., 2001 ; Basu & Samet, 2002 ; Levy et *al*., 2016 ; Geruso & Spears, 2018).

Our results also indicate that democracy contributes significantly to the reduction of years of life lost or lived with morbidity. This observation demonstrates that democracy is an essential factor in the fight against social inequalities, especially those of health. This result is in line with the one found by Pinzon-Rondon et *al*. (2015). The conclusion of these authors reveals that the promotion of the rule of law is a fundamental determinant of the health of individuals in a society. In contrast to this result, comparing the quality of life between India and China, Sen (2011) finds that India, which is relatively more democratic, has higher mortality rates and lower life expectancy. In contrast, in the long run, we find that access to public services does not have a significant effect on women's DALYs. This means that access to public services is not a determinant of reduced health inequalities in SSA. This result is contrary to the assertion that the quality of institutions influences people's lives more than democracy (Halleröd et *al*., 2013). As for GDP per capita, it significantly reduces DALYs for men, but not for women.

Table 5: Effects of climate change on disability-adjusted life years

Disability-adjusted life years						
	Female			Male		
	PMG	MG	DFE	PMG	MG	DFE
Long run						
Temperature	9.321**	42.451	15.221**	23.213***	-11.227	22.267***
	(7.532)	(47.722)	(6.405)	(7.432)	(21.904)	(6.522)
Precipitation	14.704*	26.056	13.611*	17.203**	-44.305	16.213**
	(8.654)	(45.359)	(7.532)	(9.105)	(29.88)	(8.206)
GDP per capita	4.311***	75.74	-2.620***	-4.612***	83.62	-3.814***
	(1.609)	(120.1)	(0.629)	(0.76)	(208.9)	(0.76)
Democracy	-13.721***	3.681	-12.826***	-16.210***	-2.33	-15.105***
	(4.264)	(3.781)	(4.264)	(5.632)	(7.44)	(4.563)
Acces to public services	7.015	6.732	7.015	9.123*	2.695	8.441*
	(4.954)	(7.419)	(4.954)	(4.837)	(4.221)	(4.837)
Short run						
Temperature	-5.794	-1.391	-5.794	-12.603	-2.763	-11.883
	(5.236)	(1.554)	(5.236)	(8.341)	(2.764)	(7.754)
Precipitation	-1.771	-677.8	-1.771	-5.16	-1.589	-4.26
	(1.909)	(1.722)	(1.909)	(4.213)	(3.142)	(3.117)
GDP per capita	-4.061*	-66.3	-4.061*	-7.342**	-112.9	-6.844**
	(2.446)	(61.57)	(2.446)	(4.017)	(108.2)	(3.047)
Democracy	-3.063	271.2	-3.063	-6.432**	359.9	-5.596**
	(2.127)	(278.6)	(2.127)	(3.512)	(378.2)	(2.658)
Acces to public services	-687.2	-327.5	-687.2	-978.3	-945.9	-845.4
	(1.756)	(504.4)	(1.756)	(3.123)	(1.051)	(2.541)
ECT	-0.388*	-0.0602***	-0.388*	-0.827***	-0.0645***	-0.617***
	(0.216)	(0.0204)	(0.216)	(0.106)	(0.021)	(0.206)
Constant	-177.402	-17.815	-177.402	-295.714*	-42.997	-395.814*
	(147.054)	(18.192)	(147.054)	(312.123)	(32.207)	(205.298)
Observations	2208	.	.	2208	.	.
Hausman	PMG & MG Chi2 (4) = 4.406 P-value = 0. 896		MG & DFE Chi2 (4) = 1.03 P-value = 0. 546		PMG & MG Chi2 (4) = 1.04 P-value = 0. 764	MG & DFE Chi2 (4) = 0.09 P-value = 0. 345

Note: Numbers in parentheses represent the robust standard errors of the estimated coefficients;
*, **, *** represent significance at 10%, 5% and 1%,
Source: Author based on data from WDI, Global Health Metric and CRU (2021)

4.3 Robustness check

To check the robustness of our results, we use alternative health indicators. For this, we choose under-five mortality and health expenditure.

4.3.1 Effects of climate change on under-five mortality

Here we use the under-five mortality rate as an alternative measure of health to check the robustness of our results. Table 6 shows that the coefficient of the error correction term (ECT) is negative and significant, so this implies that the coefficients of the long-run explanatory variables are valid. The results obtained using the PMG estimator reveal that temperatures have a positive and significant long-term effect on both girls and boys mortality. In terms of magnitude, we find that a 1°C increase in temperature leads to an increase in mortality of 12.86 for girls and 12.19 for boys. In contrast, changes in precipitation have no significant effect on long-term mortality. These results are consistent with those obtained previously. Thus, using the under-five mortality rate does not change our main results. Thus, we can argue that our previously obtained results are robust to the change in health indicator.

4.3.2 Effects of climate change on health expenditure

At this level, health expenditure is used as an alternative health indicator. The results of the estimation of the effects of climate change on health expenditure are shown in Table 6. We observe that temperatures significantly affect health expenditure in the long run. A temperature increase of 1°C causes a decrease in health expenditure of 2.28. This indicates that health losses due to climate change can undermine economic development and increase vulnerability. For example, the resulting shortfall in tax revenues can lead to reduced public investment in health, which can create a vicious circle of economic underdevelopment, poor population health, vulnerability and non-adaptation. In contrast, we did not find a significant effect of rainfall on health expenditure. As a result, we observe no difference between these results and those obtained previously, so our main results are robust.

5. Conclusion

In this study, we examined the relationship between climate change and health indicators in a sample of 45 sub-Saharan African countries over the period 1960 to 2019. We found that increasing temperatures are associated with long run health losses. Similarly, rainfall negatively influences health status. These losses are manifested in lower life expectancy at birth, higher adult mortality rates, and years of life lost due to mortality and morbidity. These results show that climate change can increase health inequalities and degrade the quality of human life. However, these health losses can be mitigated by adaptation measures. In addition, our results reveal that women are highly vulnerable to weather shocks. For example, our estimates indicate that a temperature increase of 1°C leads to a decrease in women's life expectancy of 4.96 years.

These results have implications for improving population health, reducing health inequalities and slowing climate change. For this purpose, the implementation of a resilient climate policy can reduce health losses. The policy will involve the adoption of new heat-resistant crops, which can improve agricultural production and reduce malnutrition. Also, the adoption of a water resources management approach will help meet water needs and avoid water-borne diseases. In the context of climate change, improving the quality of and access to public services, including access to financial services, can help to reduce health inequalities. These measures should be accompanied by reforestation and the use of green and renewable energy sources.

Our empirical approach provides an estimate of the total short and long run effect of climate change on health. It does not take into account the potential mechanisms through which climate change affects the health stock. We believe that it would be useful to look at the transmission channels to identify which one has the greatest effect on health. Future research can also explore the health effects of climate change by considering cause-specific disability adjusted years.

Annexe

Table 6: Effects of climate change on child mortality and health expenditure

	Mortality under five		Health expenditure
	Girl	Boy	PMG
	PMG	PMG	
Long run			
Temperature	12.86***	12.19***	-2.287***
	(2.654)	(2.713)	(0.356)
Precipitation	-0.0765	-0.0894	0.415
	(1.452)	(1.42)	(0.272)
GDP per capita	-0.0373***	-0.0376***	-9.75e-05***
	(0.00363)	(0.00369)	(2.38E-05)
Democracy	-8.251**	-7.125**	0.215
	(3.362)	(3.593)	(0.202)
Acces to public services	23.02***	19.76***	1.257***
	(4.043)	(4.421)	(0.245)
Court Terme			
Temperature	-0.107	-0.0852	0.352***
	(0.142)	(0.142)	(0.0876)
Precipitation	0.396*	0.427**	-0.410**
	(0.213)	(0.214)	(0.164)
GDP per capita	-0.0159**	-0.0164**	-0.00743***
	(0.00807)	(0.00812)	(0.00197)
Democracy	0.000464	-0.0137	0.0875
	(0.124)	(0.133)	(0.0607)
Acces to public services	0.262	0.303	0.0936**
	(0.237)	(0.257)	(0.0412)
ECT	-0.0117**	-0.0109*	-0.226***
	(0.00593)	(0.00584)	(0.0355)
Constant	-5.248***	-4.941***	12.18***
	(1.275)	(1.088)	(1.924)
Observations	2110	2110	774

Note: Numbers in parentheses represent the robust standard errors of the estimated coefficients; *, **, *** represent significance at 10%, 5% and 1%,

Source: Author based on data from WDI, Global Health Metric and CRU (2021)

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