Climate Change and Homicide: Global Analysis of the Moderating Role of Information and Communication Technology

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ABSTRACT: The link between climate change and human conflict has received substantial attention in academic research using different measures of "conflict"; however, it is yet to interpret interpersonal violence in terms of homicide. This study takes a global perspective to investigate how climate change, typically represented by temperature and precipitation, directly and indirectly affects national homicide rates across countries. From longitudinal archival data from 171 countries from 2000 to 2018, we detect a direct and positive relationship between higher temperatures and homicide, whereas an indirect pathway between wetter climate and homicide through the occurrence of more natural hazards has also been shown in our empirical results. The relationship between climate change and homicide can be moderated by the level of information and communication technologies (ICT). We conclude that the development of ICT contributes to building the countries' resilience to climate change with better information and communication technologies to help alleviate the negative impacts of climate change on homicide.

KEYWORDS: Social Science; Precipitation; Climate change; Temperature; Crime

1. Introduction

Climate change refers to a scientifically identified variation in the state of weather patterns that can be statistically measured by changes in the mean or variability of climatic properties over an extended period, typically decades or longer (IPCC 2013). There are many indicators of climate change, including changes in temperature, atmospheric water vapors, precipitation, severe events, glaciers, and ocean and sea level (Mohammadiziazi 2017; IPCC 2013). It is important to note that a single climate change can result in a range of impacts. Even the same type of change can cause seemingly opposite effects depending on the local topography, urbanization, and many other factors. Climate change disrupts people's lives, livelihoods, and mental and physical health, exacerbating existing vulnerabilities and inequalities and increasing insecurities (International Committee of the Red Cross 2020). A growing body of literature has made claims about the influence of climate change on human society, particularly on conflicts. Human conflict has been typically operationalized in two ways, namely, interpersonal conflict and intergroup conflict (Burke et al. 2015; Koubi 2019). Interpersonal conflict refers to violent actions between people that are commonly classified as crimes, including assault, homicide, rape, and murder (Mares and Moffett 2016). Intergroup conflict looks at violent acts between groups of people, including civil war, civil conflict, riots, intercommunal violence, and political repression (Burke et al. 2015).

Extant research has identified two possible pathways between climate change and human conflict (Koubi 2019; Salehyan 2014). Some assessments of the direct impacts of climate change focus on physiological factors and resource scarcity, identifying underlying effects of hot/uncomfortable temperatures and extreme precipitation on aggression (Anderson and Bushman 2002; Barnett and Adger 2007). Spurred research interest has also emerged in the indirect effect of climate change on human conflict. Its impacts are indirectly manifested in economic output, the health of the natural environment, and the resources on which people's livelihood depend (Hsiang et al. 2013). Possible links between climate change and various conflicts have gained considerable attention, including interpersonal conflicts and aggression (Anderson et al. 2000), violence (Mares 2013), property crime (Mehlum et al. 2006), intergroup conflicts, and armed civil confrontation (Bergholt and Lujala 2012; Theisen et al. 2013; von Uexkull et al. 2016) and political instability (Chaney 2013), as well as institutional breakdown and population collapse (Buckley et al. 2010; Kelly et al. 2013).

Although the bulk of the work has investigated the link between climate change and multiple types of conflicts (Barlett et al. 2020; Burke et al. 2015; Hsiang et al. 2013; Koubi 2017; 2019), its impact specifically on interpersonal conflict, namely, homicide, has received little attention [i.e., seldom studies including Gamble and Hess (2012), Gates et al. (2019), Lynch et al. (2020), Mares and Moffett (2016), and Xu et al. (2020)]. As a complete manifestation of different types of commonplace interpersonal conflict, homicide refers to irreversible human-made accidents. Homicide causes extreme impacts of severe grief and causalities, frequently happening in our society and attracting wide publicity. According to the 2021 report presented by the Institute for Economics and Peace (IEP) evaluating the economic impact of human conflict on the global economy, the economic impact of homicide was $1.06 trillion in 2019 (Institute for Economics and Peace 2021). On the other hand, climate change is a global phenomenon,

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and therefore its impact on homicide should be examined on a global scale (Hsiang et al. 2013). According to Messer (2010), to what extent climate change is responsible for conflicts is determined by multidimensional, country-specific factors and localized patterns within nations. Nonetheless, most existing studies that examined the relationship between climate change and homicide typically focused on specific regions [e.g., Lynch et al. (2020) for New York, New York, and London, United Kingdom; Xu et al. (2020) for American cities; Gamble and Hess (2012) for Dallas, Texas; and Gates et al. (2019) for South Africa].

Consequently, it is unclear whether climatic variability—both lower or higher temperature and precipitation—is linked to homicide on a global scale: Are there pathways between climate change and homicide? Also, are there any countermeasures that could alleviate the potential impacts of climate change on homicide? To address these questions, this study takes a contingency approach to investigate how a change in climatic conditions in terms of temperature and precipitation systematically influences the intensity of homicide across the globe and whether this relationship holds over a variety of temporal and spatial scales.

Specifically, we first examine the direct impacts of temperature and precipitation on national homicide rates. Then, we test the potential indirect relationship between climate change and homicide via natural hazards as weather-related hazards (e.g., heatwaves, storms, cyclones, floods, or blizzards) are deemed to be the possible causal mechanisms underlying these relationships (Hirabayashi et al. 2013; McBean and Rodgers 2010; Wolf et al. 2010). Last, we test the potential moderating effects of information and communication technologies (ICT) because the level of ICT reflects a country's mitigating ability to deal with human conflict and natural hazards.

Our study makes several theoretical and practical contributions to climate research. First, this study contributes to expanding the investigation of climate change and human conflict into a specific area of homicide. Our study cogently confirms the stimulating effects of higher temperatures and wetter climates and highlights the significance of natural hazards in motivating the national homicide rate. Second, this study opens the "black box" present in two potential pathways between climate change and homicide, which is the most significant contribution of our research, thus answering the call for research on the micromechanism of the climate change–conflict relationship (Hsiang et al. 2013). Third, we enrich the climate literature on human conflict by revealing a new contextual factor, namely, ICT. Thus, our findings can adequately guide policy makers to alleviate the negative influence of climate change on homicide. Policy makers should realize that adaptations to interpersonal violence caused by climate change can be weakened through the development and adoption of ICT.

The following section presents a concise review of the literature on climate change's direct and indirect impacts on human conflict and presents our theoretical argument. Then we describe the operationalizations of the critical variables and data in section 3. The empirical results are reported in section 4, and in section 5 we offer some concluding remarks on the implications of the findings from the study.

2. Climate and human conflict: Pathways and contextual factors

Climate change can have both direct and indirect impacts on human conflict. The direct impacts are those associated with climate features, such as uncomfortable temperatures and unusual precipitation, affecting human behavior and available resources and infrastructure, while the indirect effects are through the impacts of natural hazards triggered by climate change. Both types of impacts affect people's income and livelihoods, resulting in violent responses. They are discussed below, followed by an overview of ICT as a contextual factor in the response to natural hazards.

a. Direct pathway between climate change and human conflict

The direct pathway of climate change affecting human violence relates to how changing climatic factors impact conflict through immediate psychological reactions and resource scarcity. As concern over global climate change intensifies, there is a burgeoning quantitative literature that focuses on its direct impacts on human violence and conflict. According to Salehyan (2014), studies of the connection between climate change and conflict have adopted a broad array of methodological approaches, units of analysis, temporal and spatial scales, indicators of climate, and definitions of conflict, leading to what seems like a cacophony of different findings. For instance, many studies analyzed whether a specific conflict is related to climate change in a particular geographic area, such as the United States (Jacob et al. 2007; Card and Dahl 2011), sub-Saharan Africa (Buhaug 2010; Harari and Ferrara 2018), India (Sekhri and Storeygard 2012), Europe (Lee et al. 2013; Tol and Wagner 2010), and Australia (Auliciems and DiBartolo 1995). The local dimensions of conflict mean that its likelihood is spatially and temporally specific. Hsiang et al. (2013) evaluated 60 primary quantitative studies published from 1986 to 2013, which focused on the impacts of climate change on human conflict and concluded that deviations from mild temperature and standard precipitation patterns systematically increase the risk for many types of conflict.

Climate change is widely predicted to decrease the availability of vital resources (Bowles et al. 2015) and affect the redistribution of scarce resources such as productive land and freshwater (Hidalgo et al. 2010; Jacob et al. 2007). As a result, people may engage in violent behavior fighting for food, water, or land, especially those unemployed and with insufficient income, whose reaction may be prompted by survival, out of envy or resentment. There is ample evidence in the literature that resource scarcity, predominantly freshwater, and arable land, can lead to conflict. This can generate grievances and conflict over resource distribution as people fight directly over control of the means needed for survival. As Salehyan (2014) indicates, researchers have tried to look at land, food, and water to determine whether or not there is a direct link between scarcity and violence or whether climate factors, such as rainfall, can be used as instruments for growth in conflict models.

Prior research confirms that a hotter climate can influence individual behavior, increasing the rate of violence and the number of conflict incidents (Anderson et al. 2000; Burke et al. 2009; Cohn and Rotton 1997; Larrick et al. 2011; Ranson 2014). Card and Dahl (2011) studied the link between family violence and the emotional cues associated with wins and losses by professional football teams. They showed a significant positive effect of hotter weather on increasing intimate partner violence. The more recent Climate, Aggression, and Self-Control Model in Humans (CLASH) proposed by Van Lange Rinderu and Bushman (2017) outlines that slow life strategy, future orientation, and strong self-control that come from lower temperatures are essential determinants of inhibiting aggression and violence. As the temperature rises, many people will go out to participate in social activities, resulting in an increased likelihood of interpersonal conflict. High temperatures may increase individuals' negative emotions, causing them to be impatient with social contact (e.g., drinking wine, rage, engaging in dangerous driving). People may have problems controlling their behavior and aggression in high temperatures, even over a minor dispute. Concerning homicide, Gamble and Hess (2012) depicted a curvilinear temperature–violent crime association. They claimed that hotter temperature could positively affect crime, while it acts in the opposite direction beyond a certain level, exhibiting an inverted U-shaped relationship. Recently, Gates et al. (2019) adopted the mortality data from South Africa to investigate the impact of ambient temperature on homicide. Their findings suggest that higher temperatures tend to boost the homicide rate mildly. Likewise, based on more than 19 000 intentional homicide cases in the U.S. cities, Xu et al. (2020) also detected a linear temperature–homicide relationship that increased homicide cases could be attributed to the hotter weather.

A considerable body of literature has researched the effect of precipitation on conflicts. As Hendrix and Salehyan (2012) summarize, rainfall variability can have adverse macroeconomic effects, and deviations may lead to conflict among water consumers. Both excess and water shortages can lead to price disputes between rural producers and urban consumers due to temporary food shortages and spikes in market prices. Hence, rainfall deviations may promote aggressive behavior due to scrambling for scarce resources. Furthermore, intensive rainfall may cause traffic accidents because of bad driving conditions.

Thus, the current literature and our theoretical argument highlight a direct pathway for the expected direction of the relationship between temperature rise and precipitation deviation on the level of human conflict resulting in homicide. The first expectation is that human conflict will increase under temperature rise conditions because of more social interaction, negative emotions, and poor self-control. Similarly, the second expectation is that human conflict will increase under conditions of precipitation deviation due to contending for scarce resources and poor conditions on the road.

b. *Indirect pathway between climate change and human conflict: Natural hazards*

In contrast to the direct pathway, the indirect pathway postulates that climate change could affect human conflict by incurring natural hazards, decreasing agricultural output, accelerating rural-to-urban migration, and contributing to rising food prices (Koubi 2019). Although different potential causal mechanisms may be underlying the indirect pathways, we focus primarily on natural hazards as a possible mediating mechanism. There is a direct influence between climate change and natural hazards with many climate-related hazards, such as floods, storms, droughts, and sea level rise. McBean and Rodgers (2010) showed that climate and climate-related hazards have served as trigger events for more than 75% of the disasters globally during the first decade of the twenty-first century. The Centre for Research on the Epidemiology of Disasters (CRED 2015) estimates this percentage to be higher at 90% with an increasing frequency of weather-related disaster events; it recorded 335 weather-climate related events during 2005–14, which was a 14% increase from 1995 to 2004 and almost 2 times the level during 1985–94 (CRED 2015). Between 1995 and 2014, weather-related disasters claimed the lives of 606 000 people, and an additional 4.1 billion people were affected, with annual economic losses estimated at between $250 and $300 billion (U.S. dollars; CRED 2015). As a result, climatic variability is more likely to be associated with extreme weather events, which thus cause more natural hazards.

There is growing evidence that changes in the climate can have far-reaching impacts on economic outcomes. Global warming is expected to make the climate warmer, wetter, and wilder, increasing the severity and frequency of climate-related disasters while also hurting economic growth, and the impact is considerable (Bergholt and Lujala 2012). In addition, evidence has emerged that climate change might reduce agricultural production (Burke et al. 2009), industrial outcomes, and gross investment (Dell et al. 2012). Dell et al. (2014) presented evidence that economic growth is sensitive to climate change and variability. Carleton and Hsiang (2016) also pointed to climate as an essential influence on the historical evolution of the global economy, probably resulting in a slowing of global economic growth rates by 0.28% per year. Regardless of the various mechanisms, there is a broad consensus that conflict and violence will increase during periods of economic decline.

Climate-related disasters tend to influence individuals'/households' incomes, especially agricultural incomes, because they rely on natural conditions (Klomp and Hoogezand 2018). This implies that loss of agricultural incomes because of weather-related hazards would be expected to have a strong correlation with conflict. Additionally, output contractions due to natural hazards are likely to shrink government coffers since economic losses caused by natural hazards could lead to a significant reduction in tax revenue. Such a reduced revenue thus hampers a government's ability to respond and mitigate violence and crime quickly. Therefore, extreme climatic conditions, for example, extreme weather events, warmer temperatures, and excessive precipitation, could affect human conflict by causing natural hazards.

On the other hand, poverty lowers the opportunity cost of fighting and rebellion, and civil war is more likely to occur (Collier and Hoeffler 2002). It is easier to recruit individuals to participate in violence when they have fewer economic alternatives because of worse wage-earning opportunities and lower fighting opportunity costs (Salehyan 2014). Furthermore, poor economic growth reduces the state's capacity to quell protests and rebellions (Fearon and Laitin 2003). There may be a conjecture between reduced employment opportunities and income following climate-related natural disasters and violence and homicides.

c. Contextual factor: ICT deployment

In recent years, there has been significant growth in ICT in all countries and sectors worldwide due to its solid transformational power beneficial to productivity and efficiency. The existing studies on the relationship between ICT and climate change have similarly contradictory findings (e.g., Faisal et al. 2020; Añón Higón et al. 2017). On the one hand, the levels of CO_2 emissions are expected to increase with the widespread adoption of ICT facilities because they are likely to be associated with the additional energy consumption during device manufacturing and use, as well as in electronic waste recycling (Hilty et al. 2011; Añón Higón et al. 2017). Human activities involving financial transactions, large information systems, global supply chain networks, and big data processing facilities contribute to climate change. Likewise, Añón Higón et al. (2017) also argued that the investment in ICT infrastructure contributes to increasing CO_2 emissions only at its initial development stage.

On the other hand, the adoption of ICT could also alleviate the impacts of climate change in several ways: 1) by directly reducing CO_2 emissions in the ICT sector through the incremental use of more energy-efficient equipment; 2) by reducing the emissions of greenhouse gases derived from other industrial sectors through improving energy efficiency with the adoption of ICT; and 3) by enhancing sustainable adaptation to climate change via employing ICT-based systems to alleviate the potential adverse impacts of climate change (Abdollahbeigi and Salehi 2021; Qureshi 2019). For instance, extant research has demonstrated that ICT contributes to alleviating the negative impacts of natural hazards (de Jong 2013; Sood and Rawat 2021). Kayisire and Wei (2016) also showed that ICT could influence local economic development, which helps alleviate the impacts of climate change on human conflict by mitigating economic shocks. Moreover, the empirical results of Añón Higón et al. (2017) depict that ICT investment could help alleviate greenhouse gas emissions once the level of ICT development reaches a specific threshold. Similarly, Heeks and Ospina (2010) argued that ICT could provide systemic resilience to climate change by enhancing physical preparedness through relevant technologies.

Consequently, ICT might exert contextual impacts on the relationship between climate change and violence caused, particularly through improved communication. Hence, we propose an integrative theoretical framework (Fig. 1) for understanding climate change and interpersonal conflict in homicide. It shows that climate change, represented by temperature and precipitation, will impact homicide directly and indirectly through natural hazards. At the same time, the development of ICT may moderate the relationships between climate change, natural hazards, and homicide.

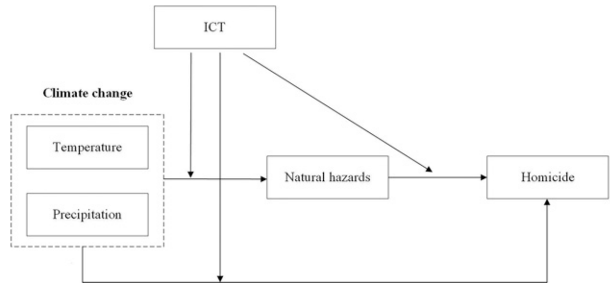

FIG. 1. Theoretical framework.

3. Data and method

Using longitudinal data from archival sources for diverse countries across the globe is a way to investigate how climate change impacts the homicide level. Homicide tends to be a valid predictor of interpersonal conflict and is likely to be consistently reported across countries (Mares and Moffett 2016; Visser et al. 2020). Given that homicide trends in a specific country might change over time, it is entirely possible that evidence of a link between climate change and homicide is a result of the time period. Using a long time series also enables the evaluation of trends and the application of nonstationarity and heterogeneity correction methods to offer a more accurate assessment of this connection. Hence, we constructed a panel dataset for 171 countries from 2000 to 2018 to assess the impact of climatic variables on interpersonal violence in terms of homicide. As for national-scale indicators, we briefly summarize the primary data sources: Data on homicide, temperature, and precipitation, ICT, and CO_2 emissions are from the World Bank/subset of the World Bank; natural disasters data are collected from the Emergency Events Database (EM-DAT); land area, population, GDP per capita, and human development index (HDI) data derived from the United Nations (UN) dataset, while the corruption perceptions index (CPI) data are from the database of Transparency International, an international nongovernmental organization monitoring corruption across the globe; sea level rise data are collected from the Commonwealth Scientific and Industrial Research Organization (CSIRO). Although national-scale data derived from different organizations might generate vagueness in definitions and measurements, we have tried our best to employ the data from the same sources. In this regard, the data for our key variables (dependent, independent, and moderating variables) are primarily collected from the World Bank, which could help to alleviate the potential measurement bias due to the multiple data sources.

In total, 2204 observations are included in our analysis. In the remainder of this section, we discuss the variables used in the empirical analysis. A summary of all of the variables is presented in Table 1, and the last part of the section describes the models used.

TABLE 1. Variable operationalization and sources.

Variables	Operationalization	Data source
Homicide	National homicide mortality per 100 000 people in year *t* for country *i*	World Bank; UN-DCIHS
Temperature	Avg temperature in year *t* minus average temperature in year $t - 1$ for country *i*	WB-CCKP
Precipitation	Avg precipitation in year *t* minus average precipitation in year $t - 1$ for country *i*	WB-CCKP
Natural hazards	ln(affected people) in year *t* for country *i*	EM-DAT
ICT	Mobile telephone subscriptions per 100 people in year *t* for country *i*	World Bank-World Telecommunication/ ICT Development Report
Land area	ln(land area) in year *t* for country *i*	UN Statistics Division data
Population	ln(population) in year *t* for country *i*	UN Statistics Division data
GDP per capita	ln(GDP per capita) in year *t* for country *i*	UN Statistics Division data
HDI	From 0 (worst) to 1 (best) in year *t* for the country *i*	UN data
CPI	From 0 (most corruption) to 10 (least corruption) in year *t* for the country *i*	Database of Transparency International
CO_2 emissions per capita	Emissions ($MtCO_2$) in year *t* for country *i*	The World Bank
Sea level rise	Sea level rise (mm) in year *t* for country *i*	CSIRO and NOAA

a. *Dependent variable*

Our hypotheses examine interpersonal conflict rather than intergroup disputes or violence by organized and armed groups. The dependent variable (DV) is the homicide rate. We operationalize homicide by using the national homicide rate as homicide mortality per 100 000 people. Data on homicides are adopted from the open database of the World Bank, derived from the UN Office on Drugs and Crime International Homicide Statistics (UN-DCIHS). They cover homicides from domestic disputes, interpersonal violence, violent conflict over land resources, intergang violence over turf or control, and other universal conflicts but kill in armed conflict.

b. *Independent variables*

Our independent variables are measures of temperature and precipitation based on a long and rich panel dataset of monthly temperatures and precipitations for countries across the world obtained from the Climate Change Knowledge Portal of the World Bank Group (WB-CCKP). These reports aim to identify multidimensional climate change and evaluate its impacts on human society and natural hazards. Temperature is generally accepted in climate science as a critical stressor of climate change, representing its direct impact on nature and human society (Hsiang et al. 2013; Tol and Wagner 2010). Precipitation is another significant climatologic stressor of climate change. More intense precipitation events, extended dry periods, and erratic rainfall are expected to represent the typical stressors of climate change, increasing pressure on human agriculture and the economy (Hendrix and Salehyan 2012). To keep the period consistent, we use data aggregated to the annual level with annual mean values of temperature and observed precipitation for each country.

While global precipitation and temperature are expected to change due to anthropogenic forcing, they are independent of human activities in an immediate sense. Yearly, social conflict cannot cause variation in temperature and precipitation. Thus, endogeneity between our independent and dependent variables is not a concern.

c. *Mediating variable*

To measure the severity of natural hazards, we include the annual count of people affected by natural hazards in each country. Considering the potential impacts of heterogeneous attributes in different countries, we use the affected rate, measured as the number of affected people per 100 000 population. The data are derived from the EM-DAT, which has the most comprehensive statistics of past natural disaster events globally and uses geocoded data on disaster losses. Although theoretically direct economic losses associated with natural hazards that represent the monetary value of total or partial destruction of physical assets existing in the affected areas should be included to measure the impact of natural hazards, almost 40% of the relevant data are empty missing. Hence, we opted to use the national count of affected people by natural hazards rather than the resulting economic losses to measure the impact of natural hazards. This is our mediating variable.

d. *Moderating variable*

As discussed earlier, ICT can operate as a multiplier (Qureshi 2019). It can alleviate or exacerbate a broad range of existing interactions between climate change and conflict. A wide range of technologies is described as ICT, including fixed telephone lines, Internet connections, and mobile cellular telephones. In this study, we operationalize the ICT level as the number of subscriptions to mobile telephones in a country, and this is the moderating variable. It seems like an appropriate indicator given the historical period of the analysis when the coverage of mobile phones and the Internet was relatively low, especially in less developed countries. Furthermore, fixed phones are less susceptible to the direct impacts of climate change and climatic events. Corresponding data are from the open database of the World Bank, based on the World Telecommunication/ICT

Development Report. Thus, we take the fixed telephone subscriptions per 100 people, representing the sum of active numbers of analog fixed telephone lines, voice-over-Internet protocol subscriptions, fixed wireless local loop subscriptions, integrated services digital network (ISDN) voice-channel equivalents, and fixed public payphones.

e. Control variables

Our empirical research includes a range of commonly used socioeconomic and institutional variables that are recognized to affect homicide rates as control variables. Specifically, existing studies have detected that conflicts will increase in society with corrupt public officials turning a blind eye to crime and basic departments, such as the police, not functioning correctly (Le Billon 2008). In this regard, more corrupt governments are likely to be associated with more conflicts. Furthermore, the degree of democracy may also impact government corruption, as democracy allows people to monitor their government better, thus curbing corruption. According to Gardiner (2006), the CPI reflects how a country's democracy can exert positive impacts on the preparedness for climate change. Therefore, we use the CPI, which ranges from 0 (most corrupt) to 10 (least corrupt), to control the potential influence of the national democratic regime. Data for CPI are used from the database of Transparency International, which has developed and published annual CPI data since 1995. We also incorporate the HDI into our research model to control for the societal aspects of a healthy life, population education, and living standards in a country. The HDI scores can be acquired from the UN data, and we use them as another control variable.

Second, as the negative relationship between economic development and civil conflict is the most robust finding to emerge from the conflict literature (Hegre and Sambanis 2006), we measure economic development with GDP per capita. Data are collected from the United Nations Statistics Division, and this is another control variable. We then control for a country's population size and land area. For any given level of grievance, we would expect that larger populations would see more political violence (Fearon and Laitin 2003), and societies experiencing rapid population growth have been found to be more conflict-prone (Goldstone 2016; Turchin 2005). For land area, it is possible that large areas would have more disputes and conflicts, which is another control variable. Data on population are from the UN data, based on the United Nations Population Division, while data on the land area are from the open database of the World Bank, referring to a country's total area, including areas under inland bodies of water and some coastal waterways.

We also include two climate-related control variables, considering their potential influences on natural hazards, namely, CO_2 emissions per capita and sea level rise. Data on CO_2 emissions per capita are also from the open database of the World Bank, while the data on sea level rise is from Australia's CSIRO and the National Oceanic and Atmospheric Administration (NOAA).

f. Models

Since our set is an unbalanced panel data for 171 countries over the 2000–18 period, the ordinary linear squares model specification could easily result in biased estimates due to unobserved heterogeneity. Fixed effects and random effects models are commonly used for panel data, considering unobserved heterogeneity, which could generate biased estimates. As our sample includes many countries, it can be approximately regarded as a complete set, and a fixed-effects model is appropriate in this situation. This choice is also supported by the Hausman specification test ($P = 0.000$) (Hausman 1978). As a robustness check, we also add the robust standard error estimates to the fixed effects model to alleviate the heteroscedasticity problem. We run the following equation to estimate the relationships among temperature, precipitation, ICT, and homicide rate as follows:

$$\text{homicide}_{i,j} = \alpha_0 + \alpha_1\text{temperature}_{ij-1} + \alpha_2\text{precipitation}_{ij-1} + \alpha_3\text{natural\_hazards}_{ij} + \alpha_4\text{ICT}_{ij} + \alpha_5\text{temperature}_{ij-1} \times \text{ICT}_{ij} + \alpha_6\text{precipitation}_{ij-1} \times \text{ICT}_{ij} + \alpha_7 X_{ij} + \gamma_i + \tau_j + \varepsilon_{ij},$$

where α_0 denotes the intercept, X_{ij} represents a set of control variables, γ_i captures fixed country-specific factors, τ_j denotes the timing effects by including years dummies, and ε_{ij} is the random error.

4. Empirical results

Table 2 displays the descriptive statistics for all variables, including observations, mean, standard deviation, minimum and maximum values, and Table 3 depicts the Pearson correlation coefficients. The following analysis describes the direct and indirect pathways followed by the moderating effect of ICT.

a. Direct pathway

The coefficient estimates for the effects of temperature and precipitation on homicide, with the mediating effect of natural hazards, respectively, are presented in Table 4. Model 1 shows the effect on natural hazards only of the control variables. On this basis, model 2 adds the variables of temperature and precipitation. The results (increasing the overall R^2 statistic) reveal that changes in temperature and precipitation impact natural hazards. We find the coefficient between precipitation and natural hazards to be positive and statistically significant (beta = 0.014; $p \leq 0.001$), providing evidence favoring the precipitation–natural hazards hypothesis. Model 2

TABLE 2. Descriptive statistics.

Variables	Obs	Mean	Std dev	Min	Max
Homicide	2204	6.595	9.368	0.156	73.092
Land area	2204	11.509	2.421	0.693	16.654
Population	2204	8.917	2.005	2.354	14.172
GDP per capita	2204	8.78	1.478	5.142	11.806
HDI	2204	0.734	0.138	0.303	0.956
CPI	2204	4.636	2.087	0.4	9.9
CO_2 emissions per capita	2204	5.47	6.289	0	67.311
Sea level rise	2204	58.62	23.703	29.6	107
ICT	2204	2.575	1.403	−6.502	4.615
Temperature	2204	0.022	0.529	−2.268	2.786
Precipitation	2204	0.198	22.865	−127.133	151.755
Natural hazards	2204	2.271	3.747	−6.703	11.563

also yields one marginally negative relationship between temperature and natural hazards, but the relationship is not statistically significant (beta = −0.002; $p \geq 0.1$). Similarly, model 3 illustrates the effects of the control variables on homicide, and model 4 and model 5 add the impacts of temperature, precipitation, and natural hazards, respectively.

We detect that both coefficients between temperature, precipitation, and homicide are positive and statistically significant in models 4 and 5 (consistent with Anderson et al. 2000; Gates et al. 2019; Lynch et al. 2020; Mares and Moffett 2016; Ranson 2014; Xu et al. 2020). Hence, our empirical results support the assumption that temperature and precipitation have an immediate and positive effect on national homicide rates globally. This suggests that a country with a higher increase in the observed temperature or precipitation is more likely to experience a higher homicide rate. Note also that the direct relationship between temperature and natural hazards is negative but not significant, which is different from our perception. This implies that wetter years immediately increase the incidence and intensity of natural hazards, while this does not hold for higher temperatures.

b. *Indirect pathway*

Model 5 in Table 4 introduces the natural hazards variable as the mediator as compared with model 4. Suppose natural hazards partially mediate the relationship between climate change and homicide as assumed. In that case, the coefficient for this variable is expected to be significant, and its incorporation into the model would decrease the significance of the coefficient of the relationship between the climatologic variables and homicide. According to our study, the indirect effect of temperature on homicide does not exist since the coefficient of temperature on the mediator (natural hazards) has been proven not to be significant (beta = −0.002; $p \geq 0.1$) (also see Hendrix and Salehyan 2012). Hence, there exists no indirect pathway between temperature and homicide globally.

For precipitation, model 5 illustrates that natural hazard variable is significantly associated with homicide (beta = 0.055; $p \leq 0.05$), while the coefficient of precipitation on homicide decreases and is still significant (beta = 0.008; $p \leq 0.05$) relative to model 4 (beta = 0.009; $p \leq 0.05$). The Sobel examination confirms that the natural hazards variable mediates the relationship between precipitation and homicide at the 0.001 level (two-tailed significance examination: Sobel $Z = 3.961$; $p \leq 0.001$). Therefore, these results provide strong evidence that increased precipitation can accelerate higher national homicide rates, but its effect tends to be partially mediated by augmenting the severity of natural hazards (Koubi 2019).

c. *Moderating effect*

Table 5 shows the results of the moderating effect between ICT and temperature when examining natural hazards, while Table 6 presents the interaction between ICT, temperature, and natural hazards when predicting homicide. This allows us to make the following observations.

We first examine the effect of ICT and precipitation on natural hazards and detect a positive coefficient for the interaction (beta = 0.004; $p \leq 0.05$). To facilitate the interpretation of the interaction effect, we calculate the slopes of precipitation and natural hazards at high and low levels of ICT, respectively. We find that the detrimental effect of precipitation

TABLE 3. Correlations of the variables. Here, $N = 2204$; one, two, and three asterisks indicate significance level $p \leq 0.05$, $p \leq 0.01$, and $p \leq 0.001$, respectively.

Variables	1	2	3	4	5	6	7	8	9	10	11
1. Homicide	1										
2. Land area	−0.028										
3. Population	−0.091***	0.800***									
4. GDP per capita	−0.171***	−0.144***	−0.150***								
5. HDI	−0.235***	−0.092***	−0.084***	0.893***							
6. CPI	−0.235***	−0.140***	−0.147***	0.787***	0.731***						
7. CO_2 emissions per capita	−0.195***	−0.007	−0.052**	0.590***	0.529***	0.447***					
8. Sea level rise	−0.051**	0.041*	0.068***	0.186***	0.192***	0.081***	−0.034				
9. ICT	−0.087***	−0.176***	−0.188***	0.775***	0.857***	0.598***	0.435***	−0.031			
10. Temperature	0.004	−0.001	−0.001	0.010	0.006	−0.001	0.000	0.012	0.003		
11. Precipitation	0.040*	−0.025	−0.033	0.008	0.006	0.001	−0.010	−0.030	0.031	−0.097***	
12. Natural hazards	0.224***	0.233***	0.263***	−0.362***	−.362***	−0.335***	−0.263***	0.009	−0.337***	−0.008	0.077***

TABLE 4. Fixed-effects regression estimates of the mediating role of natural hazards. Robust standard errors are in parentheses. Here, the plus sign and one, two, or three asterisks indicate $p \le 0.10$, $p \le 0.05$, $p \le 0.01$, or $p \le 0.001$, respectively.

	DV: Natural hazards		DV: Homicide		
	Model 1	Model 2	Model 3	Model 4	Model 5
Land area	−0.355 (0.595)	−0.369 (0.596)	−1.556 (1.003)	−1.629 (1.012)	−1.609 (1.010)
Population	−0.479 (0.868)	−0.545 (0.866)	2.156^{+} (1.192)	2.172^{+} (1.195)	2.202^{+} (1.203)
GDP per capita	0.574 (0.445)	0.568 (0.446)	−2.297** (0.718)	−2.319** (0.720)	−2.350** (0.715)
HDI	−13.833* (5.812)	−13.567* (5.839)	−5.632 (6.851)	−5.394 (6.885)	−4.645 (6.885)
CPI	−0.142 (0.160)	−0.146 (0.159)	−0.052 (0.210)	−0.060 (0.210)	−0.052 (0.210)
CO_2 emissions per capita	−0.037 (0.039)	−0.033 (0.038)	0.119 (0.116)	0.123 (0.116)	0.125 (0.116)
Sea level rise	0.007 (0.009)	0.008 (0.009)	0.009 (0.010)	0.009 (0.010)	0.009 (0.010)
ICT	0.156 (0.276)	0.156 (0.270)	−0.669^{+} (0.358)	−0.664^{+} (0.358)	−0.673^{+} (0.363)
Temperature		−0.002 (0.121)		0.130* (0.060)	0.130* (0.061)
Precipitation		0.014*** (0.003)		0.009* (0.004)	0.008* (0.004)
Natural hazards					0.055* (0.024)
Constant	15.661 (11.891)	16.286 (11.804)	29.178^{+} (16.664)	29.910^{+} (16.693)	29.010^{+} (16.692)
Timing effect	Yes	Yes	Yes	Yes	Yes
R^2	0.011	0.024	0.085	0.092	0.096
Groups	171	171	171	171	171
N	2204	2204	2204	2204	2204

increases on natural hazards will be more distinct with an increasing ICT level (see Fig. 2). However, we fail to predict the interaction effect of ICT and temperature since the coefficient is not significant.

Furthermore, the results suggest that the coefficient of interaction between temperature and ICT is negative and significant when estimating national homicide rates. In examining the interaction plot, we find that ICT weakens the association between temperature and homicide (beta = −0.129; $p \le 0.05$) [consistent with Abdollahbeigi and Salehi (2021) and Qureshi (2019)]. The interaction plot demonstrates that temperature is positive and significant only when the ICT level is low but not when it is high (see Fig. 3). As a result, the deployment of ICT has mitigating effects on the relationship between temperature and homicide. The interaction effect of ICT and precipitation when estimating national homicide rates is positive but not significant.

Last, ICT strengthens the relationship between natural hazards and homicide (beta = 0.024; $p \le 0.05$). As displayed in Fig. 4, the effect of natural hazards on homicide will become much lower under the relatively high deployment of ICT (see Fig. 4). Thus, ICT use could also alleviate the unfavorable impact of natural hazards on homicide.

The results of our control variables illustrate that both the level of ICT and GDP per capita is negatively associated with homicide. At the same time, the HID scores can reduce the

TABLE 5. Fixed-effects regression estimates of the moderating impact of ICT on natural hazards. Robust standard errors are in parentheses. Here, the plus sign and one, two, or three asterisks indicate $p \le 0.10$, $p \le 0.05$, $p \le 0.01$, or $p \le 0.001$, respectively.

	DV: Natural hazards		
	Model 1	Model 2	Model 3
Land area	−0.386 (0.588)	−0.373 (0.600)	−0.394 (0.591)
Population	−0.542 (0.865)	−0.558 (0.867)	−0.554 (0.866)
GDP per capita	0.569 (0.446)	0.554 (0.446)	0.555 (0.446)
HDI	−13.645* (5.824)	−13.498* (5.810)	−13.591* (5.796)
CPI	−0.146 (0.159)	−0.148 (0.159)	−0.148 (0.159)
CO_2 emissions per capita	−0.032 (0.038)	−0.031 (0.038)	−0.030 (0.038)
Sea level rise	0.008 (0.009)	0.008 (0.009)	0.007 (0.009)
ICT	0.156 (0.268)	0.158 (0.275)	0.158 (0.273)
Temperature	−0.049 (0.154)	0.002 (0.121)	−0.057 (0.153)
Precipitation	0.014*** (0.003)	0.014*** (0.003)	0.014*** (0.003)
Temperature × ICT	0.098 (0.139)		0.123 (0.140)
Precipitation × ICT		0.004* (0.002)	0.004* (0.002)
Constant	16.529 (11.707)	16.512 (11.839)	16.831 (11.729)
Timing effect	Yes	Yes	Yes
R^2	0.024	0.025	0.026
Groups	171	171	171
N	2204	2204	2204

TABLE 6. Fixed-effects regression estimates of the moderating impact of ICT on homicide. Robust standard errors are in parentheses. Here, the plus sign and one, two, or three asterisks indicate $p \leq 0.10$, $p \leq 0.05$, $p \leq 0.01$, or $p \leq 0.001$, respectively.

	DV: Homicide				
	Model 1	Model 2	Model 3	Model 4	Model 5
Land area	−1.587 (1.016)	−1.611 (1.008)	−1.590 (1.015)	−1.761^{+} (1.007)	−1.742^{+} (1.012)
Population	2.198^{+} (1.204)	2.197^{+} (1.203)	2.194^{+} (1.203)	2.172^{+} (1.197)	2.164^{+} (1.196)
GDP per capita	−2.352** (0.715)	−2.355** (0.715)	−2.356** (0.715)	−2.336** (0.713)	−2.341** (0.713)
HDI	−4.538 (6.891)	−4.627 (6.880)	−4.530 (6.886)	−4.550 (6.892)	−4.428 (6.894)
CPI	−0.052 (0.209)	−0.052 (0.209)	−0.053 (0.209)	−0.051 (0.210)	−0.052 (0.209)
CO_2 emissions per capita	0.124 (0.116)	0.125 (0.116)	0.124 (0.116)	0.126 (0.116)	0.125 (0.116)
Sea level rise	0.010 (0.010)	0.009 (0.010)	0.009 (0.010)	0.008 (0.010)	0.009 (0.010)
ICT	−0.673^{+} (0.361)	−0.672^{+} (0.361)	−0.672^{+} (0.360)	−0.717* (0.356)	−0.717* (0.353)
Temperature	0.190** (0.071)	0.131* (0.061)	0.187** (0.071)	0.125* (0.060)	0.187** (0.071)
Precipitation	0.008* (0.004)	0.008* (0.004)	0.008* (0.004)	0.008* (0.004)	0.008* (0.004)
Natural hazards	0.056* (0.024)	0.055* (0.024)	0.055* (0.024)	0.056* (0.024)	0.056* (0.024)
Temperature × ICT	−0.126* (0.050)		−0.119* (0.051)		−0.129* (0.052)
Precipitation × ICT		0.002 (0.001)	0.001 (0.001)		0.001 (0.001)
Natural hazards × ICT				0.024* (0.011)	0.024* (0.011)
Constant	28.689^{+} (16.703)	29.110^{+} (16.675)	28.794^{+} (16.692)	31.046^{+} (16.586)	30.808^{+} (16.596)
Timing effect	Yes	Yes	Yes	Yes	Yes
R^2	0.096	0.096	0.097	0.097	0.098
Groups	171	171	171	171	171
N	2204	2204	2204	2204	2204

intensity of people affected by natural hazards. The population is more likely to be positively related to national homicide rates. However, our research has insignificant coefficients of land area, CPI, and CO2 emissions per capita.

5. Discussion

a. General discussion

The identified direct effects of climate change on homicide mean that an increasing rate of national homicide would be incurable with the temperature rising. This link between temperature and homicide is consistent with previous studies implying that hotter weather and violence go hand in hand; the temperature has a strong positive effect on criminal behavior (Anderson et al. 2000; Gates et al. 2019; Lynch et al. 2020; Mares and Moffett 2016; Ranson 2014; Xu et al. 2020). Hotter temperatures are more likely to trigger hostility and violence by elevating aggressiveness and discomfort, contributing to rising homicide rates. Hence, our research supports the argument that individuals exposed to hotter temperatures tend to be more violent as an immediate result of the heat. However, this study did not verify the indirect mechanism of natural hazards when examining the impact of hot weather on homicide. One possible explanation is that the indirect effect of hotter temperatures on homicide would be expected to occur through economic aspects, such as migration, economic recession, income inequality, and decreased food production (Koubi 2019). Temperature rise indeed causes natural hazards, such as sea level rise, typhoons, and tsunamis, posing significant threats to humanity. However, we were unable to identify immediate effects, most likely because, with global warming,

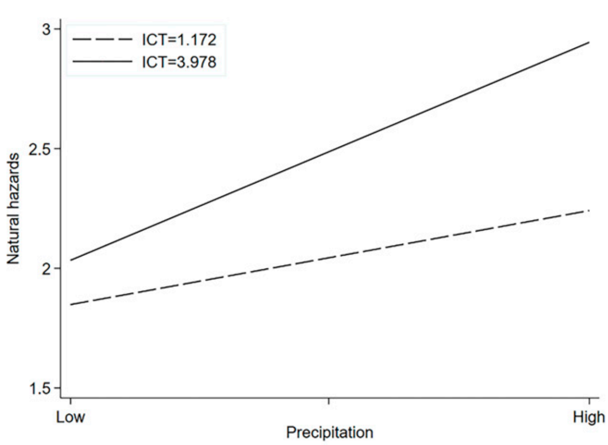

FIG. 2. Interaction effect of precipitation and ICT on natural hazards.

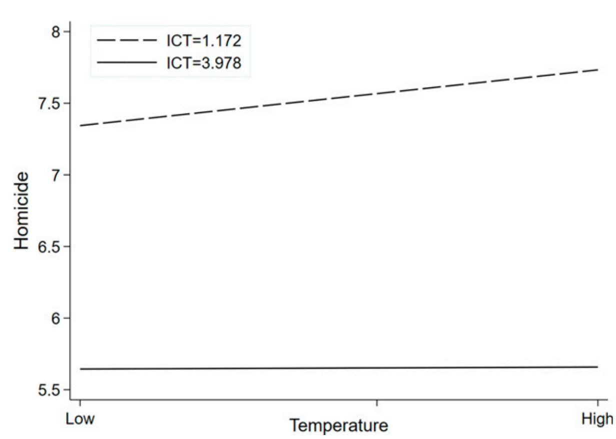

FIG. 3. Interaction effect of temperature and ICT on homicide.

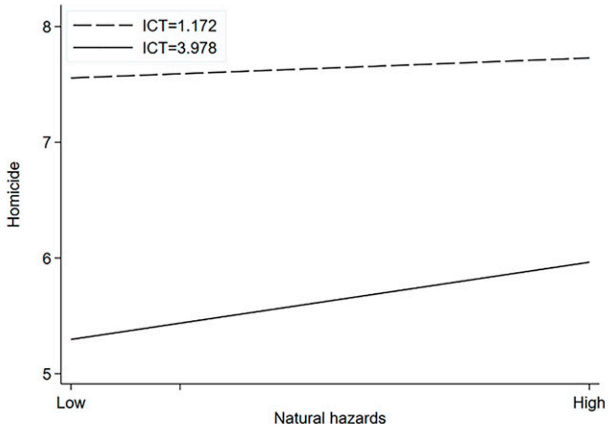

FIG. 4. Interaction effect of natural hazards and ICT on homicide.

the temperature rises gradually, so people may have the time to adjust, moderating any harm or exploiting any beneficial opportunities.

Although the existing studies present contradictory results when examining the impact of precipitation on conflict, they fail to identify robust effects (e.g., Hendrix and Salehyan 2012; Sarsons 2015). Scarcity because of limited rainfall may indeed encourage violence and increase conflicts. However, it may also reduce fighting capabilities as individuals focus on immediate survival rather than engage in aggressive behavior, countering the effects of violence. Moreover, plentiful rainfall may, in reality, provide abundant resources and create more reasons for conflict; however, the opportunity costs may also increase, reducing people's motivation for violence. However, in our study, we find that wetter years directly increase homicide rates.

First, heavy precipitation could become a significant contributing factor by triggering mass population migration due to extreme weather events (Koubi 2019) and possible fights for resources in the new regions. Besides, low incomes will reduce the opportunity cost of participating in homicide cases, as individuals may decide to prey rather than produce by considering the relative returns, costs, and risks. Second, unusually wet periods and precipitation extremes make people uncomfortable, causing negative emotions and wet-related diseases (e.g., febrile disease). They can make it easier to trigger human conflict, as someone may have a hard time controlling their behavior in such a situation. Finally, our analysis also demonstrates that wetter-than-normal years could increase the intensity of homicide indirectly through the occurrence of more natural hazards. Precipitation is shown to increase the impact of natural disasters, such as extreme weather events, floods, landslides, mud-rock flows, and storms. Natural hazards also increase human conflict by killing human lives, endangering crops, and damaging public infrastructure, which is expected to generate scarcity that can ignite more human conflict. Wetter years have significantly higher levels of natural hazards, which could ultimately lead to more homicides.

Effective adaptation to climate change is becoming increasingly necessary. However, it should be facilitated by more substantial mitigation efforts, requiring a significant commitment to identifying the challenges and putting in place effective countermeasures. Our empirical results demonstrate that the deployment of ICT has moderating effects on the relationship between climate change and homicide and natural hazards. On the one hand, the adverse impacts of temperature rise on homicide can be mitigated by enhancing ICT. This might occur through the broader adoption of telephones and mobile phones to assist the police forces in alleviating the homicide rate. Also, ICT has proven to slow the impacts of natural hazards on homicide. Information systems can help people adapt to natural hazards and improve their capability to cope with the adverse impacts, thus decreasing homicide rates.

On the other hand, the detrimental effects of wetter years on natural hazards, causing deaths and economic losses, can be counteracted with the increasing deployment of ICT. A substantial investment in ICT infrastructure may increase CO_2 emissions because of device production and energy consumption (Abdollahbeigi and Salehi 2021; Qureshi 2019), and natural hazards increase with higher levels of greenhouse gases. However, with a transition to renewable energy sources and a circular economy, these impacts may be diminished, and homicide caused by climate change, particularly by temperature rising, could be facilitated through the deployment of ICT infrastructure. The appropriate use of ICT by government agencies (e.g., police forces) can enhance their capability to respond to and alleviate the impacts of climate change on homicide.

b. *Contributions*

Our analysis identifies three main contributions. First, our findings add to the current climate–conflict literature focusing on homicides. Extant studies have examined intergroup conflict in terms of civil war or civil conflict (von Uexkull et al. 2016), intercommunal violence (Detges 2016), and armed conflict (Theisen et al. 2013). We limited the impacts of climate change on individual-level conflicts and interpersonal violence in terms of homicide, which was not fully explored before but appeared commonly and attracted attention in society. Second, the analysis of the two potential pathways between climate change and homicide allows us to gain a better understanding of the influence of climate variability, including not only directly "stimulating" the incidence and intensity of homicide but also indirectly "accelerating" the homicide rate through the occurrence of more natural hazards. Third, our study documents a hitherto unexplored interaction between ICT and climate change in alleviating adverse effects. To the best of our knowledge, we are some of the first to empirically document the moderating effect of ICT on both pathways between climate change and homicide, thus identifying a potential response strategy. Fourth, in contrast to most existing studies, which focus on a particular geographic region, we extended the empirical findings to a global scale.

c. *Practical implications*

Our analysis highlights the importance of climate change in affecting the homicide rate on a global scale. The latest report presented by the IEP suggests that governments should commit to alleviating the economic impact of homicide on the global economy as homicide becomes the third largest component in evaluating the economic impact of violence (Institute for Economics and Peace 2021). Our empirical results show strong evidence of the direct and indirect pathways (through weather-related natural hazards) between climate change and homicide. Hence, our findings could help policy makers to better understand climate change in response to homicide and prevent such conflicts. National governments should continue to make commitments to decrease CO_2 emissions, which have proven to be the most significant contributions to climate change.

Moreover, our study has further implications for ICT policy because it plays an essential role in moderating the climate change–homicide relationship. Policy makers should realize that adaptations to human conflicts caused by climate change can be weakened by developing and adopting ICT, particularly mobile telephones. The popularization of ICT facilities and the adoption of ICT by vulnerable populations can alleviate the adverse impact of climate change on homicide. Thus, the findings of our study potentially help governments/policy makers in the successful development and diffusion of ICT in countries that are specifically vulnerable to climate change.

6. Limitations and future research prospects

Our paper also has some limitations, which may provide avenues for future research. First, we acknowledge that using the global aggregated datasets that are coming from different sources might suffer specific limitations since vagueness in definitions and measurements is inevitable in this case (Visser et al. 2020). Although we struggled to collect national-scale data from the same organization, we cannot collect all the data from a single source at this moment. Therefore, our study is limited in generalizing the findings widely because the aggregated data may differ from different organizations. Future studies should verify whether our inferences hold by collecting data from a single source.

Second, although we elaborately examined both the direct and indirect relationships between climate change and homicide, the mechanisms behind the climate change–homicide association are more complex than the way they are depicted in Fig. 1. Hence, future research could investigate more complex connections between precipitation and homicide, that is, how a wetter climate affects both motivations to fight and the opportunity or capability to do so. Third, we only investigated the role of ICT at the country level as a contextual factor in affecting the climate change–homicide relationship. In addition to the mitigating effects of ICT, other contextual factors can also be incorporated in future studies to enhance the national capacity for reducing and resilience to climate-related conflicts and disasters, including measures taken beforehand to prevent and prepare and afterward to respond and assist recovery. The ultimate goal is not only to understand homicide but also to prevent it.

7. Conclusions

Climate change–human conflict association has been widely studied by climatologic and sociological researchers in recent years. However, as a specific type of interpersonal violence, the climate change–homicide nexus has not received sufficient attention, particularly globally. This study conducted an empirical analysis across 171 countries for the 2000–18 time period during which heterogeneous climate change manifestations were salient. We provide evidence about a direct pathway between climate change and homicide and an indirect pathway that impacts homicide through weather-related natural hazards.

Our study detects a direct and positive association between higher temperature and homicide and an indirect pathway between wetter climate and homicide via the occurrence of more natural hazards. The degree of information and communication technology development can attenuate the association between climate change and homicide. We conclude that improved ICTs help mitigate the detrimental effects of climate change on homicide. The growth of ICTs also improves a country's resilience to climate change.

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Data availability statement. The relevant data are available and can be obtained from the corresponding author.

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