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Extremely Hot Ambient Temperature and Injury-related Mortality

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Abstract

This pilot study aimed to evaluate the effects of extremely hot ambient temperatures on the total number of fatal injuries. Data were collected from a population-based mortality registry of Thanh Hoa, a province in the North Central region of Vietnam. This study qualified the distributed lag non-linear model and calculated the RR and 95% CI adjusted for long-term trend and absolute humidity. For the entire study population with 3,949 registered deaths due to injuries collected during 2005-2007, after the onset of extremely hot ambient temperatures, an increased risk of death was observed on the 9th day RR (95% CI) = 1.44 (1.06–1.97), and reached the peak on the 12th day RR (95% CI) = 1.58 (1.14–2.17), and at the 15th day RR (95% CI) = 1.49 (1.08–2.06). Men and old adults were identified as the most vulnerable groups. This study confirmed a positive association between hot temperatures and injury-related deaths in the province of 3.6 million people. The findings motivated further investigation into the effect of warm climate changes and the risk of deaths related to other specific causes such as road traffic, work-related injury, and etc.

Keywords: distributed lag non-linear model, fatal injuries, hot ambient temperature

Introduction

The Intergovernmental Panel on Climate Change reported that the global surface temperature was 1.09°C higher in 2011–2020 than in 1850–1900.[1] Global warming is well known to cause a rise in adverse health effects on humans. Extremely high temperatures trigger cumulative physiological stress on the human body and increase incidence rates of mortality,[2] and hospital admissions.[3] Previous studies highlighted the heat on all-cause mortality,[4,5] or specific diseases, such as cardiovascular,[6,7] and respiratory illness.[8,9] Few studies still discuss the association between temperature and injury mortality.

This study investigated the effect of hot temperatures on injury-related mortality among adults (aged ≥16 years) in Thanh Hoa Province, Vietnam. The study population of interest was in the North Central region of Vietnam, with a registered population of over 3.6 million during 2005–2007. The distributed lag non-linear model (DLNM) proposed by Gasparrini,[10] was applied to identify the lag effects of temperature anomalies on the incidence of injury-related death. Moreover, age- and sex-specific analyses were performed to implement a more targeted preventative strategy.

This study was motivated by several perspectives. First, injury-related deaths are remarkably high in Vietnam. Injury-related deaths are characterized by both unintentional events (poisonings, falls, and road traffic accidents) and intentional behaviors (self-harm, assault, and suicide).[11] Vietnam is presently regarded as one of the fastest-growing economies in Southeast Asia, and it is becoming a more significant contributor to the global economy.[12] This change contributes to increased mortality risk due to injury because infrastructure and safety provisions fail to keep up with economic development. Injury-related deaths account for 9% of total deaths and are mainly caused by road injuries, falls, exposure to mechanical forces, and interpersonal violence.[13] Road traffic accidents are always among the leading causes of death in Vietnam. The incidence of road traffic accidents is reported as the highest rate globally (30.54 deaths per 100,000 population in 2019).[14]

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Second, epidemiological studies have stated that extremely hot temperatures affect human behaviors and feelings. Miles-Novelo and Anderson,[15] concluded that hot temperatures increase aggression and violence. Similarly, Noelke, *et al.*,[16] reported that daily average temperatures above 21°C diminish positive feelings and magnify negative ones. Long-term exposure to hot temperatures is linked with high incidence rates of assault cases in South Wales, Australia.[17] Grjibovski, *et al.*,[18] used time series regression analysis and found that a 2.1% rise in suicide rates in Astana, Kazakhstan, is associated with a 1°C increase in average ambient temperature. These results then motivated a study to examine whether injury-related deaths are affected by hot temperatures. Therefore, this study aimed to evaluate the effects of extremely hot ambient temperatures on total fatal injury rates in Vietnam.

Method

Time series analysis determined the relationship between the health outcome and risk factors. The dependent variable was the daily mortality caused by injury, described by the International Classification of Diseases code from S00 to Y59. In Vietnam, the lack of consistent, reliable national mortality data continues to be a serious problem.[19] Currently, data on annual mortality are exclusively derived from the Government Statistics Office's yearly mortality surveys.

Daily counts of deaths in Thanh Hoa Province were obtained from the Vietnamese A6 mortality reporting system, a logbook used to routinely record every death event noted by primary health care (PHC) staff across the country. Data on population-based mortality registration were very good, with completeness, sensitivity, specificity, and positive predictive values of 94%, 75.4%, 98.4%, and 88.4%, respectively.[20] The database from the A6 system was not, however, regularly shared and publicized. There was only access to Thanh Hoa Province's daily death tolls from 2005 to 2007. Thus, this investigation was conducted as a pilot study to determine the relationship between hot temperatures and injury-related deaths in Vietnam. A temporal and geographic extent will be conducted in the future after the complete data is obtained.

The data sets consisted of daily counts of deaths and meteorological data in Thanh Hoa Province from 1 January 2005 to 31 December 2007. Mortality data consisted of the death date, sex, and age. Age was categorized as 16-29 years (young adults), 30-59 years (middle-aged adults), and ≥60 (old adults). The weather data were obtained from the National Center for Hydrometeorological Forecasting,[21] including the daily average temperature (°C) and absolute humidity (g/m^3).

Table 1 summarizes the descriptive statistics of daily injury-related mortality and weather data. This study identified 3,949 injury-related deaths in 2005 to 2007, with the average daily count being approximately four cases, higher for men and adults. The daily mean temperature was 24.13°C, ranging from 11.2°C to 33.1°C. The daily mean absolute humidity was 18.48 g/m^3, ranging from 5.90 to 25.8 g/m^3.

It was necessary to determine the statistical distribution that best fits the injury mortality variable. The Poisson and negative binomial distributions commonly describe the count data. Table 2 presents the goodness-of-fit criteria. Akaike information criterion (AIC) and Bayesian information criterion (BIC) are derived from the maximum likelihood estimation. The Chi-squared statistics with Poisson assumption was 48.96, whereas it was only 4.21 in the case of a negative binomial distribution. Thus, the null hypothesis that injury mortality followed the negative binomial distribution was supported. Also, the smaller AIC and BIC confirmed again that the negative binomial distribution fitted the data better than the Poisson distribution.

The negative binomial distribution combined with the distributed lag non-linear model (DLNM) proposed by Gasparini,[10] was used to identify the potential delayed

Table 1. Summary of the Descriptive Statistics of Daily Injury-related Mortality and Weather Data

Variable		Mean	SD	Percentile				
				Min	25th	50th	75th	Max
Injury-related death		3.05	2.00	0.00	2.00	3.00	4.00	11.00
Sex	Male	1.73	1.87	0.00	1.00	2.00	3.00	11.00
	Female	0.87	1.02	0.00	0.00	1.00	1.00	4.00
Age	16–29 years	1.09	1.14	0.00	0.00	1.00	2.00	7.00
	30–59 years	1.23	1.22	0.00	0.00	1.00	2.00	7.00
	≥60 years	0.72	0.86	0.00	0.00	1.00	1.00	5.00
Temperature (°C)		24.13	4.80	11.20	20.40	25.20	28.10	33.10
Absolute humidity(g/m^3)		18.48	4.79	5.90	14.90	19.70	22.70	25.80

Note: SD = Standard Deviation

effects of daily temperature on injury mortality in Thanh Hoa Province. The supposed DLNM to temperature,[22] is given as in Formula 1. The non-linear temperature and lagged effects were modeled using a natural cubic spline. The two spline knots of temperature were placed at the 33.3rd and 66.7th percentiles, whereas only one knot was placed at the median of the logarithm scale of lags. Because of the long-lagged effect of temperature on mortality, the maximum lag at 30 days was often used to determine the overall temperature effects completely.[23,24] The cubic spline bases,[25] were used to control the non-linear effect of some confounders, including long-term trends and absolute humidity. The degree of freedom (df) was 7 per year and 3 for trend and absolute humidity, respectively. The degrees of freedom of the temperature–lag–response curve and the smoothing function of confounders were chosen by minimizing the quasi-AIC. The days of the week were included as dummy variables. The estimated relative risk (RR) was computed relative to the reference median temperature value at 25.2°C. The significant level was chosen at 5%.

Results

Figure 1 shows the overall effects of daily mean temperatures on injury mortality over 30 days, with 95% confidence intervals (95% CIs). The exposure–response curves for cumulative effects on the total population and men were non-linear with a J-shaped curve, where the RR changed gradually and increased rapidly at low and high temperatures, respectively. The overall effects of heat exposure on injury mortality were estimated at an RR of 1.40 (95% CI = 0.99–1.99) and 1.41 (95% CI = 0.94–2.11) in the total population and men, respectively. The overall curve for women was U-shaped, but it showed that both cold and heat had no significant effect on injury-related deaths.

The single lag effects of heat on injury mortality, with 25.2°C as a reference, are presented in Figure 2. The hot temperature increased injury mortality by 1.15 (95% CI = 0.80–1.64) and 1.56 (95% CI = 0.88–2.76) for men and women, respectively, but these relationships were not statistically significant. Furthermore, no single significant effect was found along the lags.

The cumulative RRs of extremely hot temperatures on injury mortality at different lags are shown in Table 3. The cumulative effects of the heat on female mortality induced by injuries were found to be insignificant at every lag. No significant cumulative RR was observed for the total population during 0-8 days lags. Excessive heat events lasting at least nine consecutive days significantly increased the risk of fatal injury. Statistically significant results among men started at lag 9 and lasted until 15. Besides, injury mortality had the highest risk of death related to the extremely hot temperature on day 12 after

Table 2. Goodness-of-fit Criteria Comparing the Performance of Poisson and Negative Binomial Distributions

	Chi-squared Statistic	AIC	BIC
Poisson distribution	48.96 (<0.001)	4510.378	4515.37
Negative binomial distribution	4.21 (0.65)	4468.67	4478.66

Notes: AIC = Akaike Information Criterion, BIC = Bayesian Information Criterion, p-values are in parentheses

$$Y_t \sim \text{Negative binomial}$$
$$\log(\mu t) = \alpha + f\cdot g(Temp_t\,, lag) + s(trend, df = 7/year) + s(AH_t, df = 3) + \theta Dayt$$

Notes:
Yt is the observed daily all-cause mortality at day t;
μt is the expected mortality on day t;
$f\cdot g(Temp_t, lag)$ denotes the bidimensional function on temperature and lag produced by the distributed lag non-linear model (DLNM);
s(trend) and s(AH) are the smoothing functions for trend and absolute humidity (g/m^3), respectively; and
Day_t is the day of the week dummy variables.

Formula 1. Distributed Lag Non-linear Model to Temperature[22]

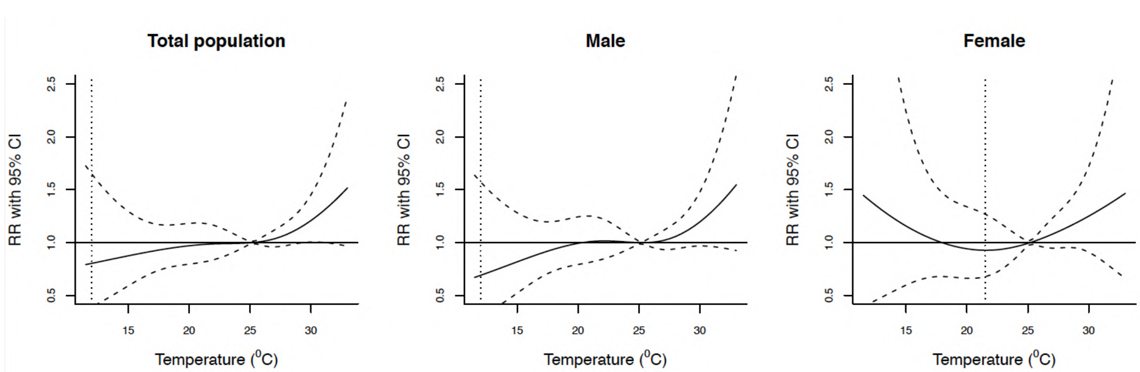

Figure 1. Cumulative Exposure–Response Relationships between Mean Temperature and Injury Mortality over 0-30 Days

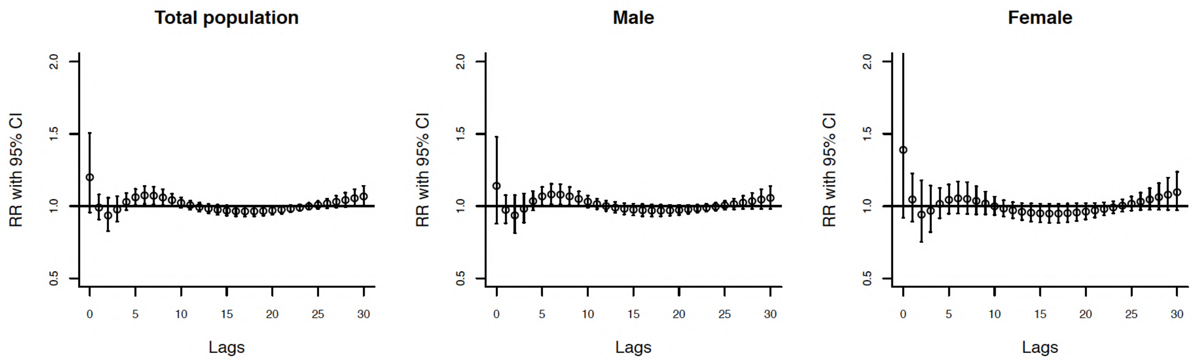

Figure 2. The Single-day Relative Risk (RR) of Extremely Hot Temperature on Injury Mortality over 0-30 Days

Table 3. Cumulative Relative Risks (95% Confidence Interval) of the Heat Effects on Injury-related Mortality over Different Lags (Entire Study Population)

Lag	Relative Risks (95% CI)		
	Total Populaton	Male	Female
0	1.24 (0.91–1.70)	1.14 (0.80–1.64)	1.56 (0.88–2.76)
0–1	1.13 (0.82–1.56)	1.14 (0.79–1.65)	1.10 (0.61–1.97)
0–5	1.25 (0.92–1.71)	1.21 (0.85–1.73)	1.38 (0.78–2.44)
0–9	1.44 (1.06–1.97)*	1.41 (0.99–2.01)	1.55 (0.89–2.72)
0–10	1.51 (1.11–2.06)*	1.48 (1.04–2.11)*	1.63 (0.93–2.84)
0–11	1.56 (1.14–2.14)*	1.53 (1.07–2.19)*	1.67 (0.95–2.93)
0–12	1.58 (1.14–2.17)*	1.56 (1.08–2.24)*	1.66 (0.94–2.95)
0–13	1.57 (1.13–2.17)*	1.55 (1.07–2.25)*	1.62 (0.91–2.90)
0–14	1.53 (1.11–2.12)*	1.53 (1.06–2.22)*	1.55 (0.87–2.77)
0–15	1.49 (1.08–2.06)*	1.50 (1.04–2.17)*	1.47 (0.83–2.61)
0–20	1.21 (0.86–1.69)	1.27 (0.86–1.86)	1.06 (0.58–1.94)
0–25	1.11 (0.78–1.60)	1.17 (0.78–1.77)	0.95 (0.49–1.83)
0–30	1.40 (0.97–1.99)	1.41 (0.94–2.11)	1.37 (0.74–2.55)

Notes: CI = Confidence Interval, *Values indicate statistically significant results at 5%.
Heat effect is the relative risk at the 99th percentile of temperature (32°C) against the reference temperature (25.2°C).

Table 4. Cumulative Relative Risks (95% Confidence Interval) of the Heat Effects on Injury Mortality over Different Lags by Age Groups

Lag	Relative Risks (95% CI)		
	Young Adults	Middle-aged Adults	Old Adults
0	1.19 (0.72–1.95)	1.16 (0.72–1.87)	1.50 (0.84–2.68)
0–1	1.45 (0.87–2.43)	1.03 (0.63–1.69)	0.90 (0.50–1.64)
0–5	1.16 (0.71–1.88)	1.39 (0.86–2.23)	1.22 (0.69–2.16)
0–9	1.55 (0.96–2.51)	1.41 (0.88–2.26)	1.39 (0.79–2.44)
0–10	1.63 (1.01–2.62)*	1.42 (0.88–2.29)	1.55 (0.89–2.72)
0–11	1.67 (1.03–2.71)*	1.43 (0.88–2.32)	1.70 (0.96–2.99)
0–12	1.67 (1.02–2.74)*	1.42 (0.87–2.32)	1.80 (1.01–3.20)*
0–13	1.65 (0.99–2.72)	1.40 (0.85–2.30)	1.84 (1.03–3.30)*
0–14	1.60 (0.97–2.64)	1.37 (0.83–2.25)	1.85 (1.03–3.30)*
0–15	1.53 (0.93–2.53)	1.33 (0.81–2.19)	1.81 (1.02–3.23)*
0–20	1.20 (0.71–2.03)	1.17 (0.70–1.95)	1.41 (0.77–2.57)
0–25	1.12 (0.64–1.96)	1.16 (0.67–2.00)	1.15 (0.60–2.18)
0–30	1.52 (0.88–2.63)	1.48 (0.87–2.51)	1.26 (0.67–2.37)

Notes: CI = Confidence Interval, *Values indicate statistically significant results at 5%.
Heat effect is the relative risk at the 99th percentile of temperature (32°C) against the the reference temperature (25.2°C).

exposure, with cumulative RRs of 1.58 (95% CI = 1.14–2.17) and 1.56 (95% CI = 1.08–2.24) for the total population and men.

The cumulative RRs of sweltering temperatures on age-specific injury mortality are shown in Table 4. Old adults (≥60 years) seemed to have the highest risk of dying due to injuries. The RRs associated with high temperature were significant at lags 0-12 days (RR = 1.80, 95% CI = 1.01–3.20) to lags 0-15 days (RR = 1.81, 95% CI = 1.02–3.23). The highest cumulative effect was observed 14 days after exposure to hot temperatures (RR = 1.85, 95% CI = 1.03–3.30). Among young adults, the cumulative heat effects increased the risk of injury-related death significantly at a lag of 0-10 days with cumulative RRs of 1.63 (95% CI =1.01–2.62) and reached the peak RRs at lags of 0–12 days with cumulative RRs of 1.67 (95% CI = 1.02–2.74). Regarding middle-aged adults, there were no significant cumulative heat effects.

Discussion

This study observed a significantly increased risk of death 9-15 days after the onset of extremely hot ambient temperatures for the total population. Men and old adult subpopulations were identified as the most vulnerable groups to high temperatures. Excessive heat events lasting at least nine consecutive days increased the risk of fatal injury. Statistically, significant results among men started at a lag of 9 days and lasted up to 15 days.

Long-term exposure to sweltering temperatures was significantly associated with an increased risk of injury mortality. In agreement with the findings of this study, Kim confirmed that hot temperatures significantly caused accidental mortality rates in Korea.[26] Also, Sheng, *et al.*, stated that a 1°C increase in maximum temperature is related to a 1.4% increase in daily injury claims in Guangzhou, China.[27] In a review by Otte, *et al.*, 11 out of 13 studies confirmed that high temperatures increased unintentional injuries.[28]

It is possible to outline several specific mechanisms by which high temperatures could increase the frequency of injury-related mortality. On hot days, physical issues (fatigue and dizziness) and mental issues (inability to focus, irritability, and mood swings) often occur.[29] These issues reduce the work performance of humans and exacerbate the risk of unintentional injuries. Increased discomfort in hot weather contributes to increased sentiments of animosity and violent thoughts, which may result in aggressive behavior and indirectly increase injury mortality.[30] External factors also cause injury mortality. For example, the changes in road and car conditions in extremely hot temperatures raise the risk of road accidents, or outdoor fires occur more frequently in high temperatures.

This study found significant positive increases in injury-related mortality only in men and no effect on women. This result was consistent with some previous studies.[27,31] A significant increase in injury claims for male workers with increased temperature possibly reflects sex segregation and division at home and work. Men are more likely than women to engage in high-risk activities.

The relationship between higher daily injury-related mortality with hot temperatures considerably rises in young adults (aged 16-29 years). Long-term exposure to high temperatures significantly affects the neural circuitry of emotion regulation of young individuals,[32] predisposing them to increased stress, anxiety, and aggression. Besides, a significant increase in mortality risk in old adults may be due to their poor acclimatization compared to other groups, resulting in decreased wakefulness, impaired performance, and increased injury risk.

The sensitivity of populations to excessively hot temperatures considerably rises in Vietnam due to population aging. Therefore, it is essential to develop adaptation plans to reduce the detrimental effects of global warming.[33] In the context of global warming, measures to prevent exposure to excessively hot temperatures and implementing systems for alerting specific sensitive subgroups of temperature-related health concerns may lower injury mortality.

There were several limitations in this study. First, this study focused on the general injury risk without considering the cause-specific injury. Thus, this study could not evaluate the underlying, immediate, or contributing causes by which extreme temperatures influence the number of injury-related deaths. Second, this study used a small sample from only one province, causing biased estimates. The data from 2005-2007 cannot reflect the current situation accurately.

Conclusion

This pilot study examines the effect of extremely hot ambient temperatures on injury mortality in Thanh Hoa Province, Vietnam. Despite several limitations, this pilot study suggests that warm climate changes increase the risk of deaths from injuries and reveals a group of additional causes of mortality that could be preventable. Further investigation can focus on the effect of warm climate changes and the risk of cause-specific deaths due to road traffic, suicides, work-related injury, interpersonal violence, and others.

Abbreviations

PHC: Primary Health Care; SD: Standard Deviation; AIC: Akaike Information Criterion; BIC: Bayesian Information Criterion; DLNM: the Distributed Lag Non-linear Model; RR: Relative Risk; CI: Confidence Interval.

Ethics Approval and Consent to Participate

Not Applicable

Competing Interest

The authors declare that there are no significant competing financial, professional, or personal interests that might have affected the performance or presentation of the work described in this manuscript.

Availability of Data and Materials

All datasets generated and analyzed are available in the article.

Authors' Contribution

NTL participated in collecting the data, conceptualizing, and designing the manuscript. HVN wrote the introduction section. MTNN and HVTL ran the R-codes and wrote the method section. MVMN and VAN participated in analyzing and writing the result section. All authors interpreted the findings and discussed the results of the study.

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