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Implications of Climate-Related Factors on Living Standards: Evidence from Sub-Saharan Africa

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Abstract

This paper investigates the effects of climate-related factors (rainfall, temperature, floods, and droughts) on living standards through human development and its dimensions (life expectancy at birth, mean and expected years of schooling) in Sub-Saharan Africa (SSA), a region characterized by lower economic and human development. The data used span from 1996 to 2015. The findings suggest that there is an inverted U-shape relationship between human development and rainfall in non-Sahel countries. Temperature influences positively human development in non-Sahel countries, while a U-shape effect is found for Sahel countries. Droughts affect positively human development in Sahel countries. For the life expectancy at birth, there is an inverted U-shape association with rainfall in SSA countries. Floods influence positively the life expectancy at birth in non-Sahel countries, and droughts affect it positively in Sahel countries. Moreover, the findings indicate that in Sahel countries rainfall and temperature have an inverted U-shape and a U-shape effect on the expected years of schooling, respectively. Furthermore, floods affect positively the expected years of schooling in Sahel countries.

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1. Introduction

Sub-Saharan Africa (SSA) is characterized by low levels of living standards in comparison to the rest of the world, even more so, to other developing regions. According to the United Nations Development Program (UNDP), in 2014, SSA was the only region that registered below average Human Development Index (HDI) scores, while those scores had been quite similar to other developing regions throughout most of the 60s (UNDP 2015). However, since 1990 the world, in general, and SSA, in particular, have made significant progress in terms of living standards, and consequently, the number of people below the UNDP HDI threshold fell from three billion in 1990 to slightly more than one billion in 2014 (UNDP 2015). Meanwhile, poverty incidence which is an important dimension of HDI is still high in SSA. According to a growing body of literature, changes in climate conditions are found to highly correlate with living standards, and to poverty in particular. For instance, historical observations reveal that hot countries tend to be poor (Gallup *et al.* 1998; Dell *et al.* 2009). Dell *et al.* (2009) argued that 23% of the variation in cross-country income can be explained by temperature alone. The implication of this is that geographic factors can explain at least partly differences in livelihoods and in living conditions between different regions of the world. For example, an annual increase by one degree Celsius can lead to a decrease in export growth in developing countries by 2.0 to 5.7 percent, but would have almost no effect on rich countries (Jones and Olken 2010). It should be noted that institutional factors are not controlled for in all the existing studies; institutional factors are included in studies such as Gallup *et al.* (1998).

One important general finding of the climate change literature is that climate change has a huge impact on the livelihoods of the people across the world, especially in poor countries. In addition, vulnerability to poverty is found to increase with climate change and climate variability; so the probability to fall below the poverty line or remain poor if already under the line increases with climate change and variability (Adger 1999; Fujii 2016; Herrera *et al.* 2018). Carvajal (2007) finds that climate-related factors such as droughts and water security, tropical cyclones and storms, rising tides, warming seas, coral bleaching, fish stocks, melting glaciers, heat waves and cold spells have differentiated impacts on countries with various levels of human development. For the African Union *et al.* (2010), climate change increases the costs of development as well as the levels of poverty and inequity across the world, and its impacts on poverty are found to be more pronounced in tropical countries.

In SSA countries, the livelihoods of people are threatened by climate change owing to the fact that the large part of the population relies on rain-fed agriculture which is mainly extensive (Seo *et al.* 2009; Nelson *et al.* 2010; Di Falco *et al.* 2012). Health outcomes are already low in SSA and the situation is going to be exacerbated by climate change. Climate change affects health through increases in vector-borne and zoonotic diseases such as malaria, avian flu, dengue and yellow fever epidemics, and increases in water-borne diseases such as diarrhea and typhoid fever (African Union *et al.* 2010; Egbendewe-Mondzozo *et al.* 2011). According to the UNDP (2015) data, in 2013 the maternal mortality ratio amounted to 506/100,000 compared with the world average of 210/100,000 and with the one of developing countries of 225/100,000. Over the 2001-2013 period, there were on average 1.9 physicians per 10,000 inhabitants against 10.3 and 13.8 for the developing countries and for the world, respectively. Actually, the impact of climate change on farm income can affect the other economic sectors through sectoral linkages, resulting to the inability of many people to afford health care services. Moreover, climate change is also already increasing the exposure to unsafe water in Africa. Going beyond health outcomes, climate change affects and is expected to continue affecting human development in the African continent (UNDP *et al.* 2007).

This paper fits into the existing literature on climate change impact and aims at investigating the extent to which climate-related factors affects living standards and livelihoods in SSA, by also disaggregating the findings between Sahel and non-Sahel countries. The existing body of papers investigated the implications of weather, climate, climate change, and extreme events on relative economic performance (e.g., Dell *et al.* 2009; Barrios *et al.* 2010; Jones and Olken 2010; Dell *et al.* 2012), on mortality (e.g., Curriero *et al.* 2002), and on health (e.g., Egbendewe-Mondzozo *et al.* 2011; Tseng *et al.* 2009; Hasegawa *et al.* 2016). The major findings of those papers suggest that climate-related factors affect economic and social outcomes such as gross domestic product (GDP), exports, vector-borne diseases, agricultural output, and mortality. Although, there are studies that include Africa or SSA (e.g., Barrios *et al.* 2010; Egbendewe-Mondzozo *et al.* 2011; Dell *et al.* 2012), none takes into account the distinction between Sahel and non-Sahel countries. However, the economics literature on climate change has largely overlooked the impact of climate change on living standards (for example human development and its dimensions such as the gross national income (GNI) per capita, the life expectancy at birth, the mean and the expected years of schooling[1]). Therefore, the debate on the impact of climate-related factors on living standards remains open. For instance, some regions may benefit from changing in climate conditions in various dimensions of human development, while others may suffer from them. Actually, Egbendewe-Mondzozo *et al.* (2011) showed that Central African Republic, Ethiopia, and Guinea will experience a reduction in malaria prevalence due to climate change by the end of the century (2080-2100), and this may lead to an increase in the life expectancy at birth. This paper focusses on the dimensions of human development to shed light on the effects of climate-related factors on living standards. The analyses are disaggregated for Sahel and non-Sahel countries as the effects of climate-related factors may differ between these two categories of countries (Sahel countries being characterized by a tropical semi-arid climate that is mainly hot and dry throughout the year unlike for non-Sahel countries).

The remainder of the paper is organized as follows. Section 2 reviews the salient conclusions of the literature on socio-economic effects of climate change. Section 3 presents our methodology and data sources. Section 4 presents our findings, and a short section on conclusion and policy recommendations follows.

2. Climate change and living standards: a brief survey of the literature

Climate change may threaten livelihoods in SSA countries due to the fact that the large part of the population relies on rain-fed agriculture which is mainly extensive, and agriculture is the mainstay of the economies of these countries. The effect of climate change on living standards and on human development can be negative as well as positive (African Union *et al.* 2010). In fact, climate change may pave ways for opportunities to improve livelihoods (Bruckner and Ciccone 2011). The African Union *et al.* (2010) pointed out that vulnerability level of current and projected climate change is high for most countries in SSA due to lack of adaptive capacity.

Human development is "about enlarging the set of human choices - focusing on the richness of human lives rather than simply the richness of the economies" (UNDP 2015, p. 1). The dimensions of human development are classified in two which are directly enhancing human

[1] The expected years of schooling refer to the number of years of schooling that a child of school entrance age is expected to acquire if prevailing patterns of age-specific enrolment rates persist throughout the child's life.

capabilities, and creating conditions for human development (Aguna and Kovacevic 2011). Directly enhancing human capabilities includes (i) long and healthy life, (ii) knowledge, and (iii) decent standard of living. Creating conditions for human development includes (i) participation in political and community life, (ii) environmental sustainability, (iii) human security and rights, and (iv) promoting equality and social justice. The UNDP assesses human development through the HDI, which is a composite index, similar to the multidimensional approach of poverty (Sen 1976, 2004) that focuses on three basic dimensions such as a long and healthy life, measured by the life expectancy at birth; the ability to acquire knowledge, measured by the mean and the expected years of schooling; and the ability to achieve a decent standard of living, measured by the GNI per capita. Large differences within countries can be masked by national HDI values, then disaggregation may be done by countries to unmask the differences for proactive policies to provide more support to less developed areas (UNDP 2015).

Each of these three dimensions are recognized to be affected by climate-related factors. In SSA, the livelihoods of the population depend largely on agriculture. Thus, the GNI per capita is highly sensitive to climate-related factors in SSA countries (Dell *et al.* 2009; Barrios *et al.* 2010; Dell *et al.* 2012). For instance, the agricultural economics literature has proven that the performance of the agricultural sector will be reduced in most cases if nothing is done to mitigate the impacts of climate-related factors, ceteris paribus (Seo *et al.* 2009; Nelson *et al.* 2010; Di Falco *et al.* 2012). However, this literature also points out that some regions, even within the tropics, will benefit from changes in climate conditions (Seo 2013; van Wart *et al.* 2013). In urban areas, infrastructures such as roads can be hampered by natural disasters such as floods and hurricanes. In many coastal areas of SSA, people are suffering from erosion which make them homeless and oblige them to abandon their dwellings that are devastated by the sea. The GNI per capita alone cannot provide full information on living standards and on human development, and going beyond this measure is of paramount importance to establish a link between climate-related factors and living standards. For instance, the GNI provides more information on the economic performance of the countries than on living standards.

Turning to the life expectancy at birth, it is also associated with the vagaries of climate. Health outcomes and mortality are hypothesized to be affected by climate-related factors (Curriero *et al.* 2002; Tseng *et al.* 2009; Egbendewe-Mondzozo *et al.* 2011; Funari *et al.* 2012). Indeed, floods will increase the outbreak of water, vector borne and zoonotic diseases such as malaria, dengue fever, diarrhea, typhoid fever, and avian flu, among others. With droughts, access to water will be critical in rural areas, and this will affect the health of the population in many ways such as drinking unsafe water collected from rivers far away from dwellings. As many households, even in peri-urban areas, do not have access to safe drinking water, floods lead to water contamination, and therefore cause health problems to the population. Climate-related factors can also affect the intake of food, and increase the number of undernourished population (Hasegawa *et al.* 2016).

The mean and the expected years of schooling can also be affected by climate conditions. A reduction in income due to the vagaries of climate may prevent the households to afford school fees and then may lead the households to keep children at home. Moreover, in rural areas, households may be obliged to send children to look for activities that can provide the households with income to cope with the bad situation attributable to the vagaries of climate (African Union *et al.* 2010). Even in urban areas, schools may be flooded and the situation may jeopardize school activities, and therefore impacts on the ability of the pupils to acquire knowledge and to remain in the education system. With droughts, households in rural areas will be obliged to go far away to seek for water due to the low coverage of potable water sources, and this will lead to drop out children from schools.

Changes in climate conditions are caused partly by anthropogenic greenhouse gases (GHGs) attributable to human activities (IPCC 2013). For instance, human beings are partly responsible for the increase in the concentration of GHGs in the atmosphere, which thereby lead to the changes in climate conditions. Overall, climate-related factors are hypothesized to impact on human development through its dimensions, ceteris paribus.

Several control variables are used in the literature such as per capita GDP, population density, inequality index, per capita health expenditures, number of hospital beds per 1,000 people, economic policies, institutional factors, openness, number of years of civil wars, depending on the nature of the dependent variable. Improvements in factors like per capita GDP, per capita health expenditures, number of hospital beds per 1,000 people, economic policies, institutional quality, and trade openness are hypothesized to lead to better living standards (Gallup *et al.* 1998; Barrios *et al.* 2010; Egbendewe-Mondzozo *et al.* 2011). However, increases in population density, inequality index, number of years of civil wars would deteriorate living standards (Barrios *et al.* 2010; Egbendewe-Mondzozo *et al.* 2011).

3. Material and methods

In this paper, we use a similar methodology as the one from Dell *et al.* (2009). However, there are some challenges to be accounted for, especially regarding the fact that the HDI index cannot be negative, it is bound by 0 and 1. Therefore, accounting for this is important and the preferred estimator may be the two-sided model (Honoré and Leth-Petersen 2006; Alan *et al.* 2011). Certainly, estimating the HDI index by the ordinary least squares (OLS) may yield predictions of the index outside of the interval $[0,1]$. The empirical model used is then specified as follows:

$$HDI_{it} = \beta X_{it} + \delta L_{it} + \alpha_i + \gamma_{it} \quad (1)$$

where X is the vector of climate-related factors (average annual temperature, annual total rainfall, floods, and droughts), L is the vector of control variables, β and δ is the vectors of parameters associated with X and L, respectively, α_i represent the country fixed effects, and γ_{it} is the error term assumed to be independently and identically distributed. Following the literature review, the control variables include per capita GDP, and institutional factors such as political stability and absence of violence / terrorism, government effectiveness, and control of corruption.

This econometric setting accounts for time-invariant correlated heterogeneity (fixed effects). Actually, controlling for correlated unobserved fixed factors is likely to be important in the context of this paper, as human development is likely to be influenced by time-invariant factors (at least in the short run), such as other geographic factors (elevation, slope, and landlocked). Alan *et al.* (2011) developed the estimation procedure of panel data regression models with two-sided censoring or truncation. The method is the generalization of the approach of the one-sided truncation or censoring of Honoré (1992) which is based on Powell (1986).[2]

After estimating the model with HDI as dependent variable, models are estimated to investigate the extent to which climate-related factors affect each dimension of human development individually, replacing the dependent variable by the indicators capturing each dimension, except

[2] Panel data regression models with two-sided censoring or truncation developed by Alan *et al.* (2011) can be implemented with STATA 'two_side' (version 0.1) available at: www.princeton.edu/~honore/stata.

the GNI per capita. In this paper, the estimation is not going to be run for GNI per capita as numerous papers have already done it. Thus, the model is estimated for the life expectancy at birth, the mean and the expected years of schooling. The model can be specified as follows:

$$Y_{it}^{*} = \theta X_{it} + \rho L_{it} + \pi_i + \varphi_{it} \tag{2}$$

where Y represents the life expectancy at birth, the mean or the expected years of schooling depending on the equation. The observed value of Y is given by:

$$Y = \begin{cases} Y^{*} \; if \; Y^{*} > 0 \\ 0 \; if \; Y^{*} \leq 0 \end{cases} \tag{3}$$

Due to the fact that the dependent variables cannot be negative, these models can be estimated using a Tobit model with fixed effects as suggested by Honoré (1992).[3]

We expect that increases in rainfall will be associated with an improvement in human development with the effect expected to be non-linear (an inverted U-shape effect). The same expectation holds for temperature. For extreme events (floods and droughts), the effects are expected to be either positive or negative, as a climate shock may induce direct and indirect effects in the economy. Indeed, extreme events may affect adversely some economic agents, and some others may take advantage from the fact that the extreme event affects the former adversely through the rises in prices, ceteris paribus. GDP per capita and institutional factors are expected to influence positively human development. The likely endogeneity of climate-related factors are not accounted for in this paper, even though there may be reverse causality from human development to changes in climate conditions. For instance, the contribution of SSA to the emissions of GHGs is low. Thus, the reverse causality is considered as weak. Two specifications of the models are estimated depending on the inclusion of climate variables (linear and quadratic terms), and extreme events (floods and droughts). The first specification includes linear and quadratic terms of rainfall and temperature, while the second specification takes into account linear terms of rainfall and temperature, and the occurrence of extreme events. Thus, the second specification helps to capture the effects of the occurrence of floods and droughts on living standards. As the effect of climate-related factors may differ between Sahel and non-Sahel countries, this paper complements the analyses with a disaggregation across these two groups of countries. In fact, the Sahel region is characterized by a tropical semi-arid climate that is mainly hot and dry throughout the year, which makes the countries of this region different from the remaining SSA countries.

The data we use are from different sources. Data on extreme events (floods, and droughts) are collected from the Emergency Events Database (EM-DAT) of the Centre of Research on Epidemiology of Disasters in Brussels (CRED) (Guha-Sapir *et al.* 2016). The CRED classifies disasters into two categories which are natural and technological. Natural disasters include floods and droughts. In the CRED's classification, the natural disaster category is divided into six sub-groups namely geophysical, meteorological, hydrological, climatological, biological, and extraterrestrial. The CRED records hydrological floods and climatological droughts. In the CRED's terminology, a hydrological hazard is caused by the occurrence, movement, and distribution of surface and subsurface freshwater and saltwater, while a climatological disaster is caused by long-lived meso to macro-scale atmospheric processes ranging from intra-seasonal to

[3] Fixed effects Tobit models can be implemented with STATA 'pantob' (version 0.6) available at: www.princeton.edu/~honore/stata.

multi-decadal climate variability. Historical climate data (monthly rainfall and temperature) are collected from the World Bank Climate Change Knowledge Portal[4]. HDIs are collected from the UNDP. The mean and expected years of schooling are from the United Nations Educational, Scientific and Cultural Organization (UNESCO) Institute of Statistics.[5] Institutional factors are from the Worldwide Governance Indicators (WGI).[6] The remaining data are from the World Development Indicators (World Bank, 2015). Forty six SSA countries are accounted for in the estimations, among which nine belong to the Sahel region (Appendix 1). The study period spans from 1996 to 2015 due to data availability, especially the availability of institutional data.

4. Results and discussion

Table I reports the descriptive statistics on the variables used in the paper, with disaggregation between Sahel and non-Sahel countries. As already stated two specifications of the models are estimated depending on the inclusion of climate-related factors. Table II presents the estimation results of the model of human development, and the two specifications are overall significant. The effect of rainfall on human development is non-monotonic for the full sample, and for non-Sahel countries (Model 1). Indeed, the finding suggests that human development improves with rainfall up to a certain level and then declines (an inverted U-shape relationship). Temperature has a positive effect on human development in SSA (on average), and in non-Sahel countries. The effect of temperature on human development is convex for Sahel countries (U-shape effect). Model 2 suggests that droughts are positively associated to human development in SSA and in Sahel countries. The effect of droughts for Sahel countries is consistent with the convex effect found for temperature. Normally, droughts are expected to influence negatively human development as they are supposed to jeopardize economic activities. These findings indicate that the positive effects of droughts on human development in some regions outweigh the negative ones. However, using micro-level data may provide information on the disparities of the human development effects of droughts across geographic units within the countries. Therefore, these findings reveal the non-monotonic effects of rainfall and temperature as pointed out by numerous papers. GDP per capita is found to influence positively human development irrespective to the specification. Among the institutional factors, the effect of political stability and absence of violence / terrorism is positive for non-Sahel countries, and negative for Sahel countries regardless the specification. Thus, political stability and absence of violence / terrorism is beneficial for human development in non-Sahel countries. It should be noted that the difference between Models 1 and 2 lies in the fact that the former helps to detect above which level rainfall and temperature will be detrimental to human development (because more rain means floods, and the lack of rainfall or excessive temperature will lead to droughts), while the latter captures the influence of extreme events (floods and droughts). We now turn our attention on the effect of climate-related factors on the dimensions of human development.

Estimations are thus run for the dimensions of human development except for GNI per capita to shed light on the variation of the results across these dimensions. Table III reports the estimation results for the life expectancy at birth. The direction of the effects of climate-related factors on the life expectancy at birth are almost similar to those on human development. Model 1 reveals that increases in rainfall have non-monotonic effect on the life expectancy at birth for SSA countries

[4] http://sdwebx.worldbank.org/climateportal/index.cfm?page=downscaled_data_download&menu=historical
[5] http://data.uis.unesco.org/#
[6] http://info.worldbank.org/governance/wgi/#home

like for human development. Unlike for human development, the effect of floods is positive and significant on the life expectancy at birth for SSA and non-Sahel countries (Model 2). Similarly for human development, life expectancy at birth gains from increases in drought events in Sahel countries. A positive and significant effect is found for GDP per capita only for Sahel countries. Political stability and absence of violence / terrorism, and control of corruption influence positively and significantly the life expectancy at birth in non-Sahel countries. However, these two institutional factors impact negatively and significantly on the life expectancy at birth in Sahel countries.

Table I. Descriptive statistics of the variables

Variables		**Mean**			**Standard Deviation**	**Minimum**	**Maximum**
		SSA	**Sahel**	**Non-Sahel**			
HDI	Overall	0.473	0.407	0.490	0.104	0.21	0.77
	Between				0.096	0.309	0.75
	Within				0.042	0.296	0.536
Life expectancy at birth	Overall	53.778	53.491	53.859	6.954	27.08	74.23
	Between				5.881	41.754	72.593
	Within				4.156	32.897	69.787
Mean years of schooling	Overall	4.404	2.630	4.827	2.093	0.7	9.94
	Between				2.025	1.296	9.401
	Within				0.525	1.532	7.214
Expected years of schooling	Overall	8.330	5.428	9.148	2.874	2.07	14.14
	Between				2.301	3.97	12.555
	Within				1.535	4.622	12.872
Rainfall	Overall	1077.497	567.242	1205.609	595.791	144.5	2796.7
	Between				589.605	181.349	2475.431
	Within				119.101	409.927	1660.198
Temperature	Overall	24.695	27.940	23.881	3.156	12.32	30.92
	Between				3.141	13.357	28.865
	Within				0.530	23.030	34.568
Floods	Overall	0.571	0.654	0.552	0.906	0	7
	Between				0.453	0	1.654
	Within				0.787	-1.083	5.917
Droughts	Overall	0.131	0.159	0.125	0.341	0	2
	Between				0.119	0	0.385
	Within				0.320	-0.253	1.747
GDP per capita	Overall	1803.24	786.318	2068.827	2865.196	115.794	20333.94
	Between				2614.8	249.191	10103.94
	Within				1198.331	-7570.471	12276.49
Political stability and absence of violence / terrorism	Overall	-0.570	-0.825	-0.506	0.948	-3.315	1.282
	Between				0.876	-2.732	1.022
	Within				0.384	-2.314	0.848
Government effectiveness	Overall	-0.793	-0.879	-0.771	0.599	-2.446	1.020
	Between				0.574	-2.139	0.538
	Within				0.190	-1.557	0.013
Control of corruption	Overall	-0.650	-0.731	-0.629	0.624	-1.869	1.217
	Between				0.596	-1.605	0.943
	Within				0.204	-1.629	0.479

Table II. Two-sided model with fixed effect of human development

Variables	SSA		Sahel		Non-Sahel	
	Model 1	**Model 2**	**Model 1**	**Model 2**	**Model 1**	**Model 2**
Rainfall	1.24e-04**	3.52e-05*	-1.11e-04	-5.39e-06	1.18e-04**	3.22e-05
	(5.44e-05)	(2e-05)	(9.09e-05)	(1.23e-05)	(5.97e-05)	(2e-05)
Rainfall^2	-2.94e-08**		4.21e-08		-2.71e-08*	
	(1.34e-08)		(3.99e-08)		(1.47e-08)	
Temperature	0.062*	0.006	-0.671***	0.009	0.068*	0.006*
	(0.034)	(0.004)	(0.222)	(0.012)	(0.040)	(0.003)
Temperature^2	-0.001		0.012***		-0.001	
	(0.001)		(0.004)		(0.001)	
Floods		-0.001		0.003		-3.05e-04
		(0.002)		(0.003)		(0.003)
Droughts		0.010***		0.015***		0.008
		(0.004)		(0.005)		(0.006)
GDP per capita	1.14e-05*	1.08e-05*	1.16e-04***	1.51e-04***	9.99e-06*	9.78e-06*
	(6.41e-06)	(6.16e-06)	(1.79e-05)	(3.61e-05)	(5.51e-06)	(5.55e-06)
Political stability	0.017	0.016	-0.033***	-0.032***	0.036***	0.037***
	(0.014)	(0.014)	(0.006)	(0.007)	(0.012)	(0.012)
Government effectiveness	-0.019	-0.020	-0.019	0.002	-0.015	-0.016
	(0.033)	(0.032)	(0.026)	(0.033)	(0.041)	(0.039)
Control of corruption	0.012	0.019	0.024	0.003	0.006	0.010
	(0.029)	(0.032)	(0.019)	(0.016)	(0.030)	(0.032)
Fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	247	235	48	42	199	193
χ^2	22.62	33.34	2159.79	1973.08	34.52	28.73
$Prob > \chi^2$	0.004	0.000	0.000	0.000	0.000	0.000

Note: $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. Standard Errors in parentheses.

For the mean years of schooling, the two specifications are overall significant for Sahel countries, and only Model 1 is for non-Sahel countries.[7] The estimation results for the expected years of schooling are presented in Table IV, with the findings suggesting that the two specifications are overall significant. For Sahel countries, Model 1 advocates that rainfall and temperature have an inverted U-shape and a U-shape association with the expected years of schooling, respectively. GDP per capita is found to influence positively and significantly the expected years of schooling for SSA and non-Sahel countries. However, political stability and absence of violence / terrorism leads to the decrease in the expected years of schooling in SSA, and this is the same for Sahel countries. The negative effect of this institutional factor for SSA (on average) is somehow due to the positive and non-significant effect in non-Sahel countries. With Model 2 the similar findings are obtained for GDP per capita, and political stability and absence of violence / terrorism. In addition, floods lead to positive and significant effect on the expected years of schooling in Sahel countries.

[7] Thus, the estimation results for the mean years of schooling are not reported (these results are available upon request). Model 1 shows that only the coefficient associated to the quadratic terms of rainfall is positive and significant for Sahel countries, while for non-Sahel countries, temperature has a concave effect (an inverted U-shape association) and political stability and absence of violence / terrorism has a positive effect on the mean years of schooling. Moreover, only GDP per capita influences positively and significantly the mean years of schooling in Sahel countries (Model 2).

Table III. Tobit model with fixed effect of life expectancy at birth

Variables	SSA		Sahel		Non-Sahel	
	Model 1	**Model 2**	**Model 1**	**Model 2**	**Model 1**	**Model 2**
Rainfall	0.010*	0.001	0.004	0.005**	0.006	4.53e-04
	(0.005)	(0.001)	(0.011)	(0.002)	(0.007)	(0.001)
Rainfall^2	-2.62e-06**		-3.90e-07		-1.45e-06	
	(1.33e-06)		(5.71e-06)		(1.90e-06)	
Temperature	-2.844	0.457	-0.632	-0.483	-2.822	0.417
	(5.227)	(0.337)	(0.980)	(1.026)	(2.555)	(0.660)
Temperature^2	0.063		0.015		0.066	
	(0.102)		(0.452)		(0.047)	
Floods		0.377**		0.107		0.318**
		(0.170)		(0.316)		(0.150)
Droughts		-0.236		1.628***		-0.746
		(0.387)		(0.541)		(0.511)
GDP per capita	4.85e-04	0.001	0.004***	0.005***	3.82e-04	3.63e-04
	(5.91e-04)	(0.001)	(0.001)	(0.002)	(2.81e-04)	(2.26e-04)
Political stability	1.196	1.447	-1.703	-2.152*	2.709***	2.792***
	(1.314)	(1.657)	(1.483)	(1.221)	(0.940)	(0.837)
Government effectiveness	-2.415	-2.223	0.164	0.689	-2.812	-2.256
	(1.857)	(1.658)	(3.288)	(3.450)	(2.597)	(2.396)
Control of corruption	1.820	2.656	-3.952***	-4.436***	3.945	4.302**
	(3.308)	(3.019)	(1.298)	(1.534)	(2.478)	(1.860)
Fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	676	644	141	125	535	519
χ^2	177.09	36.76	1973.73	15799.58	154.30	38.83
$Prob > \chi^2$	0.000	0.000	0.000	0.000	0.000	0.000

Note: $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. Standard Errors in parentheses.

Overall, we infer that rainfall have an inverted U-shape effect on human development (SSA and non-Sahel countries), on the life expectancy at birth (SSA), and on the expected years on schooling (Sahel countries). This indicates that rainfall is beneficial to human development and its dimensions up to a certain level and then the effect becomes negative; with differences between Sahel and non-Sahel countries. In fact, rainfall is important for agricultural activities (agriculture being of paramount importance for the economies of SSA countries), but beyond a certain level rainfall jeopardizes agricultural activities. Nevertheless, annual flood events affect positively the life expectancy at birth (SSA and non-Sahel countries), and the expected years of schooling (Sahel countries). Thus, the positive effects of flood events outweigh the negative ones, and this leads to the overall positive effect. For temperature, a positive effect is found on human development for non-Sahel countries, and a U-shape effect on human development and on the expected years of schooling is found for Sahel countries. This advocates that increases in temperature are not detrimental to human development in non-Sahel countries. However, human development and the expected years of schooling deteriorate with temperature in Sahel countries up to a certain level and then increase. A positive effect is found for annual drought events on human development and the life expectancy at birth in Sahel countries. Actually, Sahel countries are more exposed to droughts compared to non-Sahel countries, and the results mean that Sahel countries turn the threats from droughts into opportunities for improvement in human development and in the life expectancy at birth. It appears that the effects of climate-related factors differ across the dimensions of human development. The detrimental effect of institutional factors on human development in Sahel countries indicates that institutions are more effective in non-Sahel countries than in Sahel countries. It may also be due to the low level of institutional quality in those countries.

Furthermore, the findings imply that the different SSA countries require different set of institutions to promote long-term human development.

Table IV. Tobit model with fixed effect of expected years of schooling

Variables	SSA		Sahel		Non-Sahel	
	Model 1	**Model 2**	**Model 1**	**Model 2**	**Model 1**	**Model 2**
Rainfall	2.37e-04	-3.93e-04	0.007*	0.001	-2.66e-04	-0.001
	(0.002)	(3.76e-04)	(0.004)	(0.002)	(0.002)	0.001
Rainfall^2	-2.00e-07		-4.18e-06*		-1.27e-07	
	(8.37e-07)		(2.17e-06)		(7.64e-07)	
Temperature	0.292	0.358**	-11.077**	-0.250	-0.019	0.318
	(0.635)	(0.163)	(4.697)	(0.506)	(1.315)	(0.248)
Temperature^2	0.002		0.198**		0.008	
	(0.012)		(0.082)		(0.031)	
Floods		0.088		0.248*		0.034
		(0.067)		(0.136)		(0.076)
Droughts		0.010		0.419		-0.122
		(0.150)		(0.301)		(0.225)
GDP per capita	6.42e-04**	0.01**	0.001	0.003	5.81e-04**	0.001**
	(3.21e-04)	(2.65e-04)	(0.001)	(0.004)	(2.66e-04)	(2.41e-04)
Political stability	-0.674**	-0.732**	-1.623***	-1.557***	0.051	0.072
	(0.338)	(0.332)	(0.255)	(0.401)	(0.607)	(0.606)
Government effectiveness	-0.057	-0.142	0.040	0.830	0.440	0.447
	(0.845)	(0.836)	(0.954)	(0.943)	(1.282)	(1.319)
Control of corruption	0.187	0.380	-0.831	-1.264	0.577	0.577
	(0.928)	(0.872)	(0.741)	(0.845)	(0.904)	(0.873)
Fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	293	281	71	60	222	221
χ^2	51.32	34.84	8548.29	9.46e+09	18.72	16.39
$Prob > \chi^2$	0.000	0.000	0.000	0.000	0.016	0.037

Note: $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$. Standard Errors in parentheses.

The influence on human development that we infer from the findings is relatively in line with the findings on pure economic outcomes such as economic growth, capital accumulation, and total factor productivity. For instance, for Skidmore and Toya (2002), natural disasters decrease the expected rate of return to physical capital, but increase the relative return to human capital. They also found that natural disasters also provide the incentive to update the capital stock and adopt new technologies, leading to enhancements in total factor productivity. Cuaresma *et al.* (2008) found that the degree of catastrophic risk tends to have a negative effect on the volume of knowledge spillovers between industrialized and developing countries, and only countries with relatively high levels of development benefit from capital upgrading through trade after a natural catastrophe. Therefore, the findings of the paper confirm the need to investigate the influence of climate-related factors on human development along with its dimensions which goes beyond the scope of pure economic outcomes.

5. Conclusion and policy implications

This paper provides an empirical analysis aimed at investigating the extent to which climate-related factors affect human development and its dimensions in SSA, characterized by lower economic and human development. To avoid biased estimations, the nature of the HDI (the index is bound by 0 and 1) is taken into account through using the estimation procedure of panel data regression models with two-sided censoring or truncation developed by Alan *et al.* (2011). Turning to the dimensions of human development, as they cannot take negative values (left side censored nature), we use the approach of the one-sided truncation or censoring of Honoré (1992) which is based on Powell (1986). Our results show an inverted U-shape effect of rainfall on human development in SSA and non-Sahel countries. Temperature has a positive effect on human development in SSA and non-Sahel countries, while it has a U-shape effect on the HDI in Sahel countries. Droughts affect positively human development in SSA and Sahel countries. The findings reveal also that the life expectancy at birth is affected by rainfall in SSA in the form of an inverted U-shape effect. Floods are found to influence positively the life expectancy at birth in SSA and non-Sahel countries, and the effect of droughts is positive in Sahel countries. Furthermore, the findings reveal that in Sahel countries rainfall and temperature have an inverted U-shape and a U-shape effect on the expected years of schooling, respectively. For Sahel countries, floods affect positively the expected years of schooling. The control variables have in some extent significant effects on human development and its dimensions. GDP per capita influences positively human development in SSA, and this effect is consistent for Sahel and non-Sahel countries. Nevertheless, GDP per capita has a positive effect on the life expectancy at birth only in Sahel countries. Regarding the expected years of schooling, a positive effect of GDP per capita is found for SSA and non-Sahel countries. Political stability and absence of violence / terrorism affects positively human development in non-Sahel countries, whereas its effect is negative in Sahel countries. In addition, political stability and absence of violence / terrorism, and control of corruption influence positively and negatively the life expectancy at birth in non-Sahel and Sahel countries, respectively. For the expected years of schooling, the effect of political stability and absence of violence / terrorism is negative in SSA and Sahel countries.

Appendices

Appendix 1. List of countries

Angola	Congo	Guinea-Bissau	**Nigeria**	South **Sudan**
Benin	Cote d'Ivoire	Kenya	Rwanda	Togo
Botswana	Democratic Republic of Congo	Lesotho	Sao Tome and Principe	Uganda
Burkina Faso	Equatorial Guinea	Liberia	**Senegal**	Tanzania
Burundi	**Eritrea**	Madagascar	Seychelles	Zambia
Cameroon	Ethiopia	Malawi	Sierra Leone	Zimbabwe
Cape Verde	Gabon	**Mali**	Somalia	
Central African Republic	**The Gambia**	Mozambique	South Africa	
Chad	Ghana	Namibia	Swaziland	
Comoros	Guinea	**Niger**	Sudan	

Note: Sahel countries are in bold.

Adaptation measures are therefore necessary to offset the negative implications of climate-related factors on human development. These adaptation measures should be country-specific by accounting for the structure of the economies, in order to be able to have the desired impact on human development. As the agricultural sector is an important contributor to employment and to economic growth in SSA countries, and is mainly done by subsistence small-holder farmers, policies should target the development of irrigation technologies, the use of improve varieties of seeds which are resistant to droughts, and the promotion of fertilizer use. Efforts should be made to prevent the population to contract water and vector-bone diseases, especially during the rainy season such as malaria, diarrhea and typhoid fever. Improvement in institutional quality should be promoted by accounting for the specificities of the countries. Moreover, efforts towards mitigating the emissions of anthropogenic GHGs would help to limit the changes in climate conditions attributable to human activities as advocated by the 21st Conference of the Parties (COP) held in Paris in 2015. Further paths of research in this topic could include disaggregated analysis to provide insights on the distribution of the impacts within the countries. To render this disaggregated analysis possible data availability on the dimensions of human development is needed across geographic units within the countries.

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