YALE JOURNAL OF BIOLOGY AND MEDICINE 96 (2023), pp.189-196.

BRIEF COMMUNICATION

YALE JOURNAL OF BIOLOGY AND MEDICINE
YJBM
CELEBRATING 95 YEARS 1928–2023

Positive Association of Aggression with Ambient Temperature

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Background: Relatively little attention has been paid to the potential effects of rising temperatures on changes in human behavior that lead to health and social consequences, including aggression. This study investigated the association between ambient temperature and aggression using assault death data from Seoul, South Korea (1991–2020). **Methods**: We conducted a time-stratified case-crossover analysis based on conditional logistic regression to control for relevant covariates. The exposure-response curve was explored, and stratified analyses were conducted by season and sociodemographic characteristics. **Results**: The overall risk of assault deaths significantly increased by 1.4% per 1°C increase in ambient temperature. A positive curvilinear relationship was observed between ambient temperature and assault deaths, which flattened out at 23.6°C during the warm season. Furthermore, risk increases were higher in males, teenagers, and those with the least education. **Conclusion**: This study highlighted the importance of understanding the impact of rising temperatures on aggression in the context of climate change and public health.

INTRODUCTION

Climate change is widely recognized as one of the most significant global challenges faced by humanity this century [1]. It has various adverse impacts on public health, including increased respiratory and cardiovascular diseases, injuries, and premature deaths related to extreme weather events, and changes in the prevalence and geographical distribution of food-and water-borne illnesses and other infectious diseases [2].

Despite the growing recognition of the health implications of climate change, relatively less attention has been placed on how rising temperatures may affect possible changes in human behavior that negatively impact health and society, such as aggression and violence. Research conducted thus far on the association between temperature and aggression is still in its preliminary stages, and the findings have been mixed. A previous study in the United States found that average annual temperatures were positively and significantly correlated with violent

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Keywords: Climate change, ambient temperatures, aggression, assault deaths, violence

Author Contributions: SEK: Conception and design, Data Analysis, Writing, Review and Editing. YK, YHonda, MH, OK, YHijioka, HK: Conception and design, Review and Editing.

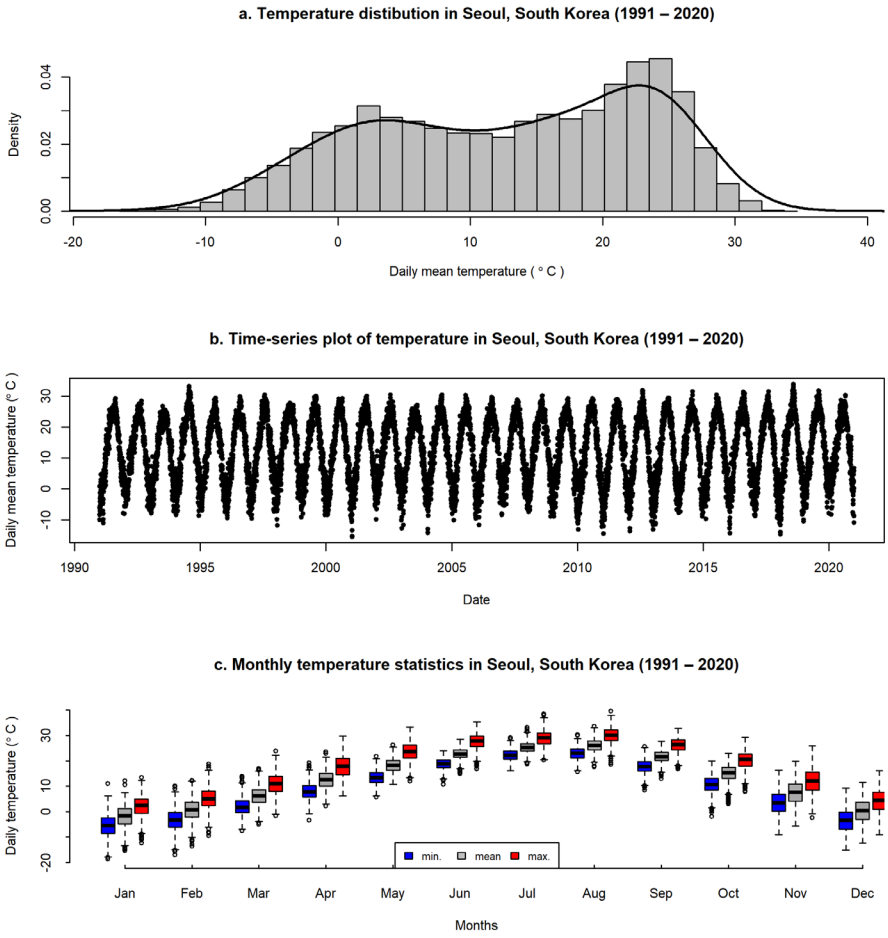

Figure 1. **Climate of Seoul, South Korea, between 1991 and 2020**.

crime rates (homicide and assault) but not with nonviolent crime rates (burglary and motor vehicle theft) [3]. Another study in Spain found that heatwaves were associated with an increase in intimate partner femicides [4]. In contrast, a study in Colombia found no evidence of an association between weather patterns and homicides [5].

Therefore, in the context of climate change and public health, it is crucial to understand the impact of rising temperatures on aggression across locations, as this information can help policymakers develop effective public health interventions to mitigate the negative effects of climate change. This study investigated the association between ambient temperature and aggression using assault death data from Seoul, South Korea.

METHODS

Study Location and Data Collection

The research was conducted in Seoul, the capital and largest city of South Korea, which is characterized by a high population density with a total population of 10 million residing within a 605.23 square kilometer area. Seoul has four distinct seasons accompanied by varying temperatures, called "Dwa" in the Köppen climate classification [6]. The city experiences cold and dry winters from December to February, with daily mean temperatures averaging around -2°C in January, which are the coldest months. Summers are hot and humid, with daily mean temperatures ranging from 23°C to 26°C from June to August (Figure 1).

In terms of safety, South Korea exhibits lower rates of crime, homicide, and gun homicide than other high-income countries. According to the United Nations Office on Drugs and Crime (UNODC), the intentional homicide rate in South Korea was 0.7 per 100,000 population in 2018, which is lower than the global average of 6.1 per 100,000 population [7]. Additionally, the firearm homicide rate in South Korea is one of the lowest in the world, at 0.0005 per 100,000 people [7]. We collected assault death data, which were defined according to the International Classification of Diseases, Tenth Revision (ICD-10: X85-Y09, Y871, U01-U02) between January

Table 1. Assault Deaths in Seoul, South Korea, Between 1991 and 2020

		No. of cases	(%)
Total		3,593	100
Season	Warm (Apr–Sep)	1,883	52.41
	Cool (Oct–Mar)	1,710	47.59
Sex	Male	2,067	57.53
	Female	1,526	42.47
Age (years)	0–9	234	6.51
	10–19	175	4.87
	20–29	521	14.5
	30–39	701	19.51
	40–49	816	22.71
	50–59	608	16.92
	60–69	286	7.96
Total (Subjects over 18 y of age)		3,242	100
Education	None to Primary School	706	22.26
	Middle School	646	20.37
	High School	1269	40.02
	Undergraduates	524	16.52
	Graduates	26	0.82
	(Missing)	71	2.19
Occupation	White collar	529	16.37
	Blue collar	478	14.79
	Service and sales workers	638	19.74
	Unemployed	1587	49.1
	(Missing)	10	0.31
Marital status	Single	945	29.15
	Married	1510	47.14
	Divorced	464	14.49
	Bereaving	284	8.87
	(Missing)	39	1.2

1, 1991 and December 31, 2020, from Statistics Korea. Meteorological data on 24 h mean temperatures (°C) and relative humidity (%) were obtained from the Korean Meteorological Administration (KMA).

Statistical Analyses

A time-stratified case-crossover design analysis based on conditional logistic regression was used to analyze the short-term effects of ambient temperature on assault deaths after controlling for the relative humidity. The time-stratified case-crossover design is a study design commonly used in environmental epidemiology to investigate the effects of acute exposure to environmental factors on short-term health outcomes, such as hospitalization, emergency room visits, or mortality [8]. This design allows for the evaluation of the short-term effects of ambient temperature on assault deaths, while minimizing the potential for confounding by controlling for temporal factors and time-invariant confounding factors. In this design, cases are defined based on the occurrence of an outcome of interest, such as a death from assault. Control days were selected from the same month and year as the case and matched by day of the week to account for any weekly patterns in the outcome occurrence. By using the case as their own control, any time-invariant confounding factors are automatically controlled by this design. Additionally, matching by time helps to control confounding due to seasonality, long-term trends, and other time-varying factors. A conditional logistic regres-

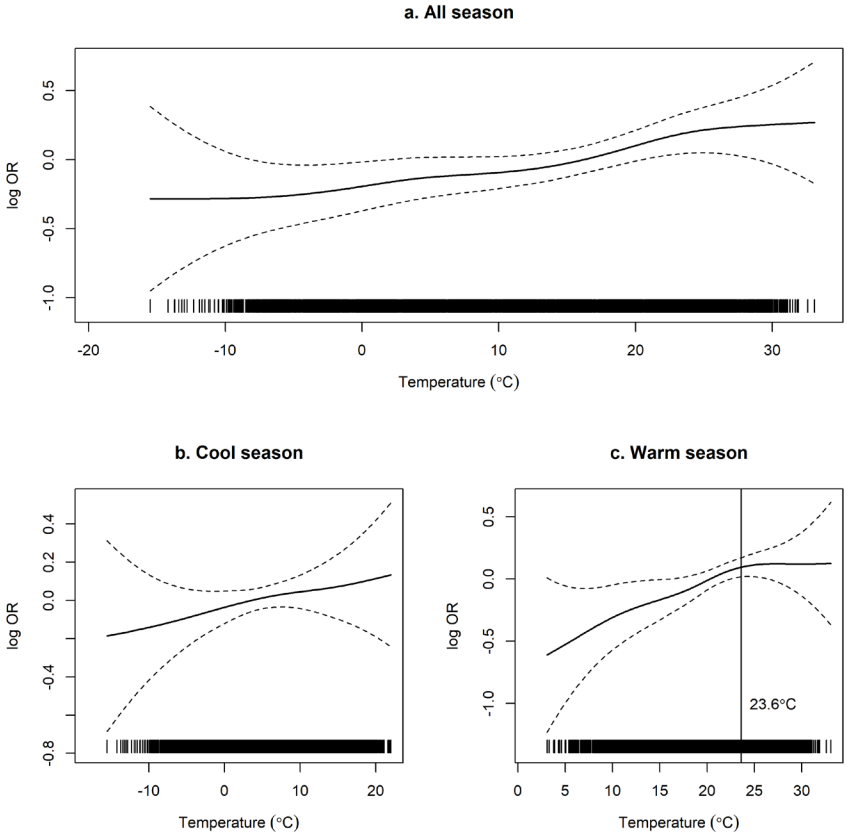

Figure 2. **Exposure-response curve between the ambient temperature and assault deaths after controlling for humidity in Seoul, South Korea, between 1991 and 2020** in **a**. all seasons, **b**. the cool season (October–March), and **c**. the warm season (April–September). The solid lines represent the estimated log-odds ratios of the temperature variable, and the dotted lines represent the 95% confidence intervals. The solid vertical lines at the bottom of each figure indicate the reference values for each temperature value, which were used as the baseline for the log-odds ratio estimates.

sion model was used to estimate the odds of assault death on the case day compared to the control day. Additional potential confounding factors, such as relative humidity, were also adjusted for in the model.

The exposure–response curve of the association between ambient temperature and assault deaths was also explored. Temperature-assault death associations may vary with the time of year; therefore, seasonal variations in the temperature-assault death association were further analyzed in "warm" and "cool" seasons, defined as April–September and October–March, respectively. We visualized the relationship between the temperature variable and the log-odds of the outcome in a conditional logistic regression model using a natural cubic spline function specified for the temperature variable. Although the exposure-response curve was quite linear during the cold season, we observed a flattening of the curve at some point during the warm season. To identify this temperature point at which flattening was observed, we fitted piecewise linear regressions to the spline curve obtained from the conditional logistic model [9,10]. A grid search method was conducted using an equally spaced grid of 0.1°C from a temperature range of 20°C to 30°C to identify the temperature that produced the minimum Akaike information criterion (AIC).

Temperature-assault death associations could possibly be modified by sociodemographic factors, and we conducted stratified analyses based on sociodemographic characteristics, including sex, age, education level, occupation, and marital status. We calculated the odd ratios of mortality for a 1°C increase in ambient temperature, and the results are presented as the percent increase in assault deaths, with the corresponding 95% confidence interval (CI). The statistical significance of the difference between subgroup-specific effects was evaluated using the *p*-value of the interaction term.

All analyses were performed using the statistical software R version 4.1.1 (R Foundation for Statistical

Table 2. Odds Ratios from the Stratified Analyses

		OR (95% CI[a])
Total		1.014 (1.003, 1.026) *
Season	Warm (Apr–Sep)	1.025 (1.005, 1.045) *
	Cool (Oct–Mar)	1.009 (0.994, 1.023)
Sex	Male	1.023 (1.009, 1.039) *
	Female	1.002 (0.985, 1.019)
Age (years)	0–9	1.012 (0.968, 1.057)
	10–19	1.073 (1.016, 1.134) *
	20–29	1.004 (0.975, 1.034)
	30–39	0.988 (0.963, 1.014)
	40–49	1.026 (1.003, 1.050) *
	50–59	1.030 (1.003, 1.058) *
	60–69	1.005 (0.968, 1.043)
	70+	1.011 (0.970, 1.054)
Total (Subjects over 18 y of age)		
Education	None to Primary School	1.042 (1.016, 1.068) *
	Middle School	1.017 (0.991, 1.044)
	High School	0.993 (0.975, 1.012)
	Undergraduates	1.011 (0.982, 1.041)
	Graduates	1.010 (0.889, 1.147)
	(Missing)	
Occupation	White collar	1.017 (0.989, 1.046)
	Blue collar	1.004 (0.974, 1.035)
	Service and sales workers	1.014 (0.988, 1.041)
	Unemployed	1.013 (0.996, 1.031)
	(Missing)	
Marital status	Single	0.997 (0.976, 1.019)
	Married	1.015 (0.998, 1.032)
	Divorced	1.020 (0.988, 1.053)
	Bereaving	1.032 (0.992, 1.074)
	(Missing)	

[a]CI: confidence interval

Computing, Vienna, Austria).

RESULTS

During the study period (1991–2020), there were 3,593 assault death cases and 12,256 control days, yielding three or four controls for each case (Table 1).

We observed that the ambient temperature was positively associated with assault deaths in a curvilinear manner (Figure 2a). The overall risks significantly increased by 1.4% [95% confidence interval (CI): 0.3% – 2.6%)] per 1°C increase in ambient temperature. For a 1°C increase in ambient temperature, 0.9% (95% CI: -0.6% – 2.3%), and 2.5% (95% CI: 0.5% – 4.5%) increases in the risk of assault deaths were observed in the cool and warm period, respectively (Figure 2b and 2c). Through grid searching, we identified that the flattening-out temperature was 23.6°C during the warm season (Figure 2c). Risk increases in males [2.3% (95% CI: 0.9% – 3.9%)] were higher than in females [0.2% (95% CI: -1.5% – 1.9%)], yet the interaction term between the two groups was not statistically significant (p=0.09). Teenagers [7.3% (95% CI: 1.6% – 13.4%)] were found to be most susceptible among the age groups. Among the assault deaths of over 18-year-olds, the highest associations were observed in the group with the least education [none to primary

school, 4.2% (95% CI: 1.6% – 6.8%)]. Occupation and marital status did not appear to considerably modify this association (Table 2).

DISCUSSION

This study investigates the association between ambient temperature and assault deaths. The results showed that the overall risk of assault death increased by 1.4% per 1°C increase in ambient temperature, particularly in males, teenagers, and people with less education. Occupation and marital status did not appear to considerably affect this association. These results are consistent with previous studies and can be explained by several plausible justifications. Heat stress may increase irritability and aggressive behavior by affecting cognitive processes and neurotransmitter activity in the brain [11,12]. Another reason may be that there are more opportunities for assaults. As the weather gets warmer, more people go outside and days are longer, increasing social interaction and, in turn, more opportunities for interpersonal conflict. This suggestion is supported by Routine Activity Theory, which states that for a crime to occur, there must be a motivated offender, a suitable target, and the absence of a capable guardian [13]. In warmer weather, there may be an increase in motivated offenders and suitable targets, such as individuals spending time outdoors, which can lead to an increase in interpersonal conflict and aggression. Additionally, an increase in social interaction during warmer months may decrease the presence of capable guardians, such as law enforcement or other authority figures, leading to an increase in aggressive behavior. Overall, these explanations suggest that temperature can have a significant impact on human behavior and social interactions.

The overall shape of the exposure-response curve suggests a positive relationship between temperature and assault deaths, implying that as temperature increases, the likelihood of aggressive behavior also increases. However, the curve flattens, especially in the warm season, as the temperature reaches 23.6°C. This finding aligns with research by Baron and Bell, who conducted experiments on the relationship between heat and aggression in humans and found that extremely high temperatures can inhibit aggressive behaviors [14]. This may be because excessively high temperatures can lead to physical discomfort, fatigue, and dehydration, which can increase irritability and decrease cognitive function, potentially limiting an individual's ability to engage in aggressive behaviors. Additionally, during the hot season, people are more likely to seek shelter indoors, which can moderate the effects of temperature on behavior and reduce opportunities for social interaction and interpersonal conflict. However, it should be noted that the confidence interval above the threshold temperature is wide, largely due to the small number of very hot days. We also acknowledge that the existing literature on the association between temperature and aggression has produced varied findings. For example, Anderson et al. and Mullins et al. have suggested positive linear relationships between temperature and aggression without clear flattening points [3,15], while Heilmann et al. have suggested an inverted hockey stick shape, and Baylis suggested an inverted U-shape [16,17]. The differences in the reported temperature thresholds and the association patterns for aggression may be due to contextual differences across studies or focusing on different outcomes. For instance, Heilmann et al. focused on the crime rate, Baylis focused on temperament on Twitter, and Mullins et al. focused on mental health. Additionally, it is important to note that the effects of a given temperature on health outcomes vary spatially based on how unusual the temperature is for that location.

The findings of this study indicate that certain subgroups of the population may be more vulnerable to the effects of temperature on assault deaths. Teenagers and individuals with lower levels of education were at higher risk of temperature-related assault deaths, possibly because those predisposed to aggressive or violent behavior may perceive them as easy targets. In fact, research by Parks et al. suggests that teenagers and young adults are more susceptible to heat-related assaults because they are more likely to be out and about during the summer months when temperatures are higher [18]. Contrary to expectations, we found that males experienced a higher number of assault-related deaths and were more vulnerable to temperature effects than females. It is important to note that these results are based on an observational study and do not necessarily indicate causation. Further research is necessary to explore the underlying factors contributing to this disparity and to develop targeted interventions to address this issue.

This study primarily investigated the short-term effects of temperature on aggression; however, it is important to consider its long-term impacts on collective mental health in the context of climate change. The CLimate, Aggression, and Self-control in Humans (CLASH) model theory posits that rising temperatures can lead to a loss of self-control and planning for the future, further exacerbating aggression and potentially leading to violent behavior [19]. Economic factors are also important considerations [20]. With climate change, extreme weather events, such as heat waves, droughts, and floods, have become more frequent, resulting in food shortages and economic losses that disproportionately affect vulnerable populations. Income disparities and poverty rates may increase, which can contribute to feelings of resentment and dissatisfaction with life, potentially leading to violent behavior.

It is evident that climate change is no longer just a concern for scientists and environmental groups but an undeniable reality affecting our daily lives. As urbanization continues to increase, these negative effects may become more pronounced [21], making it imperative to adopt adequate adaptation measures to mitigate these impacts. Education and awareness-raising efforts targeting the public, along with policy changes made by government officials and politicians, are crucial steps in addressing climate change and its impact on violence. Additionally, law enforcement and community leaders should be vigilant and proactive in identifying and preventing potential incidents of aggression or violence, especially those targeting vulnerable groups.

In conclusion, the results of this study indicated a positive and curvilinear relationship between ambient temperature and aggression. Furthermore, certain population subgroups might be more vulnerable to the effects of temperature on aggression. However, this relationship is complex and influenced by various factors such as temperature levels, time of year, and individual differences in cognitive and physiological responses to heat stress. Further research is necessary to fully comprehend the mechanisms underlying the relationship between temperature and aggression and to create effective interventions to mitigate the negative effects of extreme heat on human behavior. By identifying the underlying mechanisms, we can develop targeted interventions that aim to reduce violent crime and promote public safety during the warm season. It is also crucial to note that public health interventions aimed at reducing violent crime during the warm season should target vulnerable groups specifically.

Although there have been other studies on the subject, we believe that ours is the first to explore the relationship between assault deaths and temperature specifically in Seoul. Despite the importance of our findings, several limitations should be taken into consideration. First, owing to its observational design, it was difficult to establish a causal relationship between temperature and assault deaths. Another limitation is the lack of data on perpetrators. While we utilized national mortality data to examine the association between assault deaths and ambient temperature, we did not have access to data on the perpetrators' characteristics, including their demographic information. This limits our ability to explore how heat can influence aggressive behavior for various subgroups of perpetrators. We recognize the significance of investigating this issue in future research. Lastly, the data were obtained from a single city, which may limit the generalizability of the findings to other settings. For instance, South Korea's stringent gun regulations have resulted in an extremely low gun homicide rate, which may not be comparable to other countries. To address these limitations, future research should employ a multicity-based approach to investigate the association between temperature and aggression in diverse geographical locations.

Acknowledgments: The authors acknowledge the "Support for continued research and return to make career-building compatible with childcare and nursing care project for 2022" funded by the Center for Diversity, Accessibility and Career Development, University of Tsukuba, the JSPS Grants-in-Aid for Scientific Research (KAKENHI; 21K17894) in Japan, and the Climate Change Adaptation Research Program of the National Institute for Environmental Studies, Japan.

REFERENCES

1. IPCC. AR6 Synthesis Report: Climate Change 2023. 2023.
2. World Health Organization. Climate change and human health: impact and adaptation [Internet]. World Health Organization; 2000. Available from: https://apps.who.int/iris/bitstream/handle/10665/66776/WHO_SDE_OEH_00.4.pdf
3. Anderson CA, Delisi M. Implications of global climate change for violence in developed and developing countries. The Psychology of Social Conflict and Aggression. Taylor and Francis; 2011. pp. 249–65.
4. Sanz-Barbero B, Linares C, Vives-Cases C, González JL, López-Ossorio JJ, Díaz J. Heat wave and the risk of intimate partner violence. Sci Total Environ. 2018 Dec;644:413–9.
5. Trujillo JC, Howley P. The Effect of Weather on Crime in a Torrid Urban Zone. Environ Behav. 2021 Jan;53(1):69–90.
6. Beck HE, Zimmermann NE, McVicar TR, Vergopolan N, Berg A, Wood EF. Present and future Köppen-Geiger climate classification maps at 1-km resolution. Sci Data [Internet]. 2018 [cited 2023 Apr 16];5.
7. UNODC. Global Study on Homicide. Homicide Trends, Patterns and Criminal Justice Response. United Nations Office on Drugs and Crime Vienna; 2019.
8. Whitaker HJ, Hocine MN, Farrington CP. On case-crossover methods for environmental time series data. Environmetrics. 2007;18(2):157–71.
9. Toms JD, Lesperance ML. Piecewise regression: A tool for identifying ecological thresholds. Ecology. 2003 Aug;84(8):2034–41.
10. Lerman PM. Fitting Segmented Regression Models by Grid Search. Appl Stat. 1980;29(1):77.
11. Lõhmus M. Possible biological mechanisms linking mental health and heat—a contemplative review. Vol. 15, Int J Environ Res Public Health. Multidisciplinary Digital Publishing Institute (MDPI); 2018.
12. Cianconi P, Betrò S, Janiri L. The Impact of Climate Change on Mental Health: A Systematic Descriptive Review. Front Psychiatry. 2020 Mar;11:74.
13. Miró F. Routine Activity Theory. The Encyclopedia of Theoretical Criminology. Chichester, UK: John Wiley & Sons, Ltd; 2014. pp. 1–7.
14. Bell PA, Baron RA. Aggression and Heat: The Mediating Role of Negative Affect. J Appl Soc Psychol. 1976 Mar;6(1):18–30.
15. Mullins JT, White C. Temperature and mental health: evidence from the spectrum of mental health outcomes. J

Health Econ. 2019 Dec;68:102240.
16. Heilmann K, Kahn ME, Tang CK. The urban crime and heat gradient in high and low poverty areas. J Public Econ. 2021;197:197.
17. Baylis P. Temperature and temperament: evidence from Twitter. J Public Econ. 2020:184.
18. Parks RM, Bennett JE, Tamura-Wicks H, Kontis V, Toumi R, Danaei G, et al. Anomalously warm temperatures are associated with increased injury deaths. Nat Med 2020;26(1):65–70. Available from: https://www.nature.com/articles/s41591-019-0721-y
19. Van Lange PA, Rinderu MI, Bushman BJ. Aggression and violence around the world: A model of CLimate, Aggression, and Self-control in Humans (CLASH). Behav Brain Sci. 2017 Jan;40:e75.
20. Hsiang SM, Burke M, Miguel E. Quantifying the Influence of Climate on Human Conflict. Sci. 2013 Sep 13;341(6151). https://doi.org/10.1126/science.1235367.
21. Garschagen M, Romero-Lankao P, Garschagen M, Romero-Lankao P. Exploring the relationships between urbanization trends and climate change vulnerability. Clim Change. 2015;133(1):37–52.