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RESEARCH

Climate Change and Tourism in Sub-Saharan African Countries

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Abstract

This article assesses the effects of climate change on tourism for a sample of 45 Sub-Saharan African countries, using a Two-Way Fixed Effects (TWFE) estimator, based on country-time fixed effects panel data model over the period 2000–2020. Two key findings emerge: (i) climate change significantly reduces tourism activities in SSA; (ii) The effects of climate change on tourism activities transit through water availability, information and communication technologies (ICT), conflicts, and deforestation. We recommend (i) the implementation of mitigation and adaptation strategies of the tourism sector in the face of climate change, such as the storage and efficient management of available water; (ii) the choice of tourist destinations with less polluting transport means; (iii) the production of agricultural products less vulnerable to extreme climatic conditions; and (iv) the control of corruption, the preservation of peace and security within tourists' destinations.

Keywords Climate Change · Tourism · Two-Way Fixed Effects · Transmission channels · SSA

JEL Classification Q54 · L83 · O55 · C23

1 Introduction

Tourism is defined as the attraction and experience that actors have of touristic sites and destinations Soica [1]. According to the United Nations World Tourism Organization [2], tourism is a cultural and economic phenomenon in which people go to countries or places outside their usual environment for personal or professional reasons. It is a lever for stimulating economic growth and promoting cultural and natural heritage [3]. Tourism's contribution to the Gross Domestic Product (GDP) of SSA countries is 8.5%, while tourism export earnings have more than tripled from $14 billion to nearly $47 billion between 1995 and 2014 [3]. However, intra- and inter-state conflicts, political instability [4], and diseases[1] [5] make Africa a risky tourist destination. In addition, the special report of the Intergovernmental Panel on Climate Change [6] specifies that the effects of climate change in Africa are degrading the coasts, the beaches of which are an attraction for tourists. Indeed, the World Meteorological Organization [7] indicates that the African continent is facing the problem of climate change, following an increase in average temperatures on the surface of the globe. With an average increase of 0.3 °C per decade, the warming between 1991 and 2021 was greater than the average 0.2 °C per decade that occurred during the period between 1961 and 1990.

At the same time, the theory of vulnerability to climate change developed by Adger [8] highlights the negative effects of climate change on tourism. In addition, it highlights the exposure and sensitivity of tourists to climate shocks, as well as their ability to adapt.

Empirical work on the impact of climate change on tourism is controversial [9]. Indeed, we distinguish, on the one hand, work that highlights the positive effects of climate change on tourism and, on the other hand, work that highlights the negative aspects. Works such as those by Goh [10] and Kaján and Saarinen [11] show that landscape beauty, in the context of climate change, has a positive effect on tourism. Similarly, Rosselló-Nadal [12] and Muñoz et al. [13] show that an increase in temperature to an acceptable threshold favours the arrival of tourists from cold countries.

[1] For example, according to the World Tourism Organization (UNWTO, 2020), the implementation of barrier measures and restrictions in SSA led to a 69% decline in tourist arrivals in 2020.

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Conversely, several studies suggest that the increased intensity of extreme weather events and shocks reduces tourism by negatively affecting the image of many tourist destinations [14–19]. Given these divergent studies on this issue, we propose to empirically examine the impact of climate change on tourism in SSA to enrich the debate in this literature. Recent studies indicate that increasing temperatures and droughts, resulting from insufficient rainfall, are diminishing tourism in Sub-Saharan Africa [20, 21].

Despite this observation, the literature tells us that, in Africa, there is a lack of empirical work on the question that needs to be addressed [20–24]. Indeed, apart from the many works on the effect of tourism on African economic growth, most of the works dealing with the effect of climate change on tourism adopt the literature review judgemental approach that adds nothing to the debate [25].

Moreover, very few studies employ water availability [26], conflicts [27], and deforestation [28] as transmission channels to investigate the relationship between climate change and tourism. Furthermore, to our knowledge, no study identifies ICTs as a transmission channel between climate change and tourism. Indeed, to make tourists less vulnerable to climate change, ICT can help provide accurate information not only about the weather observed in the tourist area but also about the attractiveness of that tourist area.

On the methodological dimension, Rosselló and Santana-Gallego [9] shows that models linking climate change and tourism, like models of change in physical conditions [29] and models based on the index of climate tourism [30], suffer respectively from the problem of the non-linear behaviour of tourists and lack of data. Moreover, it shows that tourism demand models [10, 14, 31–33] have made it possible to solve this problem by introducing climatic variables.

Therefore, considering the theoretical, empirical, and methodological frameworks, this article is positioned as a major contribution to the issue and has a triple contribution: (i) it makes it possible to fill the gaps in the literature left by the limited number of empirical works regarding the impact of climate change on tourism in Africa; (ii) it identifies water availability, ICTs, conflicts, and deforestation as transmission channels between climate change and tourism; (iii) it uses a fixed effects panel data model inspired by the work of Gonseth [34] and Rosselló and Santana-Gallego [9], which capture unobserved climatic and non-climatic phenomena that can influence tourism.

The rest of the article is structured as follows: Section 2 presents the stylised facts, Section 3 outlines the literature review, Section 4 presents the methodological strategy, Section 5 presents and discusses the results, and Section 6 concludes and suggests some recommendations.

2 Stylised Facts

In this study, we present three main stylised facts: the persistence of climate change in SSA, the evolution of the tourism sector in the region, and an analysis of the correlation between these variables.

2.1 The Persistence of Climate Change in SSA

According to the World Meteorological Organisation [35], climate change, also known as climate trend, is defined as the variation in temperature and precipitation over a given period. Thus, an increase in temperature indicates global warming, while a consistent decrease in precipitation trend corresponds to drought [36]. From the above, it can be said that climate change is persistent in SSA if we look at the trend in temperature and precipitation variations in Fig. 1. Between 2000 and 2020, the variation in average temperatures rose from 2 to 2.15 °C, an increase of 0.15 °C in 21 years. Similarly, observation of the trend in precipitation variation indicates a significant drop in precipitation between 2000 and 2020.

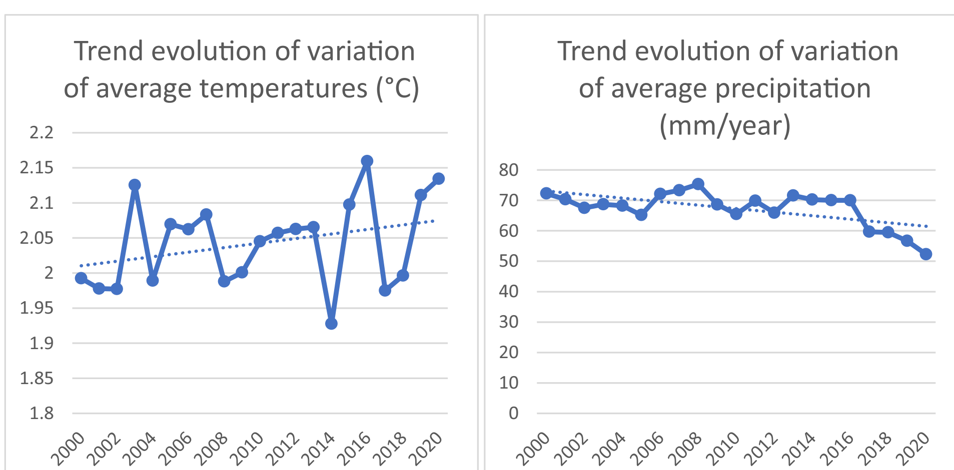

Fig. 1 Evolution of temperatures (°C) and precipitation (mm/year) in SSA. Source: Author's using data from the Climate Change Knowledge Portal (CCKP, 2021)

According to the African Development Bank [37], climate change in SSA is characterised by extreme drought and irregular rainfall. As such, these analyses are consistent with the IPCC [6] findings, which indicate that the African continent is facing the problem of climate change due to an increase in the Earth's average surface temperature [6]. Furthermore, our analyses are consistent with the United Nations report [38], which observed a 20% decrease in rainfall patterns in SSA in 2020. Overall, these analyses of the persistence of climate change in SSA are validated by the World Meteorological Organization's [39] report on climate change, which identifies West Africa, the eastern Sahel, the Horn of Africa, and parts of southern Africa as the subregions most affected by climate change.

2.2 Mixed Performance of the Tourism Sector in SSA

Figure 2 shows a significant increase in tourism activity (number of tourist arrivals) in SSA between 2000 and 2021. In fact, according to the World Travel and Tourism Council [40], Africa received almost 33.8 million visitors in 2012, compared to an estimated 6.7 million visitors in 1990. According to the World Bank [41], this increase is due to the region's abundant natural and cultural resources. However, the tourism sector in SSA experienced disruptions between 2008 and 2010 following the 2008 global crisis and irregularities in 2016 due to political instability, terrorism, and pandemics such as Ebola or COVID-19.

However, the development of tourism in SSA remains very heterogeneous from one country or group of countries to another. Referring to the information contained in Appendix 4 Table 14, it remains obvious that South Africa has a highly developed tourism sector, with tourist arrivals estimated at 16,436,236, despite the drop observed in 2020 (i.e. 600,000 tourist arrivals).

Furthermore, for tourist arrivals of between 1,032,255–6,974,160 in 2000 and 228,000–1,492,000 in 2020, tourism is well developed in countries such as Malawi, Ghana, and Mozambique, but relatively higher in Nigeria. Similarly, in countries such as Zimbabwe, Gabon, Côte d'Ivoire, Cameroon, Ghana, Liberia, and Equatorial Guinea, the tourism system is moderately developed, with tourist arrivals ranging from 639,000 to 1,342,957 in 2000 to 1,967,000–711,000 in 2020. Furthermore, in countries such as Southern Sudan, Côte d'Ivoire, Gabon, and Mali, the tourism sector is underdeveloped, with tourist arrivals estimated at 7000–900,510 in 2000 and 86,000–38,000 in 2020. Finally, in the countries comprising Comoros, Mauritania, Chad, and Namibia, the tourism sector is underdeveloped, with tourist arrivals between 7000 and 187,100 in 2000 and 24,000–759,000 in 2020. However, it should be noted that some countries that do not have a significant tourism sector have made a qualitative leap in terms of tourist arrivals between 2000 and 2020. These include Eritrea, Benin, Zimbabwe, Somalia, and the Comoros, whose tourism growth rate averaged 2% between 2000 and 2020, and countries such as Namibia and Chad, where the sector grew by 3% over the same period. There has been a significant decrease in the rate of tourism growth in all SSA countries, except for those mentioned above.

However, in addition to economics and security factors, climate change has already been identified by the World Tourism Organization [2] as one of the main causes of the decline and disparity of tourism activities in SSA. The

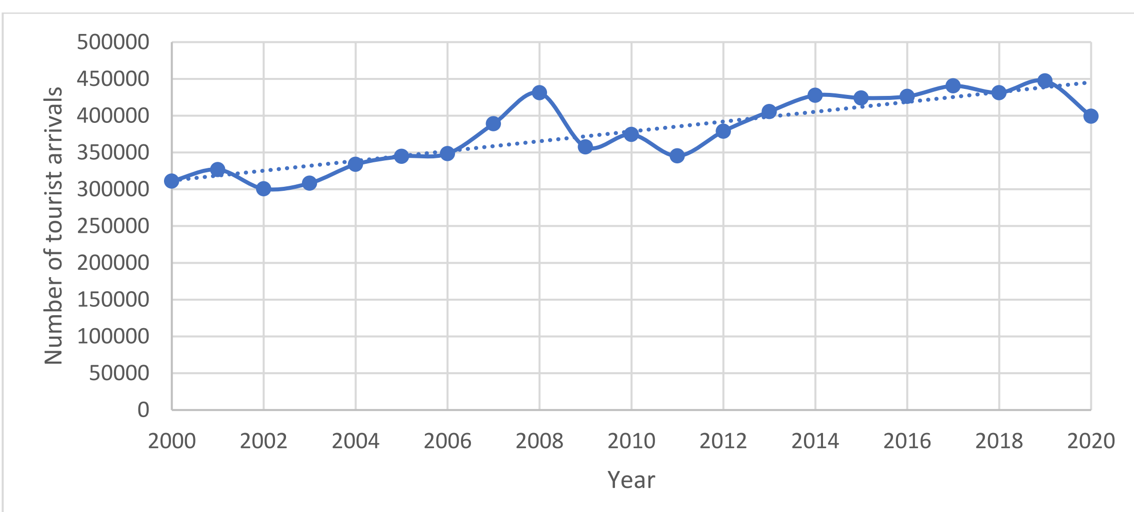

Fig. 2 An irregular evolution of the tourism sector in SSA. Author's construction

following section aims to analyse the relationship between climate change and tourism in SSA.

2.3 Climate Change and Tourism Are Linked in SSA

Figure 3 shows the correlation between climate change and tourism in SSA. There is a negative correlation between variation of temperature levels and tourism arrivals. Indeed, tourist arrivals are those of Western foreigners, who are highly vulnerable to extreme temperatures [2]. Also, there is a positive correlation between rainfall and tourism arrivals, depicted by a decrease in rainfall that reduces ecotourism by destroying certain animal and plant species sought by tourists [2]. According to the African Development Bank [37], Sub-Saharan Africa is characterised by extreme drought and erratic rainfall, which are not conducive to the practice of tourism activities. Furthermore, the conclusions of the International Monetary Fund's [42] work indicate that tourism activities in SSA are experiencing a drastic decline due to climate change.

3 Literature Review

This section presents the theoretical framework, as well as a synthesis of empirical work on the effects of climate change on tourism.

3.1 Climate Change and Tourism: The Theory of Vulnerability as a Theoretical Foundation

The link between climate change and tourism has its foundations in the theory of the vulnerability of a system to climate change developed by Adger [8]. Indeed, following the rise in temperatures and sea level, the tourism sector as a system is confronted in the short term with the problem of the decline in tourist receipts and in the long term, with the disappearance of tourist destinations [43]. For Füssel and Klein [44], the theory of the vulnerability of the tourism system in the face of climate change can be explained based on three concepts. First is exposure, which indicates that tourist destinations are exposed to climate change because of their geographical location. Then, sensitivity, which measures the degree of reaction of the tourist system to climate change. And the ability of the tourism system to adapt to the adverse effects of climate change.

3.2 Climate Change and Tourism: Empirical Work

We distinguish a review of empirical work on the direct and indirect effects of climate change on tourism.

3.2.1 Direct Impacts

The work of Rosselló-Nadal and Santana-Gallego [9] highlights the controversial effects of climate change on tourism. With this in mind, we construct our review of empirical work on the positive and negative effects of climate change

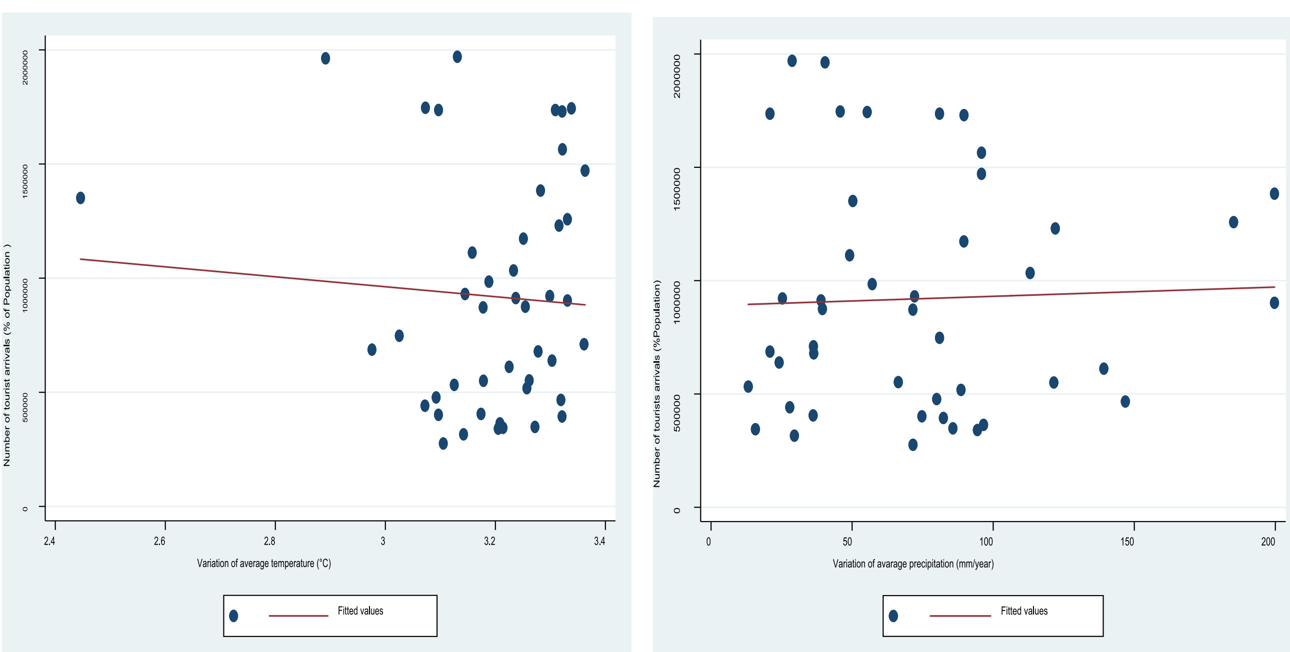

Fig. 3 Links between climate change and tourism in SSA. Author's construction

on tourism, on the one hand, and offer a synthesis of work on this topic in the African context, on the other.

Indeed, the work of Rosselló-Nadal [12] shows that climate change caused by rising freezing temperatures has a positive effect on tourism, as it will lead to an increase in travel to colder countries for travellers interested in winter tourism. Furthermore, Rosselló-Nadal and Santana-Gallego [9] show that an increase in temperatures to an optimal threshold of 15.7 °C in destination countries favours the arrival of international tourists. Furthermore, Muñoz et al. [13], in an analysis by country of origin (i) and country of destination (j), show that national tourist flows increase when the temperature level in the country of destination (j) is higher than in the country of origin (i). They also conclude that if rainfall is more abundant in the country of origin (i), international tourist flows will increase in the country of destination (j), since unfavourable rainfall conditions at home increase the probability of travelling to another region.

Finally, Kájan and Saarinen [11] show that climate change has made it possible to beautify the landscape and increase tourist flows by reducing winter snowfall in Finland. In the same vein, Goh (2012) shows that 73% of British households surveyed believe that the beauty of the landscape associated with climate change makes it possible to increase tourist flows. Recent studies such as those by Lončarić et al. [45] and Mäntymaa et al. [46] show that the beauty of the landscape, the quality of nature linked to climatic conditions, contributes to an increase in tourist activity.

However, several studies have highlighted the adverse effects of climate change on tourists' travel decisions. Hamilton et al. [14] show that the sunshine on summer beaches in Western Europe due to rising temperatures reduces European tourist flows to Mediterranean areas. In the same vein, Bigano et al. [15] and Bigano et al. [16] show that tourists prefer sunny but mild climates and are not in favour of extremely high temperatures or relatively cold climates. Amelung et al. [17] examine the potential impact of climate change on global tourism, with a particular focus on seasonality. He concludes that tourists will only travel to regions with favourable climatic conditions as a result of climate change. Like the above-mentioned works, Rosselló-Nadal and Santana-Gallego [9] show that increased precipitation hurts tourism, as tourists prefer sunny destinations. However, they show that once a maximum temperature threshold is exceeded, tourists from cold countries travel less and less. Conversely, below a minimum temperature threshold, tourists from hot countries will be reluctant to travel to northern countries. Following abnormal rainfall, summer floods, characterised by the disruption and social distress they cause, discourage visits to tourist sites [47]. Furthermore, the increase in temperatures associated with the 2003 European heatwave led to population dehydration and forest fires, which reduced tourism activities, especially in the Mediterranean region [48]. Thus, an increase in temperatures of + 2 °C above normal will lead to an increase in extreme heat episodes, affecting the tourism industry [48, 49].

As for SSA, climate change and its impacts on housing, national security, water supply and quality, health, agriculture, and food remain a threat to the sustainability of the tourism sector in Africa [50]. Tourism stakeholders are increasingly concerned about the persistence of extreme weather events that could wipe out African tourist destinations [24]. In the case of Zimbabwe, for example, many of Africa's most iconic natural tourism destinations, such as the St. Lucia Wetlands Park, Victoria Falls, and the Serengeti National Park, are affected by future travel due to climate change [24]. Dubé and Nhamo [22] point out that climate change, combined with rising temperatures and lack of rainfall, is reducing the attractiveness of certain natural tourism sites in Africa.

As a result, the work of Hoogendoorn and Fitchett [25], conducted in the African context, indicates that tourists have an aversion to destinations where thermal discomfort linked to rising temperatures is beyond the level of human comfort. Gössling et al. [51] show that in the Zanzibar region of Tanzania, humidity combined with high temperatures led to a relative decline in tourist arrivals. On the other hand, in the Okavango Delta of Botswana, excessively high temperatures harmed tourism operators, as outdoor activities that could not be air-conditioned, such as boat and canoe rides, were often cancelled [52]. In addition, the migration of wildlife species following the increase in extreme temperatures in Kenya may have reduced safaris, which are considered a key tourism activity in the region [52]. In addition, coral bleaching associated with rising temperatures is reducing diving-related tourism in the Seychelles.

The impact of rainfall on tourism activity remains highly controversial. Indeed, the aridification of the Okavango Delta due to the absence of precipitation reduces nautical tourism activity [53] and modifies the decision to travel [54]. In addition, the conditions of aridification associated with the lack of rainfall have significantly altered faunal diversity, reducing safari in Etosha Park in Namibia, where 75% of tourism is based on game viewing [55]. Reduced rainfall is also threatening floral biodiversity in Nigeria [56] and facilitating the emergence of animal diseases such as distemper virus in East Africa [57]. However, some work shows that abundant rainfall can reduce outdoor tourism activities [58]. For example, cyclones and storm surges have reduced the attractiveness of South Africa to tourists because of the predominance of nature and beach-related activities in that country [55]. Building on the observation that studies linking climate change and tourism are lacking in Africa [25], a recent study by Dubé et al. [21] shows that increasing risks associated with climate change, such as rising temperatures and droughts, are negatively affecting tourism activities.

In light of the above, this article aims to enrich the literature on the impact of climate change on tourism in SSA and to improve understanding of the issue to promote resilient tourism. Indeed, as developing countries, SSA countries have other immediate policy and development concerns and do not have sufficient capital and expertise to enhance the tourism sector's capacity to adapt to climate change.

From the above, and given that the trend of climate change in SSA is towards increasing temperatures and decreasing precipitation [36], we formulate the following:

Hypothesis 1: Climate change, characterised by increasing temperatures and decreasing rainfall, reduces tourism activity in SSA.

3.2.2 Indirect Effects

The effect of climate change on tourism transits through four transmission channels such as water availability, ICTs, conflicts and deforestation.

For Scott and Lemieux [59], any study of the relationship between water and tourism must take into account the effects of climate variability. Indeed, Medstat [60] indicates that we need to know more about the management of water resources in tourism, especially during dry periods. Therefore, it is clear that ineffective management of available water can increase the possibility of water supply crises in tourist destinations, especially in adverse climatic situations [26] and vice versa. Several studies agree on the fact that the unavailability of water due to climate change can generate conflicts between resident populations and tourists within a locality [26]. Due to climate change, and specifically due to water scarcity, conflicts can not only lead to economic losses for the tourist destination [27] but also deter tourists from returning to the area in the short term destination [61].

A handful of studies use deforestation as a transmission channel between climate change and tourism. Otrachshenko and Nunes [28] show that climate-induced bushfires harm the number of tourist arrivals. Moreover, it is supported by Kilungu et al. [62] who reveal that changes in temperature and precipitation through vegetation modification reduce tourist activities. Finally, the work of Uchegbu and Kanu [63] shows that the rise in temperature decreases the vegetation, the African species of which are the most popular with tourists.

To our knowledge, no studies use ICTs as a transmission channel between climate change and tourism. On the one hand, some works show that the use of (ICTs) has harmful effects on the environment such as greenhouse gas emissions and climate change [64], while others use ICTs as solutions for adapting to climate change [65]. On the other hand, Ruggieri and Calò [66] indicate that the use of ICTs increases tourist activity because it contributes to the promotion of destinations better than in the past, especially in cases where management problems exist. From the above, we formulate the following hypothesis:

Hypothesis 2: The effects of climate change on tourism pass through water availability, conflicts, ICTs and deforestation

4 Methodology of the Study

The methodology of our study is presented in three subsections: the presentation of the model, variables and data, and the estimation technique.

4.1 The Model of the Study, the Variables, and the Data

Rosselló-Nadal [12] identifies three main models to quantify the effect of climate change on tourism: The Physical and Environmental Condition Assessment Model, The Tourism Climate Index (TCI) Model[2], and the tourism demand model[3]. The limitations granted to these models are respectively: first, the inability to accurately predict future tourism demand due to the non-linear attitude of tourists towards climate change, and to provide a quantitative and qualitative measure of the impact of climate change on tourism [12], then the unavailability of data, especially in Africa [25], and finally, the inability to analyse the effect of climate on tourism in the long term, and to find a utility function adapted to tourism [67].

We thus retain as a conceptual model the Hamburg tourism demand model (HTM) of Hamilton and Tol [67] noted:

$$\ln A_i = f\left(G_i, T_i, T_i^2, C_i, lnY_i\right), \tag{1}$$

where $\ln A_i$, G_i, T_i, C_i, and $\ln Y_i$ represent respectively for the country i the logarithm of the number of tourist arrivals, the geographical surface in Km^2, the annual average temperature level in degrees centigrade, the length along the coast, and the logarithm of per capita income.

However, the introduction of climatic variables in these models does not resolve the issue of omission of variables from which econometric models suffer. We therefore specify a panel data model to reduce collinearity problems thanks to the introduction of the temporal and individual dimensions [68].

[2] Developed by Mieczkowski (1985)

[3] They are broken down into a time series model (Goh, 2012), a choice model (Lancaster, 1966; Morley, 1992), and aggregate tourism demand models (Hamilton, Maddison and Tol, 2005a, 2005b)

Thus, inspired by the work of Gonseth [34] and Rosselló and Santana-Gallego [9], we construct a panel data model with country-time fixed effects for 45 SSA countries (see Appendix 1) over the period 2000 to 2020. Moreover, for this specification, the results of the Hausman tests (in Appendix 2 Table 6) justify the choice of a fixed effects model rather than a random effects model.

The model is written as follows:

$$Tourism_{it} = \beta + \gamma CC_{it} + X_{it}\lambda + \psi_i + \rho_t + \varepsilon_{it} \quad (2)$$

As Dube et al. [20], the tourism variable is approximated by the number of international tourist arrivals as a percentage of the population [38]. Like Scarlett [69], we believe that measuring tourism in terms of tourist arrivals (%population) allows us to account for the scale effect of tourism specialisation. This variable is taken from the World Bank database [38].

CC_{it} is the matrix of climate change variables, including variations of average temperature and variations of average precipitation. These variables, measured in degrees Celsius (°C) and millimetres (mm/year), respectively, are obtained by applying the standard deviation to the monthly average temperature and precipitation [70]. For Mendelsohn [71], the variation in temperature and precipitation refers to climate variability, which indicates the extent to which weather conditions can differ from 1 year to the next. In addition, these data come from the geo-referenced database of the World Bank Group's Climate Change Knowledge Portal [72], where most of the information comes from North American institutions such as the National Center of Atmospheric Research (NCAR) and the International Research Institute of Columbia University.

X_{it} is the matrix of control variables including remittances, agricultural production, wheat price volatility, foreign direct investment, control of corruption, education, and GDP per capita.

Remittances represent the remittances of migrants and the share of income earned abroad. These are net current transfers from abroad equivalent to unrequited transfers of income from non-residents to residents. Remittances from official migrants represent only a small portion of the transfers that circulate the world. Mora-Rivera and García-Mora [73] state that tourism increases when households receive higher remittances.

Agricultural production, measured by the Faostat [74] Agricultural Production Index, represents the changes in agricultural production, which gives the total volume of agricultural production for each year in the country. Huller et al. [75] indicate that agricultural production positively influences tourism since these are the products that could be marketed in the tourism sector.

Wheat price volatility derived from monthly Faostat [74] measures how much and how quickly the price of wheat changes over time. We are interested in the wheat price volatility obtained by calculating the standard deviations[4] on monthly wheat consumer price index data[5]. Hanafiah and Harun [76] found that an increase in the consumer price index leads to a decrease in the number of people visiting a country.

Foreign Direct Investments are taken from the World Bank database [38] and correspond to the net investment inflows to acquire a lasting stake (10% or more of the shares with voting rights) in a company operating within an economy other than that of the investor. Studies by Al-Hallaq et al. [77] indicate that FDI is a catalyst for tourism activity.

Control of corruption obtained from the World Governance Indicator database [78] represents perceptions of the extent to which public power is exercised for private gain, including both petty and grand forms of corruption, as well as the 'capture' of the state by elites and private interests. Unlike the International Risk Guide Country database [79] for the Political Risk Services, it provides more comprehensive information on a larger number of countries. Alola et al. [80] show that the control of corruption positively influences tourism in the long term.

Education is measured by the secondary school enrollment rate [38]. For Ejiofor et al. [81], education has a positive influence on tourism.

Gross Domestic Product per capita represents the gross value added or wealth created in an economy divided by the population at mid-year. This database is taken from the World Development Indicator [38]. The works of Eugenio-Martin and Campos-Soria [82] show that income positively affects tourist activity.

Note, however, that using panel data models with country-time fixed effects has several advantages. Indeed, fixed effects models are preferable to cross-sectional models because they combine temporal and individual dimensions to mitigate potential endogeneity problems [83, 84]. Hill et al. [85] argue that fixed effects models can help reduce omitted variable endogeneity by controlling for unobserved heterogeneity across individuals in the panel. Indeed, as in this paper, we show that the introduction of the individual dimension ψ_i makes it possible to attenuate unobserved heterogeneity, that is, to take into account unobservable and quantifiable variables that are likely to influence tourism, such as the reputation

[4] As in Minot (2014), it is a question of calculating the standard deviation of the return noted $\sigma(r)$ with $r = \log(Pt/Pt\text{-}1)$, and Pt and Pt-1, the prices at period t and t-1.

[5] According to the World Tourism Organization (UNWTO and ILO, 2013), the rise in the price of wheat was at the origin of the food riots of the years 2008, the implications of which for the tourism sector were devastating.

and beauty of the landscape. Furthermore, the introduction of the specific time effect ρ_t makes it possible to capture shocks that may be common to the countries in the panel, such as macroeconomic imbalances and exchange rate fluctuations. However, even if the fixed effects model controls for endogeneity issues related to unobserved heterogeneity and omitted variables, its main limitation is that it does not fully resolve endogeneity when the source is reverse causality [86].

4.2 Descriptives and Statistics Analysis

Table 7 in Appendix 2 summarises information on descriptive statistics, variable definitions, data sources, and expected signs. Moreover, correlation analysis (Appendix 2 Table 8) indicates a positive correlation between tourism arrivals and certain explanatory variables such as variation of average precipitation, migrant remittances, agricultural production, FDI, corruption, education, water availability, total population, ICT, economic growth rate, and ethnic and linguistic diversity. In addition, there is a negative correlation between tourism arrivals and variation of average temperature, conflicts, wheat price volatility, and deforestation. In addition, the low correlation between most of the explanatory variables in the model would indicate a presumption of the absence of multicollinearity. This intuition is confirmed by the Variance Inflation Factor (VIF) multicollinearity test (Appendix 2 Table 9). Indeed, the results show that the VIF values are less than 5%, indicating that there is no multicollinearity between the explanatory variables of the model.

4.3 Estimation Technique

We are inspired by the work of Leitão and Shahbaz [87], who recommend the One-Way fixed effects estimator to address the issues of serial correlation and endogeneity between variables. However, recent studies on climate issues in general, and the link between climate change and tourism in particular [34], recommend the use of fixed effects that include specific individual and temporal factors. This technique, better known in the literature as two-way fixed effects [86, 88], is used to attenuate the unobserved heterogeneity between individuals in the panel. Thus, like Gonseth [34], we show that the introduction of the individual dimension accounts for unobservable variables that are likely to influence tourism, such as the reputation and beauty of the landscape. Furthermore, the introduction of the specific time effect allows us to capture shocks that may be common to the countries in the panel, such as macroeconomic imbalances and exchange rate fluctuations. The choice of this estimation technique is validated by the Fisher test[6], which tests for heterogeneity between individuals in the panel. Furthermore, the robustness of this estimation technique is tested by the non-parametric method of the explanatory variables of lags 1 and 2 [89] and by the System Generalised Method of Moments (S-GMM) [90].

5 Baseline Findings

Our main results focus on the direct and indirect effects of climate change on the tourism sector in SSA.

5.1 The Direct Effects of Climate Change on Tourism and Potential Transmission Channels

5.1.1 The Main Direct Effect Results

The results presented in Table 1 suggest that climate change is reducing tourism in SSA. Indeed, in specification 1, we find that rising temperatures reduce tourism activity. Thus, a 1 °C increase reduces tourism activity by 0.861%. Furthermore, a decrease in precipitation of 1 mm/year reduces tourism by 0.761% in specification 1.

Rising temperatures reduce nature-related tourism by facilitating the migration of certain wildlife species useful for safaris [34]. Moreover, in line with Hoogendoorn and Fitchett [25], the dry and hot climate prevalent in SSA is often uncomfortable for international tourists. Furthermore, in an African context characterised by low rainfall, tourist activities such as boat or canoe trips and floral species exploration are impractical [56]. Finally, like Reid et al. [57], we believe that the absence of water facilitates the emergence of animal diseases harmful to tourism, such as the distemper virus in East Africa.

These results are consistent with the theory of climate vulnerability [8], which allowed us to highlight the vulnerability of the tourism system to climate change. From an empirical view, the findings align with the work of Dubé and Nhamo [22] and Dubé et al. [21], who show that rising temperatures reduce tourism activity in SSA while decreasing rainfall reduces it. Indeed, tourism in SSA, considered as so-called nature tourism, remains vulnerable to climatic shocks. First, manifestations of climate change in Africa, such as abnormal weather conditions and declines in water supply and quality, are likely to reduce tourism activity, which has become essential for SSA countries. Manifestations of climate change lead to the emergence of tropical diseases such as malaria and yellow fever, which reduce tourism activity. In addition, droughts due to reduced rainfall in SSA raise

[6] F(21,911) = 8.92; Prob > F = 0.0000.

Table 1 The main direct results and potential transmission channels

Independent variables	Dependent variable: tourism arrivals (%population)					
	Direct effect	With potential channels				
	(1)	(2)	(3)	(4)	(5)	(6)
Variation of average temperature	− 0.861***	− 0.845***	− 0.841***	− 0.857***	− 0.768***	− 0.839***
	(0.0728)	(0.0755)	(0.0730)	(0.0731)	(0.0707)	(0.0740)
Variation of average precipitation	0.761***	0.710***	0.740***	0.746***	0.733***	0.750***
	(0.0617)	(0.0618)	(0.0609)	(0.0610)	(0.0607)	(0.0621)
Remittances	− 0.00223	0.00190	− 0.00147	− 0.00133	− 0.00368	0.000898
	(0.00676)	(0.00701)	(0.00669)	(0.00656)	(0.00653)	(0.00653)
Agricultural production index	− 0.000880	0.140	− 0.00413	− 0.0355	− 0.295	− 0.179
	(0.447)	(0.454)	(0.432)	(0.446)	(0.435)	(0.458)
Wheat price volatility	− 0.141***	− 0.165***	− 0.141***	− 0.138***	− 0.0723	− 0.109**
	(0.0511)	(0.0524)	(0.0502)	(0.0508)	(0.0486)	(0.0502)
Foreign direct investment	0.0145***	0.0151***	0.0148***	0.0154***	0.0130**	0.0148***
	(0.00378)	(0.00391)	(0.00381)	(0.00368)	(0.00390)	(0.00343)
Control of corruption	0.213***	0.229***	0.210**	0.194**	0.335***	0.199**
	(0.0823)	(0.0842)	(0.0831)	(0.0863)	(0.0928)	(0.0839)
Education	0.346***	0.320***	0.293***	0.330***	0.278***	0.341***
	(0.0649)	(0.0643)	(0.0697)	(0.0670)	(0.0659)	(0.0678)
Gross domestic product per capita	− 0.0440	− 0.0577	− 0.0377	− 0.0754*	− 0.121***	− 0.0817*
	(0.0418)	(0.0419)	(0.0423)	(0.0411)	(0.0411)	(0.0429)
Water availability		0.195***				
		(0.0598)				
Deforestation			− 0.0864**			
			(0.0408)			
Conflicts				− 0.205***		
				(0.0365)		
Internet					0.128***	
					(0.0257)	
Phone						0.0591***
						(0.0172)
Constant	7.355***	7.011***	7.023***	7.646***	8.549***	8.153***
	(0.854)	(0.851)	(0.832)	(0.858)	(0.869)	(0.894)
Countries fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
R-square	0.247	0.258	0.251	0.276	0.277	0.258
Fisher	15.85***	16.11***	17.08***	14.53***	15.85***	16.21**
Observations	945	894	894	894	945	945
Number of countries	45	45	45	45	45	45

Standard errors in parentheses. Asterisks denote significance: *$p < 0.1$. **$p < 0.05$. ***$p < 0.00$. Author's construction

the issue of water supply, which remains a major concern for African tourism. Indeed, the decline in rainfall regimes, characterised by a reduction in the supply of surface water, reduces tourism. In addition, so-called African nature tourism depends essentially on these water sources for irrigating gardens, ponds, swimming pools, spas, and all the other facilities that contribute to the well-being of tourists.

Furthermore, Eq. (1) highlights the effect of control variables such as migrant remittances, agricultural production, wheat price volatility, foreign direct investment, control of corruption, education, and economic growth.

Thus, in specification 1, our results, contrary to those of Mora-Rivera and García-Mora [73], indicate that migrant remittances received by SSA populations do not affect tourism. This result is justified by the fact that most of the diaspora resources obtained by the populations of SSA are intended to reduce their economic, social, and climatic vulnerabilities. In other words, migrant remittances are often used to meet basic needs such as healthcare, food, clothing, and coping with natural disasters. However, it contradicts the work of Hüller et al. [75] which show that agricultural production does not affect tourism in SSA. Agricultural production in Africa is subsistence production, the technology of which does not allow the production of goods to be marketed in the tourism sector. We show that a unit increase in agricultural price volatility reduces tourism by 0.141%. Close to the work of Hanafiah and Harun [76], this result depicts that the sensitivity of tourists to the fluctuation of the relative prices of a good from the country of departure to the country of arrival leads them to choose the destination with high purchasing power. In parallel with the work of Al-Hallaqet et al. [77], our results indicate that a unit increase in FDI will increase tourism by 0.0145% in SSA. This is because the availability of financial support intensifies the development of the tourism sector, especially in the case of capital-intensive activities of tourism projects that require huge start-up costs.

In the same line as Alola et al. [80], we find that a unit increase in corruption control leads to a 0.213% increase in tourism in SSA. Controlling corruption helps to reduce transaction costs for tourists during their stay, such as free access to all information related to the destinations chosen by tourists and police harassment. In line with the work of Ejiofor et al. [81], we find that education has a positive impact on tourism in SSA. Thus, each increase in the educational attainment of a unit increases tourism by 0.346%.

Finally, and contrary to the work of Eugenio-Martin and Campos-Soria [82], we find that economic growth, as measured by GDP per capita, has no impact on tourism in SSA. In addition to the inadequate infrastructure and financial resources required by the tourism sector, we believe that this result is also justified by the less significance given to tourism in various development policies. In fact, in these economies, tourism is part of the tertiary sector related to services and is not as important as the primary sector such as agriculture [91].

5.1.2 Potential Transmission Channels

Our main findings show that climate change reduces tourism activity in SSA. This finding was supported by the theory of climate vulnerability [8], which highlights the exposure and sensitivity of the tourism sector to climate shocks. Furthermore, these results were justified by the empirical work of Dubé and Nhamo [22] and Dubé et al. [21], which recognise that rising temperatures and decreasing rainfall reduce tourism activity.

However, it is accepted in the literature that climate change may indirectly affect tourism. From the point of view of the economic literature, this effect passes through variables that are considered to be direct determinants of the dependent variable [92]. Among these variables, whose description is given in Table 7 in Appendix 2, we find water availability [23], conflicts [93], and deforestation [94]. As other direct determinants of tourism, we include ICT, which plays an essential role in popularising tourist sites and reducing the cost of access to information [51, 66]. From an empirical point of view, the choice of these variables is justified by the fact that very few studies have identified them as transmission channels. In particular, to the best of our knowledge, ICTs have never been used as a transmission mechanism between climate and tourism. From an econometric point of view, the introduction of these variables makes it possible to reduce any possible omitted variables bias.

The results presented in Table 1 (specifications 2 to 6) confirm the expected impact of the different determinants of tourism in SSA. Indeed, like Dubé and Nhamo [23], our results indicate that water availability, especially water from river basins, groundwater and large lakes, has a positive effect on tourism. Following the work of Sass [93], we find that conflicts hurt tourism in SSA. Tourists do not go to conflict-affected areas because of a sense of insecurity. Furthermore, like Chen et al. [94], our results show that deforestation reduces tourism in SSA through the disappearance of certain floral and faunal species popular with tourists. Finally, ICT, through the use of telephones and the Internet, increases the development of the tourism sector in SSA by popularising tourist sites and reducing the cost of accessing information [51, 66].

Even if the main results of the study remain unchanged, it is important to note that in specifications 2 to 6, the inclusion of these potential transmission channels alters the impact of climate change on tourism in terms of intensity. Indeed, we observe that the addition of these control variables makes the coefficients associated with climate change in Table 1 (specifications 2 to 6) smaller than those observed in the baseline model (Table 1, specification 1). As it is displayed, the addition of water availability, deforestation, conflicts, telephone, and Internet to the model reduces/eliminates the significance and intensity of the temperature and precipitation coefficients. From this result, we can conclude a priori that these variables are potential transmission channels whose effectiveness should be tested.

5.2 Analysis of Mediation

In the previous section, we identified certain variables as transmission channels between climate change and tourism. In this section, we test the effectiveness of these mechanisms

Table 2 Mediation analysis by Acharya et al. (2016) approach

Dependent variable: tourism arrivals (%population)	(1)	(2)	(3)	(4)	(5)
ACDE of variation of average temperature	− 0.583***	− 0.578***	− 0.553***	− 0.554***	− 0.585***
	(0.0718)	(0.0690)	(0.0694)	(0.0690)	(0.0692)
ACDE variation of average precipitation	0.489***	0.523***	0.588***	0.541***	0.487***
	(0.0666)	(0.0665)	(0.0649)	(0.0642)	(0.0668)
Constant	11.81***	9.30***	9.30***	11.77***	2.985***
	(0.22681)	(0.21689)	(0.22983)	(0.22495)	(0.01524)
Country fixed effects	Yes	Yes	Yes	Yes	Yes
Times fixed effects	Yes	Yes	Yes	Yes	Yes
Observation	945	945	945	945	945
R-square	0.101	0.091	0.090	0.090	0.080

This table presents the average controlled direct effects of climate change on indicators of state fragility, according to Acharya et al. (2016). These specifications correspond to different mediation variables, namely, (1) water availability; (2) forest loss; (3) conflicts; (4) Internet; (5) phone; bootstrap standard error in parenthesis. Asterisks denote significance: *$p < 0.1$. **$p < 0.05$. ***$p < 0.01$. Sources: author's construction

as mediating variables using the mediation approach developed by Acharya et al. [95]. According to this approach, mediation analysis, which consists of introducing the treatment variable (climate change) and the mediating variable in the base model into the same equation, generally leads to biased and inconsistent estimators. They then propose a test that solves these econometric problems using a two-step procedure. In the first step, tourism (the outcome variable) is regressed on the mediating variable(s), climate change and a set of control variables. We then obtain the predicted values of the outcome by setting all the mediators to zero, this is the 'unmediated' outcome. In the second step, we regress the 'unmediated' outcome of climate change and the control variables considered as confounders. The coefficient associated with variation of average temperatures and precipitation is referred to as the Average Conditional Direct Effect (ACDE) by Acharya et al. [95]. Thus, a change in the magnitude and significance of the ACDE (specifications 1 to 5, Table 2) relative to the base model coefficients (specification 1 Table 1) reflects the effectiveness of the mediation effect. Following Acharya et al. [95], all regressions are estimated using a bootstrap method with 1000 replications, integrating country-time fixed effects.

From the above, we can construct the causal diagram (Fig. 4).

We proceed to test the effectiveness of mediation and measure its magnitude using the approaches of Zhao et al. [96] and Baron and Kenny [97], whose structural equations are included in Appendix 3. According to the approach of Zhao et al. [96], there is no mediation if the coefficient of the indirect effect obtained from the Monte Carlo z-test is not significant. There is full mediation when the indirect effect criterion is significant but the direct effect of climate change is not. Mediation is partial when, on the contrary, the direct effect is significant and, in particular, complementary

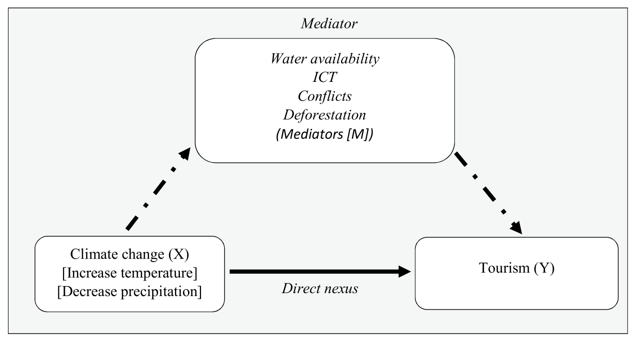

Fig. 4 Causality diagram. Author's construction

when the indirect and direct effects are in the same direction and concurrent when these effects have opposite signs. In the case of Baron and Kenny [97], there is no mediation if climate change does not affect the mediator and/or if the mediator does not affect tourism. There is 'some' mediation if both of the above effects are significant, in which case (i) mediation is complete if the test of the indirect effect is significant but not the direct effect; (ii) it is partial if only one of the direct and indirect effects is significant; or (iii) neither is significant.

The results in Table 3 (specifications 1 to 5) test the effectiveness of the mediating variables in our model. Indeed, using the criterion of Zhao et al. [96] and Baron and Kenny [97], we find that conflicts, Internet, and telephone use are effective transmission channels between climate change (when precipitations is considered) and tourism. Specifically, using the Zhao et al. [96] criterion, we show that mediation for these variables is partial and concurrent, except for conflicts, which shows complementary partial mediation. Similarly, we find by Baron and Kenny [97] criterion that mediation is partial for these three variables. On the other

Table 3 Mediation analysis

Mediation variables	Water availability (1)	Deforestation (2)	Conflicts (3)	Internet (4)	Phone (5)
Mediated effect variation of average temperature					
Step ($X \rightarrow M$)	− 0.425***	− 0.0422	− 0.656***	− 2.124***	− 0.270**
	(0.0440)	(0.0592)	(0.0974)	(0.681)	(0.132)
Step ($M \rightarrow Y$)	0.0157	0.141***	0.0563**	0.0137***	0.0567***
	(0.0558)	(0.0412)	(0.0251)	(0.00358)	(0.0191)
Step ($X \rightarrow Y$)	− 0.576***	− 0.577***	− 0.546***	− 0.554***	− 0.557***
	(0.0791)	(0.0750)	(0.0770)	(0.0753)	(0.0760)
Constant	12.36***	11.71***	12.25***	12.25***	12.51***
	(0.0632)	(0.201)	(0.0809)	(0.0686)	(0.0738)
Bootstrap replications	500	500	500	500	500
Observations	945	945	945	945	909
Sobel test (indirect effect)	− 0.070	− 0.006	− 0.037**	− 0.029**	− 0.015***
	(0.024)	(0.009)	(0.017)	(0.012)	(0.009)
RIT	0.011	0.010	0.063	0.050	0.027
RID	0.012	0.010	0.068	0.052	0.027
Conclusion of Zhao-Lynch-Chen	No mediation	No mediation	Concurrent. Partial mediation	Concurrent. Partial mediation	Complementary. Partial mediation
Conclusion of Baron-Kenny	No mediation	No mediation	Partial mediation	Partial mediation	Partial mediation
% total effects mediated	1%	1%	6%	5%	3%
Mediated effect variation of average precipitation					
Step ($X \rightarrow M$)	0.133***	− 0.201***	− 0.659***	− 2.177***	0.0722
	(0.0459)	(0.0589)	(0.0974)	(0.681)	(0.130)
Step ($M \rightarrow Y$)	0.104*	0.183***	0.138***	0.0191***	0.0638***
	(0.0537)	(0.0415)	(0.0250)	(0.00357)	(0.0191)
Step ($X \rightarrow Y$)	0.511***	0.561***	0.615***	0.566***	0.514***
	(0.0761)	(0.0756)	(0.0765)	(0.0752)	(0.0751)
Constant	10.51***	9.492***	9.794***	10.15***	12.51***
	(0.316)	(0.388)	(0.336)	(0.319)	(0.0738)
Bootstrap replications	500	500	500	500	500
Observations	945	945	945	945	909
Sobel test (indirect effect)	0.014*	− 0.037*	− 0.009***	− 0.042*	0.005
	(0.009)	(0.014)	(0.021)	(0.015)	(0.008)
RIT	0.026	0.070	0.173	0.079	0.027
RID	0.027	0.065	0.147	0.073	0.027

Table 3 (continued)

Mediation variables	Water availability (1)	Deforestation (2)	Conflicts (3)	Internet (4)	Phone (5)
Conclusion of Zhao-Lynch-Chen	Complementary. Partial mediation	Concurrent. Partial mediation	Concurrent. Partial mediation	Concurrent. Partial mediation	No mediation
Conclusion of Baron-Kenny	Partial mediation	Partial mediation	Partial mediation	Partial mediation	No mediation
% total effects mediated	3%	7%	17%	8%	1%

Standard errors in parentheses. Asterisks denote significance: $*p < 0.1$. $**p < 0.05$. $***p < 0.00$. Author's construction

hand, when we measure climate change by average precipitation, we find that water availability, deforestation, conflict, and Internet are effective transmission channels between climate change and tourism. Specifically, using the Zhao et al. [96] criterion, we show that mediation for these variables is partial and concurrent, except for the water, which shows complementary partial mediation. Similarly, using the Baron and Kenny [97] criterion, we find that mediation is partial for these variables. However, several conclusions can be drawn from these mediation analyses. Firstly, though the mediation power is only 3%, it should be noted that water availability is an effective channel when climate change is measured by rainfall variation, which is not the case for temperature variation. In fact, despite the decrease in rainfall, the rainy season is the period during which the rivers and streams that are the main tourist attractions are supplied with water. This water storage is therefore beneficial to the tourism sector.

Indeed, according to the World Lake Database[7], there are 677 lakes in SSA, of which 88 are considered large lakes, thirteen major river basins, and hundreds of rivers. These water resources promote tourism activities such as wildlife viewing from boats, river and lake cruises, visiting spectacular falls, bird watching in wetlands, sailing, windsurfing, sailing, and diving in some inland lakes. Thus, effective water management is revealed as how the tourism sector could mitigate the effects of climate change as believed by Martinez-Ibarra [26]. We also find, as Freitag et al. [64] do, that ICT through the use of the telephone plays an important role in promoting tourism, with a mediation effect of 3% when climate change is captured by temperature variation. Indeed, according to the Global System for Mobile Communication Association [98], the mobile phone penetration rate in SSA is 43%. However, we find that its use is not an effective transmission channel when climate change is captured by variation of average precipitation. On the other hand, ICT through the use of the Internet proves to be an effective transmission channel for tourism when measuring climate change. An effective transmission channel for tourism when climate change is measured through variations in temperature and precipitation. Indeed, with a mediation power of 5% and 8%, the Internet, unlike the telephone use of the telephone, is the channel through which tourism agencies offer attractive destinations to most tourists. This is because thanks to search engines and social networks, the Internet has made it possible to popularisation and promotion of tourism destinations in SSA [99]. Even if the Internet promotes the popularisation of touristic sites, the low level of

[7] International Lake Environment Committee Foundation (ILEC) <http://wldb.ilec.or.jp/>

Internet connectivity in the African context compared to the rest of the world does not allow the emancipation of tourism. According to the International Telecommunications Union [100], Internet penetration in SSA is estimated at 13%.

In summary, we show that ICTs, through the use of telephone and Internet, mitigate the negative impacts of climate change on tourism in SSA. Drawing on the work of Martínez-Ibarra [26], our results show that conflicts with a mediating effect of 6% mitigate the negative impact of rising temperatures on tourism.

Furthermore, we find that when climate change is captured by rainfall, the mediating power of conflicts and its effects on tourism is 17%. We therefore show that conflict exacerbates the effects of reduced rainfall on tourism. Indeed, unfavourable climatic conditions such as decreased rainfall generate conflicts not only between local populations but especially between them and tourists due to the scarcity of resources such as water. According to Becken [18], tourists consume 70 times more water than the local population.

Finally, like Otrachchenko and Nunes [28], we find that deforestation, with a mediating effect of 7%, promotes the negative effect of failing precipitations on tourism. The decline in rainfall, characterised by increasing drought, is leading to the destruction of flora and fauna, which are very useful for nature tourism in SSA.

6 Robustness and Sensitivity Tests

We propose three robustness tests and four sensitivity tests. The robustness tests relate to an alternative measurement of tourism, another estimation technique, and finally, lag explanatory variables to control reverse causality. In terms of sensitivity tests, we test the sensitivity of our model to the specificities of the tourism sector in SSA and cultural variables.

6.1 Tourism Receipts as an Alternative Measure

To make sure our results are robust, we measure tourism by international tourism receipts relative to real GDP. Indeed, the advantage of using tourism receipts as a percentage of GDP is that they reflect the structural effect or quality of tourism [101] and capture tourism expenditure within a national economy [102]. The data used to construct this measure comes from the World Bank database [38].

For all specifications (equations 1 to 6), in results in Appendix 4 Table 10, we find that climate change through rising temperatures and falling rainfall reduces the tourism receipts in SSA. Moreover, the use of this indicator does not modify the results of the influence of the control variables on tourism.

6.2 S-GMM as an Alternative Estimator to Control Endogeneity

Dynamic panel models deal with the correlation between unobservable country-specific effects and the lagged dependent variable, which leads to inconsistent estimators under ordinary least squares [103]. Therefore, Arellano and Bond [104] developed a consistent estimator, called Difference Generalized Method of Moment (D-GMM), using as instruments the lagged values of the first difference of the endogenous variable. However, due to the persistence of the dependent variable, this estimator makes lagged values very poor instruments [90]. Using additional moment conditions, Blundell and Bond [90] proposed a more robust alternative estimator called the System Generalized Method of Moment (S-GMM) from a system of two equations, one in level and the other in difference first.

We therefore use the System Generalised Method of Moments(S-GMM) developed by Blundell and Bond [90] for robustness. Several arguments justify the use of this estimator in our study: first, our specification respects Roodman's [105] condition that the number of countries (45) must be greater than the number of periods (26). Second, the persistence or inertia condition is verified because there is a strong correlation between tourism and its past value[8]. Third, extending the approach developed by Arellano and Bover [106], Roodman [105] shows that the GMM estimator is biased when the estimation strategy imposes too many instruments and overcomes this problem by limiting the number of instruments and maximising the sample size using the direct orthogonal deviation technique.

Finally, unlike the GMM estimator, the S-GMM method corrects for endogeneity, heteroscedasticity, and autocorrelation of errors [107]. Thus, in the context of our study, S-GMM allows for the correction of potential endogeneity through the use of instrumental variables [85]. In particular, this method allows (i) to control for unobserved heterogeneity between individuals in the panel, such as the beauty and reputation of the landscape, the exchange rate, and the economic situation of the destination; (ii) to correct for the potential reverse causality that may exist between tourism and all the explanatory variables; and (iii) to correct for any endogeneity problem arising from a potential correlation between the error term and the lagged endogenous variable. Thus, to obtain an efficient and consistent estimator, we use as internal instruments the explanatory variables lagged by at least two periods, such as GDP per capita, population growth rate, and water availability. The choice of lagged exogenous variables as instruments put an end to the debate related to the subjectivity of external instruments, the choice of which is not unanimous in the literature [108].

[8] The correlation between tourism arrivals and its lagged value from one period ago is 0.916, which exceeds the threshold of 0.8000.

The results (see Appendix 4 Table 11) indicate that in almost all specifications (1 to 6) we validate the hypothesis of the direct effect of clitic shift on tourism in SSA. Moreover, we find that the effect of the control variables on tourism is not modified. Also, the robustness of our results by the S-GMM is validated by the hypothesis of autocorrelation of order 1 and the absence of autocorrelation of order 2.

6.3 Lagged Explanatory Variables to Control Reverse Causality

The nonparametric method focusing on lagged explanatory variables, inspired by the literature [89], allows us to test the robustness of the results obtained by the TWFE and to better account for potential endogeneity problems. However, Bellemare et al. [89] point out that the use of this technique leads to biased and inconsistent estimators if the source of endogeneity is not taken into account. Thus, in the case of reverse causality type endogeneity, which we suspect in our study, this technique is effective when there is a contemporaneous or instantaneous causal relationship between the dependent and independent variables (variables of interest). We believe, on the one hand, that the causality between climate change and tourism is bidirectional and, on the other hand, that this causality is instantaneous. Indeed, if the literature presented in this article discusses the detrimental effects of climate on tourism, it is useful to recall that certain works have presented the tourism industry as a factor that exacerbates climate risks [109, 110]. Moreover, the relationship between the two is contemporary in the sense that the decision of individuals to engage in tourism in a given period depends on the climatic conditions prevailing in that period.

In addition, Gnimassoun and Santos [111] show that the use of this method makes it possible to solve the problem posed by the two-step least squares (2SLS) method, in particular, that is linked to the subjectivity of the choice of the relevant instruments. The results contained in Appendix 4 Table 12 (for the variables lagged by one period) and Appendix 4 Table 13 (for those lagged by two periods) are consistent with the previous results. Specifically, our results, as presented in equations 1–6 respectively, remain globally unchanged, thus confirming their robustness.

6.4 Sensitivity to the Specificities of Tourism in SSA and Consideration of Outliers

UNWTO [112] indicates that tourist attractiveness in SSA is unequally distributed. Indeed, Southern Africa followed by East Africa are the main tourist destinations, while the destinations of West and Central Africa are the least privileged. In addition, the World Bank report [113] proposes a classification country according to the level of tourism development. These analyses allow us, on the one hand, to test the sensitivity of our results to the heterogeneity of the tourism sector in terms of sub-regions and level of development and, on the other hand, to address the sensitivity of our results to the exclusion of outliers.

6.4.1 Control of Sub-regional Specificities of Tourism in SSA

To test the sensitivity of our results to sub-regional specificities, we construct a dummy variable whose general form is written:

$$Dummy\,sub - region_i = \begin{cases} 1 & if\ the\ sub - region\ i\ is\ observed \\ 0 & Otherwise \end{cases}$$

As we have 4 sub-regions, also called modalities, we will define three dummy variables for the sub-regions of West, Central, and East Africa. As tourism is more developed in the Southern Africa sub-region, we will use this dummy variable as a reference variable to study the interactions, i.e. the differential impact of climate change on tourism in the other sub-regions. The results of our study, presented in Table 4 (specification 1), indicate that climate change affects tourism in Southern Africa. Indeed, we find that a one-unit increase in temperature leads to a − 1.104-point decrease in tourism. However, our results highlight a different effect of temperature change on tourism in other sub-regions compared to Southern Africa. We find that the effect of an increase in temperature on tourism is 0.759 points higher in West Africa than in Southern Africa. This effect on tourism is also 0.727 points higher in Central Africa than in Southern Africa. WMO studies [7] estimate temperatures in these sub-regions to be between 25 and 30 °C, compared with an average of 15 to 25 °C in the southern African regions. Furthermore, in contrast to these sub-regions, the tourism sector in Central and West Africa is not yet sufficiently structured to cope with climate change [114].

Similarly, for rainfall, we find that a 1-point increase in rainfall leads to a 1.161 increase in tourism in Southern Africa. In contrast, we find that the differential effect of rainfall variation on tourism in Central Africa is − 1.857 and − 1.098 points lower than in West and Central Africa, respectively. This difference can be explained by the fact that the sub-regions of Central and West Africa are characterised by a Sudano-Sahelian climate with lower rainfall [7]. In contrast, we find that the positive effect of rainfall on tourism is 2509 points higher in East Africa than in Southern Africa. This result is explained by the fact that the abundance of rainfall in East Africa helps to boost nature tourism by benefiting the fauna, flora, and landscape [115].

Table 4 Analysis of the interactions and treatment of the outliers

	Dependent variable: tourism arrivals (%population)		
Independent variables	Estimation by sub-regions (1)	Estimation by tourism disparities (2)	Estimation without outliers (3)
Variation of average temperature[a]	− 1.104***	− 1.873***	− 0.275***
	(0.211)	(0.203)	(0.0845)
Variation of average precipitation[b]	1.161***	0.0319	0.354***
	(0.185)	(0.131)	(0.0823)
Variation of average temperature*West Africa dummy	0.759***		
	(0.269)		
Variation of average temperature *East Africa dummy	− 0.298		
	(0.254)		
Variation of average temperature*Central Africa dummy	0.727***		
	(0.268)		
Variation of average precipitation *West Africa dummy	− 1.857***		
	(0.209)		
Variation of average precipitation *East Africa dummy	2.509***		
	(0.305)		
Variation of average precipitation *Central Africa dummy	− 1.098***		
	(0.320)		
Variation of average temperature*emergent dummy		1.826***	
		(0.243)	
Variation of average temperature * potential dummy		1.930***	
		(0.248)	
Variation of average temperature* pre-emergent dummy		2.314***	
		(0.233)	
Variation of average precipitation * emergent dummy		1.522***	
		(0.295)	
Variation of average precipitation * potential dummy		− 1.441***	
		(0.156)	
Variation of average precipitation * pre-emergent dummy		0.429**	
		(0.175)	
Remittances	0.0214***	0.0390*	0.0495***
	(0.00688)	(0.0229)	(0.00711)
Agricultural production index	0.125**	0.221***	0.428
	(0.0545)	(0.0501)	(0.592)
Wheat price volatility	− 0.0302***	− 0.00396	− 0.138*
	(0.00514)	(0.00463)	(0.0742)
Foreign direct investment	0.329***	0.183***	0.0159***
	(0.0664)	(0.0587)	(0.00610)
Control of corruption	0.215***	0.173**	0.273***
	(0.0637)	(0.0671)	(0.0768)
Education	0.276***	0.143***	0.194**
	(0.0405)	(0.0348)	(0.0768)
Gross domestic product per capita	0.0214***	0.0390*	0.0687*
	(0.00688)	(0.0229)	(0.0416)
Constant	17.73***	0.221***	9.018***
	(1.023)	(0.0501)	(1.261)
R-square	0.438	0.557	0.175
Fisher	18.77***	30.54***	5.54***
Country fixed effects	Yes	Yes	Yes
Time fixed effects			
Observations	930	935	785
Number of countries	45	45	38

[a]References dummy variables are southern sub-region for equation 1 and countries with a consolidated tourism sector

[b]Idem

Standard errors in parentheses. Asterisks denotes significance: *$p < 0.1$. **$p < 0.05$. ***$p < 0.01$. Source: author's construction

6.4.2 Control of Disparity in the Development of the Tourism Sector in SSA

Similarly, to test the sensitivity of our results to differences in the development of tourism in SSA, we define the following dummy variables:

$$\textit{Dummy tourism development}_i = \begin{cases} 1 & \textit{if the level of tourism development i is observed} \\ 0 & \textit{Otherwise} \end{cases}$$

As before, we have 4 modalities, but we will define three dummy variables representing the SSA countries whose tourism sector is pre-emergent, potential, and emerging. In addition, we use as a reference variable the one for countries whose tourism sector is consolidating.

The results in Table 4 (specification 2) show that a one unit increase in temperature reduces tourism by − 1.465 units in countries where the tourism sector is consolidating. Furthermore, we find that there is a differential effect of temperature variation on the tourism sector between countries where tourism is emerging, potential, and pre-emerging and countries where it is consolidating. The difference in the effect of temperature variation on tourism is 1.826 points between countries where tourism is emerging and those where it is consolidating. Similarly, the effect of a temperature increase on tourism is 1.930 points higher in countries with a potential tourism sector than in countries where the tourism sector is consolidating. Finally, in countries with an emerging tourism sector, the impact of an increase in temperature on tourism is 2.314 points higher than in countries where tourism is consolidating. However, given the insignificance of the coefficient associated with the variation in average precipitation, it is not important for us to analyse the differential effect of the above; we note that the negative impact of climate change on tourism is greater in countries where the tourism sector is less developed. This result can be explained by the fact that countries with a consolidating tourism sector find it easier to develop resilience strategies in the face of climate change than other sub-regions [116].

6.4.3 Control of Outliers

In this study, similar to Vinutha et al. [117], we used interquartile range (IQR) technique for detecting outliers in continuously distributed data. It is the difference between the first and third quartiles, denoted IQR = Q3 − Q1. In addition, this method makes it possible to construct a moustache box, the purpose of which is to highlight the outliers graphically. The information contained in Appendix 4 Table 14 and the moustache box in Appendix 5 identify the outliers. In this way, we test the sensitivity of our results by excluding these countries from our sample.

The analysis in Table 4 (specification 3) shows that excluding outliers does not alter our main results, nor does the effect of the control variables.

6.5 Sensitivity to Cultural Variables

Ethnocultural tourism uses ethnic, cultural, and linguistic resources [118] to emancipate itself. Thus, the language, through the ethnic and cultural identity it contains, becomes a marketable commodity for tourism [119]. As a sensitivity test, by adding two cultural variables from the database of La Porta et al. [120]. We measure ethnic and linguistic diversity by ethnic and linguistic fractionalisation, respectively.

For specifications (1 to 3) in Table 5, we find that ethnic and linguistic diversity has a positive effect on tourism in SSA. This result brings us closer to the results of [118] and [119] who respectively indicate that ethnic and linguistic resources are of paramount importance for the development of tourism. The influence of ethnolinguistic wealth on tourism in Africa is the reason that obliges UNESCO to promote the safeguarding of this heritage, a guarantee of development [121]. Moreover, the introduction of cultural variables does not change our basic results.

7 Conclusion and Implications

Two observations have allowed us to refine our problem concerning the effect of climate change on tourism. First, it is recognised that the literature on the direct and indirect effects of climate change on tourism in SSA is very limited, despite the vulnerability of the African tourism sector to extreme weather events. Then, from a methodological point of view, most of the models observed in the literature are full of several limitations, the most important of which is the failure to take into account climatic factors that can influence tourism. To make a contribution to fill these gaps, estimates are done over a period ranging from 2000 to 2021 and for 45 SSA countries in a country-time fixed effects panel data model to mitigate unobserved heterogeneity and omited variables bias and take into account commons shocks.Our results obtained by TWFE indicate that climate change characterised by rising temperatures and falling rainfall negatively affects tourism in SSA. Furthermore, through water availability, conflicts, ICTs, and deforestation, we find that climate change indirectly influences tourism. In addition, robustness and sensitivity tests were implemented to test the solidity of our results.

Specific recommendations include mitigation and adaptation measures for the tourism sector in the face of climate change. Mitigation measures include the promotion of less polluting transport and the use of renewable energy by tourism operators. In addition, to mitigate the negative effects of rising temperatures, tourism operators can organise tourist activities at cooler times of the day, increase the number of

Table 5 Sensitivity to cultural variables

Independent variables	Dependent variable: tourism arrivals (%population)	
	(1)	(2)
Variation of average temperature	− 0.944***	− 0.975***
	(0.0745)	(0.0745)
Variation of average precipitation	0.767***	0.741***
	(0.0626)	(0.0648)
Remittances	0.00246	0.00827
	(0.00691)	(0.00706)
Agricultural production index	− 0.0337	0.0289
	(0.451)	(0.435)
Wheat price volatility	− 0.121**	− 0.123**
	(0.0512)	(0.0498)
Foreign direct investment	0.0115***	0.0137***
	(0.00393)	(0.00366)
Control of corruption	0.305***	0.308***
	(0.0938)	(0.0929)
Education	0.355***	0.347***
	(0.0646)	(0.0640)
Gross domestic product	− 0.0585	− 0.0544
	(0.0420)	(0.0414)
Ethnic fractionalisation	1.013***	
	(0.263)	
Linguistic fractionalisation		0.957***
		(0.224)
Constant	6.863***	6.871***
	(0.883)	(0.849)
Countries fixed effects	Yes	Yes
Time fixed effects	Yes	Yes
R-square	0.261	0.269
Fisher	15.16***	16.08***
Observations	930	930
Number of countries	45	45

Standard errors in parentheses. Asterisks denotes significance: *$p < 0.1$. **$p < 0.05$. ***$p < 0.001$. Source: author's construction

water points such as swimming pools and ponds, and provide as many shaded areas as possible.

Adaptation measures include the storage and rational management of water resources, the production of agricultural products that are less vulnerable to extreme conditions to reduce food insecurity, the construction of tourist facilities adapted to climate change, and the implementation of sustainable forest management. The diversification of tourism products is also one of the key strategies for adapting tourism to climate change. For example, the transition from water-based tourism activities to land-based activities could be an adaptation strategy for the tourism sector in the face of climatic shocks such as drought. Finally, we believe that the resilience of the tourism sector to climate change is not only an issue for tourism operators but also for governments in their support roles. For example, in addition to subsidising tourism, states can alert tourism operators to future climate risks and threats so that they can plan their activities without constraints. This includes climate and weather forecasting based on economic modelling to ensure the viability of a future tourist destination.

Like all studies, our research has two main limitations in time and space that should be taken into account in future work. First, due to the unavailability of some observations for important countries in our sample, we had to conduct our study over 21 years, which seems short, whereas climate change is a long-term phenomenon. Therefore, our future research should aim to conduct such a study over a long period of time.

Secondly, our study is spatially limited to the context of SSA, whereas the effects of climate vulnerability on tourism are also observed in other regions of the world. Therefore, depending on data availability, our future research aims to overcome this limitation by extending the sample to other countries whose tourism sector is threatened by climate change. These are countries in the island regions of the Pacific and Indian Oceans, South and Southeast Asia, Latin America, and the Caribbean, and especially those in the coastal and Mediterranean regions of Europe.

8 Appendix 1. Sample of the study

Angola, Benin, Burkina Faso, Botswana, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Congo-Brazzaville, Djibouti, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea-Bissau, Guinea, Cote d'Ivoire, Kenya, Liberia, Lesotho, Mauritania, Madagascar, Mauritius, Malawi, Mali, Mozambique, Namibia, Nigeria, Niger, Rwanda, South Africa, Senegal, Sierra Leone, Somalia, Sudan, Tanzania, Togo, Uganda, Dem, Rep, of Congo, Zambia, and Zimbabwe.

9 Appendix 2. Hausman test specification, descriptive analysis, and VIF test

Table 6 Hausman test results

Dependant variable	Hausman test		Model chosen
	Chi^2 (11)	*P*-value	
Conflicts (number of death)	99.17	0.000	Fixed effect model

Author's construction

Table 7 Description of the main study variables

Variables	Definition of variables	Source	Expected signs	Obs	Mean	Std. dev.	Min	Max
Tourist arrivals	Approximate tourism by the variable number of international tourist arrivals as a percentage of the population	WDI (2021)						
Tourist receipt	Measured by tourism revenue as a percentage of real GDP. Indeed, the advantage of using tourism revenue as a percentage of GDP is that it reflects the structural effect or quality of tourism and captures tourism spending within a national economy.	WDI (2021)		945	3.245445	3.531597	.1323478	15.8801
Variation of average temperature	Variation of average temperature (°C) is obtained by applying standard deviations in monthly temperature.	(CCKP, 2021)	-	945	2.292662	1.455645	.406761	7.972619
Variation of average precipitation	Variation of average precipitation (mm/year) is obtained by applying standard deviations in monthly rainfall.	(CCKP, 2021)	+	945	74.12822	48.39955	9.915553	361.4276
Remittances fund	The remittances of migrants and the share of income earned abroad. These are net current transfers from abroad equivalent to unrequited transfers of income from non-residents to residents. Remittances from official migrants represent only a small portion of the transfers that circulate around the world.	WDI (2021)	+	945	4.808855	8.134079	.0001832	57.50477
Agricultural production index	This index is a measure of agricultural output changes, which gives the level of the aggregate volume of agricultural production for each year in the country	FAOSTAT (2021)	+	945	90.08889	20.81472	27.2	181.51
Conflicts	Conflict is a georeferenced dataset that collects information on conflict-related events and deaths. Indeed, ACLED collects the dates, actors, locations, fatalities, and types of all reported political violence and protest events in many countries	ACLED (2021)	-	945	51.68466	133.6119	2	1146
Wheat price volatility	The volatility of wheat prices is obtained by applying the standard deviations on the monthly food (wheat) consumer price index data	FAOSTAT (2021)	-	945	187.9091	2384.349	4.18	69435.37
Foreign direct investment	These investments correspond to the net investment inflows to acquire a lasting stake (10% or more of the shares with voting rights) in a company operating within an economy other than that of the investor.	WDI (2021)	+	945	4.513236	7.934918	− 11.19897	103.3374

Table 7 (continued)

Variables	Definition of variables	Source	Expected signs	Obs	Mean	Std. dev.	Min	Max
Control of corruption	Control of corruption captures perceptions of the extent to which public power is exercised for private gain, including both petty and grand forms of corruption, as well as the 'capture' of the state by elites and private interests.	WGI (2021)	+	938	− .6698951	.6639798	− 1.868714	7
Education	Education is measured by the secondary school enrollment rate in each country.	WDI (2021)	+	945	44.66217	23.90447	− 21.70256	114.5126
Water availability	Measured by renewable inland freshwater resources (inland river flow groundwater from rain in cubic metres)	WDI (2021)	+					
Deforestation	Deforestation measured by Forest loss is a georeferenced dataset that provides information on forest cover and change. represents the amount of forest lost, taken from the georeferenced database Global Forest Change from Hansen (2021). Forest loss measures the net change in forest cover, specifically loss in forests due to deforestation plus any expansion of forest through afforestation.	Hansen's Global Forest Change (2021	-	945	218,389.8	277,829.8	.9332071	1,545,801
Gross domestic growth per capita (Gdp per capita)	Gdp per capita represents the gross domestic product (GDP) per capita. It measures the level of economic activity and corresponds to the ratio between the value of GDP and the number of inhabitants of a country.	WDI (2021)	+	945	3065	4577.565	− 3716.025	24036.38
Internet	Internet variable represents the Internet subscription rate per hundred people in the population.	WDI (2021)	+	945	9.37456	13.7853	− 33.15867	70
Phone	This is the population's mobile phone subscription rate for the last 3 months.	WDI (2021)	+	819	3.677992	13.46397	− .7874241	98.46405
Foreign direct investment	These investments correspond to the net investment inflows to acquire a lasting stake (10% or more of the shares with voting rights) in a company operating within an economy other than that of the investor.	WDI (2021)	+	945	4.513236	7.934918	− 11.19897	103.3374
Control of corruption	Control of corruption captures perceptions of the extent to which public power is exercised for private gain, including both petty and grand forms of corruption, as well as the 'capture' of the state by elites and private interests.	WGI (2021)	+	938	− .6698951	.6639798	− 1.868714	7

Table 7 (continued)

Variables	Definition of variables	Source	Expected signs	Obs	Mean	Std. dev.	Min	Max
Education	Education is measured by the secondary school enrollment rate in each country.	WDI (2021)	+	945	44.66217	23.90447	− 21.70256	114.5126
Water availability	Measured by renewable inland freshwater resources (inland river flow groundwater from rain in cubic metres)	WDI (2021)	+	24.13167	87.62102	.0203604	673.375	24.13167
Ethnic and linguistic	Ethnic and linguistic fractionalisation is measured by an average of five existing fragmentation indices ranging between 0 and 1, namely: (i) the probability that two randomly selected individuals do not belong to the same ethnolinguistic group in a country; (ii) the probability that two randomly selected individuals speak different languages; (iii) the probability that two randomly selected individuals do not speak the same language; (iv) the percentage of the population not speaking the official language; and (v) the percentage of the population not speaking the most commonly used language.	LaPorta t al. (1999)	+	.6814378	.6222222	.485039	0	1

Author's construction

Table 8 Matrix of correlation

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
Tourism arrivals	1.0000																
Variation of average temperature	− 0.243*	1.0000															
Variation of average precipitation	0.2193*	0.3656*	1.0000														
Remittances	0.0753*	− 0.1637*	0.0349	1.0000													
Agricultural production index	0.1546*	− 0.1386*	0.0190	0.1354*	1.0000												
Wheat price volatility	− 0.2151*	0.0588	− 0.0359	− 0.0941*	− 0.2083*	1.0000											
Foreign direct investment	0.0846*	0.0115	− 0.0016	0.0710*	− 0.0236	− 0.0589	1.0000										
Control of corruption	0.1690*	− 0.0599	0.1753*	− 0.1031*	− 0.0084	0.0917*	0.0495	1.0000									
Education	0.2228*	0.0825*	0.0512	0.1312*	0.2277*	− 0.3666*	0.0777	− 0,0346	1.0000								
Gross domestic product per capita	− 0.0224	− 0.0267	− 0.0845*	0.2022*	0.1013*	− 0.1744*	0.0174	− 0.1529*	0.0211	1.0000							
Water availability	0.0817*	− 0.3003*	0.0939*	0.2283*	0.1269*	− 0.1191*	0.0327	0.0967	− 0.0072	− 0.0434	1.0000						

Table 8 (continued)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)
Deforestation	− 0.1132*	− 0.0232	− 0.1104*	− 0.0362	0.0791*	− 0.1117*	0.0000	0.0240	0.3248*	− 0.0500	0.0363	1.0000					
Conflicts	− 0.1211*	− 0.2139*	− 0.2149*	0.1703*	0.1491*	− 0.2721*	0.0335	− 2.2466*	0.1758*	0.3888*	0.1336*	0.1223*	1.0000				
Internet	0.1436*	− 0.1010*	− 0.1034*	0.0438	0.0910*	0.0028	0.0930	0.0465	0.0532	0.0655*	0.0037	0.0099	0.0587	1.0000			
Phone	0.1111*	0.0097	0.0538	0.0118	− 0.0563	− 0.0847*	0.0012	− 0.0221	0.0792*	− 0.1121*	0.1888*	0.1295*	0.0151	0.0198	1.0000		
Ethnic fractionalisation	0.0252*	0.2913*	0.0084	− 0.1752*	− 0.0596	− 0.0627	0.1187	0.3217	0.0464	0.0918*	0.0367	0.0100	0.2548	0.0423	0.0340	1.0000	
Linguistic fractionalisation	0.0028*	0.3727*	0.1054*	− 0.3269*	− 0.0976*	− 0.0349	0.0203	0.2264	0.0353	0.0166	0.0657	0.1091	0.0792	0.0535	0.1303	0.7004*	1.0000

(1) Tourist receipt, (2) variation of average temperature, (3) variation of average precipitation, (4) remittances, (5) agricultural production index, (6) conflicts, (7) wheat price volatility, (8) foreign direct investment, (9) control of corruption, (10) education, (11) water availability, (12) deforestation, (13) total population, (14) Internet, (15) phone, (16) gross domestic product per capita, (17) ethnic fractionalisation; (17) linguistic fractionalisation. Source: construction authors

Table 9 VIF test

Variables	Tourism Arrivals (%population)	
	VIF	1/VIF
Variation of average temperature	1.20	0.833550
Variation of average precipitation	1.88	0.531978
Remittances	1.37	0.727849
Agricultural production index	1.23	0.811750
Conflicts	1.37	0.730069
Wheat price volatility	1.39	0.717399
Foreign direct investment	1.86	0.536736
Control of corruption	1.90	0.525590
Education	1.36	0.735449
Water availability	1.19	0.837047
Deforestation	1.81	0.551752
Internet	1.13	0.881651
Phone	2.65	0.377556
Gross domestic product per capita	2.30	0.435186
Ethnic fractionalisation	1.20	0.833550
Linguistic fractionalisation	1.88	0.531978

Author's construction

10 Appendix 3. Structural equations analysis

$$med_{it} = \varphi_1 + \theta_1 CC_{it} + a + \mu_{it}, \tag{3}$$

$$tourism_{it} = \varphi_2 + \theta_2 CC_{it} + \theta_3 med + \pi_{it} \tag{4}$$

MED represents mediation, that is to say, the set of mediating variables such as economic growth, renewable energy, ICT, water availability, and food insecurity. θ_1 represents the direct effect of international trade on mediation (equation 5). θ_3 measures the direct effect of mediation on climate vulnerability (equation 5). The indirect effect is measured by $\theta_1 * \theta_3$, while the total effect is measured by $\left(\theta_1 * \theta_3\right) + \theta_2$. The results contained below validate the mediating role of each of the variables.

11 Appendix 4. Robustness and sensitivity results

Table 10 Tourism receipts (%GDP) alternative measure

Independent variables	Dependent variable: tourism receipts (%GDP)					
	Direct effect	Sensitivity to transmission channels				
	(1)	(2)	(3)	(4)	(5)	(6)
Variation of average temperature	− 0.143***	− 0.0944***	− 0.143***	− 0.117***	− 0.142***	− 0.120***
	(0.0163)	(0.0199)	(0.0164)	(0.0182)	(0.0169)	(0.0171)
Variation of average precipitation	0.102***	0.0749***	0.106***	0.105***	0.101***	0.0870***
	(0.0127)	(0.0118)	(0.0128)	(0.0132)	(0.0135)	(0.0119)
Remittances	0.00598***	0.00363***	0.00612***	0.00559***	0.0060***	0.00617***
	(0.000996)	(0.000993)	(0.000986)	(0.000890)	(0.000991)	(0.000924)
Agricultural production index	− 0.105	− 0.185*	− 0.105	− 0.186*	− 0.110	− 0.235**
	(0.0984)	(0.0970)	(0.0971)	(0.0953)	(0.0990)	(0.0913)
Wheat price volatility	− 0.0405***	− 0.0270**	− 0.0405***	− 0.0216*	− 0.0405***	− 0.0401***
	(0.0130)	(0.0111)	(0.0130)	(0.0111)	(0.0132)	(0.0120)
Foreign direct investment	0.00365***	0.00335***	0.00371***	0.00323***	0.0037***	0.00394***
	(0.00102)	(0.00106)	(0.00102)	(0.00111)	(0.00105)	(0.000984)
Control of corruption	0.0193	0.0105	0.0188	0.0529***	0.0183	0.0218
	(0.0180)	(0.0189)	(0.0182)	(0.0190)	(0.0184)	(0.0196)
Education	0.0476**	0.0623**	0.0385*	0.0290*	0.0454**	0.0369*
	(0.0206)	(0.0242)	(0.0213)	(0.0162)	(0.0222)	(0.0209)
Water availability		0.163***				
		(0.0568)				
Deforestation			− 0.0470***			
			(0.0113)			
Conflicts				− 0.0571***		
				(0.0118)		
Internet					0.00994	
					(0.0161)	
Phone						0.0282*
						(0.0152)
Constant	2.934***	3.275***	2.769***	2.703***	2.964***	3.149***
	(0.347)	(0.335)	(0.354)	(0.345)	(0.353)	(0.356)
Countries fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
R-square	0.077	0.120	0.084	0.091	0.079	0.086
Fisher	34.45***	26.72***	34.32***	26.03***	34.35***	33.25**
Observations	930	930	930	930	926	895
Number of countries	45	45	− 0.861***	45	45	45

Standard errors in parentheses. Asterisks denotes significance: $*p < 0.1$. $**p < 0.05$. $***p < 0.01$. Source: authors' construction

Table 11 GMM-S as alternative estimator

Independent variables	Dependent variable: tourism arrivals (%population)					
	Direct effect	Sensitivity to transmission channels				
	(1)	(2)	(3)	(4)	(5)	(6)
Tourism (−1)	0.715***	0.729***	0.721***	0.855***	0.821***	0.798***
	(0.0714)	(0.0751)	(0.0541)	(0.0410)	(0.0647)	(0.0450)
Variation of average temperature	− 0.476***	− 0.549***	− 0.510***	− 0.265***	− 0.488***	− 0.122***
	(0.135)	(0.165)	(0.0988)	(0.0717)	(0.131)	(0.0085)
Variation of average precipitation	0.350**	0.309*	0.0455***	0.144***	0.141***	0.256**
	(0.168)	(0.180)	(0.00173)	(0.0126)	(0.0161)	(0.123)
Remittances	0.267***	0.253***	0.129**	0.121**	0.151**	0.119***
	(0.0821)	(0.0857)	(0.0655)	(0.0472)	(0.0644)	(0.0513)
Agricultural production index	2.386***	2.766***	2.468***	2.710***	− 3.335***	− 2.617***
	(0.688)	(0.849)	(0.561)	(0.472)	(0.535)	(0.451)
Wheat price volatility	− 0.375***	− 0.360**	− 0.234**	− 0.153***	− 0.186***	− 0.275***
	(0.145)	(0.150)	(0.118)	(0.0094)	(0.0144)	(0.0990)
Foreign direct investment	0.0229	0.0284	0.0135	0.0183**	0.0290	0.0326***
	(0.0170)	(0.0187)	(0.0126)	(0.00806)	(0.0179)	(0.0113)
Control of corruption	0.164***	0.148***	0.0743	0.139***	0.0289	0.166***
	(0.0477)	(0.0524)	(0.0466)	(0.0428)	(0.0497)	(0.0426)
Education	0.210*	0.278*	0.0303	0.179*	0.545***	0.191**
	(0.123)	(0.152)	(0.123)	(0.0916)	(0.155)	(0.0814)
Gross domestic product	0.0721	0.129	0.0657	0.140	0.0230	0.029
	(0.126)	(0.137)	(0.117)	(0.129)	(0.133)	(0.217)
Water availability		0.0506***				
		(0.00631)				
Deforestation			− 0.349***			
			(0.0947)			
Conflicts				− 0.0644**		
				(0.0296)		
Internet					0.0461**	
					(0.0186)	
Phone						0.482***
						(0.0305)
Constant	7.333***	7.525***	5.541***	6.136***	6.352***	7.038***
	(1.169)	(1.219)	(1.112)	(0.820)	(1.064)	(0.873)
AR(1)	0.000	0.000	0.000	0.000	0.000	0.000
AR(2)	0.156	0.188	0.361	0.276	0.382	0.258
Sargan *p*-value	0.189	0.187	0.207	0.245	0.261	0.196
Instruments	37	31	33	30	34	29
Observations	875	875	875	875	875	872
Number of countries	45	45	− 0.861***	45	45	45

Standard errors in parentheses. Asterisks denotes significance: *$p < 0.1$. **$p < 0.05$. ***$p < 0.01$. Source: authors' construction

Table 12 Robustness with lagged explanatory variables (lag 1)

Independent variables	Dependent variable: tourism arrivals (%population)					
	Direct effect	Sensitivity to transmission channels				
	(1)	(2)	(3)	(4)	(5)	(6)
Variation of average temperature$_{t-1}$	− 0.840***	− 0.909***	− 0.836***	− 0.732***	− 0.817***	− 0.836***
	(0.0759)	(0.0791)	(0.0758)	(0.0737)	(0.0763)	(0.0758)
Variation of average precipitation$_{t-1}$	0.748***	0.790***	0.776***	0.762***	0.782***	0.737***
	(0.0658)	(0.0660)	(0.0643)	(0.0646)	(0.0643)	(0.0663)
Remittances$_{t-1}$	− 0.000789	0.00256	− 0.00024	− 0.00238	− 0.00139	− 0.00120
	(0.00697)	(0.00718)	(0.00686)	(0.00663)	(0.00633)	(0.00690)
Agricultural production index$_{t-1}$	− 0.0882	0.0226	− 0.0818	− 0.374	− 0.251	− 0.0136
	(0.445)	(0.454)	(0.426)	(0.431)	(0.447)	(0.444)
Wheat price volatility$_{t-1}$	− 0.271***	− 0.290***	− 0.262***	− 0.186***	− 0.280***	− 0.252***
	(0.0512)	(0.0532)	(0.0509)	(0.0527)	(0.0513)	(0.0507)
Foreign direct investment$_{t-1}$	0.0154***	0.0159***	0.0157***	0.0138***	0.0183***	0.0157***
	(0.00408)	(0.00417)	(0.00407)	(0.00411)	(0.00400)	(0.00408)
Control of corruption$_{t-1}$	0.211***	0.226***	0.206**	0.343***	0.189**	0.220***
	(0.0810)	(0.0828)	(0.0821)	(0.0922)	(0.0915)	(0.0821)
Education$_{t-1}$	0.00228*	0.00196*	0.00147	0.00113	0.00183	0.00221*
	(0.00118)	(0.00117)	(0.00119)	(0.00116)	(0.00121)	(0.00117)
Gross domestic product$_{t-1}$	0.0355	0.0453	0.0309	0.123***	0.0479	0.0212
	(0.0406)	(0.0418)	(0.0408)	(0.0403)	(0.0399)	(0.0412)
Water availability$_{t-1}$		0.161**				
		(0.0625)				
Deforestation$_{t-1}$			− 0.110***			
			(0.0404)			
Conflicts$_{t-1}$				− 0.220***		
				(0.0357)		
Internet$_{t-1}$					0.0177***	
					(0.00380)	
Phone$_{t-1}$						0.0105***
						(0.00185)
Constant	7.703***	7.343***	7.124***	8.771***	7.811***	7.545***
	(0.973)	(0.980)	(0.955)	(0.969)	(0.975)	(0.980)
Countries fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
R-square	0.236	0.244	0.243	0.270	0.260	0.243
Fisher	13.71***	14.30***	14.69***	14.13***	13.87***	14.06**
Observations	937	937	937	937	937	937
Number of countries	45	45	− 0.861***	45	45	45

Standard errors in parentheses. Asterisks denotes significance: *$p < 0.1$. **$p < 0.05$. ***$p < 0.01$ Source: authors' construction

Table 13 Robustness with lagged explanatory variables (lag 2)

Independent variables	Dependent variable: tourism receipts (%GDP)					
	Direct effect	Sensitivity to transmission channels				
	(1)	(2)	(3)	(4)	(5)	(6)
Variation of average temperature$_{t-2}$	− 0.839***	− 0.901***	− 0.837***	− 0.730***	− 0.816***	− 0.836***
	(0.0755)	(0.0785)	(0.0755)	(0.0740)	(0.0758)	(0.0755)
Variation of average precipitation$_{t-2}$	0.746***	0.783***	0.767***	0.760***	0.782***	0.736***
	(0.0665)	(0.0669)	(0.0652)	(0.0648)	(0.0649)	(0.0669)
Remittances$_{t-2}$	− 0.00201	0.000979	− 0.00144	− 0.00363	− 0.00264	− 0.00242
	(0.00699)	(0.00714)	(0.00693)	(0.00668)	(0.00632)	(0.00695)
Agricultural production index$_{t-2}$	0.0146	0.115	0.0184	− 0.278	− 0.158	0.0880
	(0.449)	(0.457)	(0.435)	(0.435)	(0.450)	(0.447)
Wheat price volatility$_{t-2}$	− 0.271***	− 0.287***	− 0.265***	− 0.184***	− 0.281***	− 0.252***
	(0.0515)	(0.0532)	(0.0513)	(0.0525)	(0.0509)	(0.0511)
Foreign direct investment$_{t-2}$	0.0152***	0.0156***	0.0154***	0.0135***	0.0181***	0.0154***
	(0.00393)	(0.00401)	(0.00391)	(0.00394)	(0.00387)	(0.00393)
Control of corruption$_{t-2}$	0.169**	0.183**	0.166**	0.304***	0.146*	0.178**
	(0.0782)	(0.0797)	(0.0790)	(0.0878)	(0.0884)	(0.0791)
Education$_{t-2}$	0.00290**	0.00262**	0.00230*	0.00173	0.00242**	0.00283**
	(0.00116)	(0.00116)	(0.00119)	(0.00114)	(0.00119)	(0.00116)
Gross domestic product$_{t-2}$	− 0.0355	− 0.0453	− 0.0309	− 0.123***	− 0.0479	− 0.0212
	(0.0406)	(0.0418)	(0.0408)	(0.0403)	(0.0399)	(0.0412)
Water availability$_{t-2}$		0.143**				
		(0.0629)				
Deforestation$_{t-2}$			− 0.0799*			
			(0.0410)			
Conflicts$_{t-2}$				− 0.224***		
				(0.0355)		
Internet$_{t-2}$					0.0184***	
					(0.00372)	
Phone$_{t-2}$						0.0103***
						(0.00173)
Constant	7.444***	7.123***	6.998***	8.605***	7.548***	7.301***
	(0.978)	(0.987)	(0.967)	(0.971)	(0.978)	(0.981)
Countries fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
Time fixed effects	Yes	Yes	Yes	Yes	Yes	Yes
R-square	0.231	0.236	0.234	0.265	0.256	0.237
Fisher	13.11***	12.88***	13.14***	14.36***	13.24***	13.61***
Observations	936	936	936	936	936	936
Number of countries	45	45	45	45	45	45

Standard errors in parentheses. Asterisks denotes significance: *$p < 0.1$. **$p < 0.05$. ***$p < 0.01$ Source: authors' construction

Table 14 Detection of outliers with interquartile range (IQR)

Country	Incoming tourists in 2000	Incoming tourists in 2020	Growth rate of arrivals	Outliers
Comoros	7000	24,000	2.4285714	1
Mauritania	8000	18,000	1.25	0
Chad	10,399	43,000	3.1346155	1
Somalia	18,400	58,000	2.152174	1
Eritrea	23,162	70,000	2.0221106	1
Guinea-Bissau	55,200	34,967	− .36654592	0
Burkina Faso	67,000	126,000	.88059701	0
Guinea	69,638	33,000	− .52612144	0
Sierra Leone	77,334	65,334	− .15517241	0
Djibouti	78,597	20,100	− .74426795	0
Niger	85,000	50,000	− 41176471	0
Madagascar	87,099	127,000	.45809417	0
Central African Republic	89,100	11,200	− .87429854	0
Congo, Rep,	150,214	195,000	.29814551	0
Cabo Verde	180,000	115,000	− .36111111	0
Namibia	187,100	759,000	3.0566541	1
Mali	209,900	86,000	− .59028109	0
Gambia	246,000	79,000	− .67886179	0
Angola	249,320	51,000	− .79544361	0
Burundi	286,428	29,000	− .89875312	0
Mauritius	316,000	678,000	1.1455696	0
Benin	352,000	1,068,000	2.0340909	1
Congo, Dem, Rep,	381,626	103,000	− .73010258	0
Uganda	473,000	193,000	− .59196617	0
Togo	482,000	60,000	− .87551867	0
Zambia	502,000	457,000	− .08964143	0
Ethiopia	518,000	136,000	− .73745174	0
Zimbabwe	639,000	1,967,000	2.0782473	1
Gabon	654,636	230,000	− .64865991	0
Cote d’Ivoire	668,000	381,600	− .42874251	0
Sudan south	900,510	38,000	− .9578017	0
Malawi	1,032,255	228,000	− .77912439	0
Cameroon	1,073,300	660,807	− .38432205	0
Ghana	1,128,971	399,000	− 64658109	0
Lesotho	1,175,100	302,000	− .7430006	0
Liberia	1,306,000	466,000	− .6431853	0
Equatorial Guinea	1,342,957	711,000	− .47057143	0
Tanzania	1,414,570	501,000	− .64582877	0
Rwanda	1,557,000	1,283,375	− .1757386	0
Senegal	1,559,300	950,125	− .3906721	0
Kenya	1,824,130	1,037,000	− .43150982	0
Botswana	1,944,800	1,306,000	− .32846565	0
Mozambique	2,411,200	1,468,000	− .39117452	0
Nigeria	6,974,160	1,492,000	− .78606745	0
South Africa	16,436,236	6,001,000	− .63489208	0

Author's construction

12 Appendix 5.

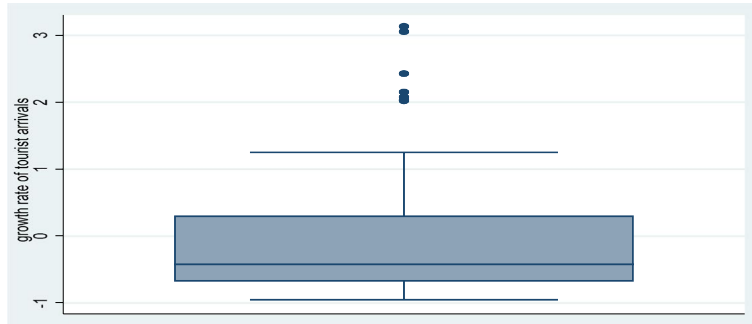

Fig. 5 Detection of outliers with boxplots. Source: author's construction

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Author Contribution All elements provide for author, conceptualization, methodology, litterature review and implications

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Declarations

Ethical Approval Not applicable.

Conflict of Interest The authors declare no competing interests.

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