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ORIGINAL PAPER

The impact of diurnal temperature range on the risk of hospitalizations in a low-income setting: the case of the Central Coast of Vietnam

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Abstract

The study aims to evaluate the effects of diurnal temperature range (DTR) on all causes, cardiovascular and respiratory conditions in the Central Coast of Vietnam, a tropical, low-income region with high DTR exposure but limited research. Daily hospital admission data from the largest hospitals in three provinces were analyzed alongside meteorological data. A time-series analysis using a generalized linear distributed lag model was conducted to examine the non-linear DTR-hospitalization association. A random-effect meta-analysis using restricted maximum likelihood was performed to calculate the pooled effects across three provinces. Stratified analyses by gender, age, season and natural disaster occurrence were conducted to identify vulnerable subpopulations. The multi-province pooled effects indicated that a 1 °C increase in DTR raised the risk of hospitalizations for all causes and respiratory diseases by 1.5% [1.2-1.8%] and 0.5% [0.0–1.0%], at lag 0–6 days. The effects of DTR on cardiovascular diseases, as well as those stratified by subgroups, were not statistically significant. Additionally, DTR had a greater adverse effect during the dry season and in the presence of natural disaster. Females and the elderly were slightly more susceptible to respiratory admissions, while males and younger individuals had a higher risk of all-cause admissions due to greater DTR effects. DTR was an independent risk factor for the exacerbation of all and specific causes, particularly among the susceptible subgroups. The findings suggested that it is necessary to take preventive measures to protect these at-risk populations from the adverse effects of extreme DTR exposure.

Keywords DTR · Cardiovascular diseases · Respiratory diseases · Tropical region

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Introduction

The potential effect of climate change on human health is a pressing concern for the healthcare system (Cheng and Su 2010). Beyond heat waves and cold spells, the diurnal temperature range (DTR)– the variation between daily maximum and minimum temperature– serves as an important indicator of climate variability (Braganza et al. 2004). High DTR has been associated with increased mortality and morbidity, particularly from cardiovascular and respiratory diseases (Aghababaeian et al. 2023; Lee et al. 2017; Zhai Qi et al. 2021; Zhai Zhang et al. 2021). Additionally, factors such as gender, age and season might modify the acute health effects of DTR (Zheng et al. 2016). Previous studies have established a significant relationship between daily DTR and hospitalizations for cardiovascular and respiratory conditions, with higher rates observed in specific age and

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gender groups (Aghababaeian et al. 2023; Lim et al. 2012; Wang Zhou et al. 2020; Zhai Qi et al. 2021; Zhai Zhang et al. 2021).

The disaster is also an effect modifier of the relationship between temperatures and health. A systematic review on climate change and human health in Vietnam highlighted that natural disasters, including floods and droughts, were associated with an increase in the risk of hospitalizations (Linh Tran et al. 2023). These disasters are closely linked to weather and climate events and exacerbate the health impacts of temperature variations by increasing population vulnerability and straining already overburdened healthcare systems, particularly in developing countries (Peduzzi 2019; Salam et al. 2023). Affected populations often face elevated stress and physical strain, making them more susceptible to the health impacts of temperature fluctuations (Davis et al. 2010; Makwana 2019). Vietnam, a low-middle income country in Southeast Asia, is particularly vulnerable to climate change and temperature fluctuations (Gilfillan et al. 2017; Institute of Meteorology 2015). According to the Global Climate Risk Index, Vietnam has endured 216 extreme weather events, many of which have occurred in the Central Coast of Vietnam (Kreft et al. 2015). The region is often impacted by adverse weather conditions and frequently experiences severe natural disasters (Disaster Prevention Committee 2021; Tran et al. 2020). Therefore, it is needed to explore whether the impact of DTR on hospital admissions is modified by the presence of a natural disaster.

Despite these risks, few studies have examined the impact of temperature changes, including DTR, on hospitalization rates in Vietnam. Our prior research identified a significant association between DTR and hospital admission for all causes and respiratory diseases in northern and southern Vietnam, but these studies focused solely on preschool children (Luong et al. 2019; Ngo et al. 2021). They did not assess the modifying effects of DTR across subgroups such as gender and older age groups. Given that the Central Coast of Vietnam is among the areas most affected by natural disasters, it is crucial to investigate whether these disasters modify the effects of DTR on hospital admissions. A comprehensive analysis of the epidemiological evidence concerning climate variability and health outcomes in this region, particularly the modifying effects of DTR is urgently needed.

The study aims to evaluate the effects of DTR on hospitalization for all causes, cardiovascular and respiratory conditions across three provinces in the Central Coast of Vietnam. It would also identify susceptible groups based on age, gender, season, and natural disaster occurrence.

Materials and methods

Study sites

The Central Coast of Vietnam comprises 13 provinces, covering an area of 95,875 km^2. The region, including the studied provinces, is shown in Fig. 1. It has a population of over 20 million, representing 20.8% of Vietnam's total population, with an average population density of 212 people per km^2 (General Statistics Office of Vietnam 2018). The South-Central Coast region features a tropical savanna climate with minimal temperature variation and relatively low annual precipitation. In contrast, the North-Central Coast region has a tropical monsoon climate characterized by cold, wet winters and hot, dry summers. This particular climate type has wider temperature fluctuations throughout a day or over a few days compared to the tropical savanna climate.

Data sources

Data on daily admissions, meteorological conditions, and local disasters were collected from three Central Coast provinces (Quang Binh, Khanh Hoa and Binh Dinh). These data spanned a period of 10 to 13 years, covering Quang Binh (2010–2020), Khanh Hoa (2008–2020), and Binh Dinh (2008–2019), as shown in Table 1. Electronic health records of all admissions were extracted from the largest or highest-level hospitals in each province, using the International Classification of Diseases,10th Revision (ICD-10). The data comprised hospitalizations for all causes, cardiovascular and respiratory issues with ICD-10 codes presented in the Supplementary Material (Table S1). Information included hospitalization categorized by diagnosis coding with ICD10, admission and discharge dates, gender, age, and address location (only at the district and province names). The patients came from all districts within the studied provinces, as well as nearby provinces. Patients who were not residents of the three studied provinces were excluded from the study.

Meteorological data were obtained from the NOAA Global Historical Climatology Network (GHCN) and processed to generate daily maximum temperature (Tmax - ^oC), minimum temperature (Tmin - ^oC), average temperature (Tavg - ^oC), and dew point temperature (TDp). DTR was determined by subtracting the daily minimum temperature from the daily maximum temperature. Relative humidity (RH) was calculated based on average temperature and TDp. Missing data were imputed by averaging the values from the two adjacent days.

We also collected data on local disasters from the Emergency Events Database (EM-DAT). The database contains

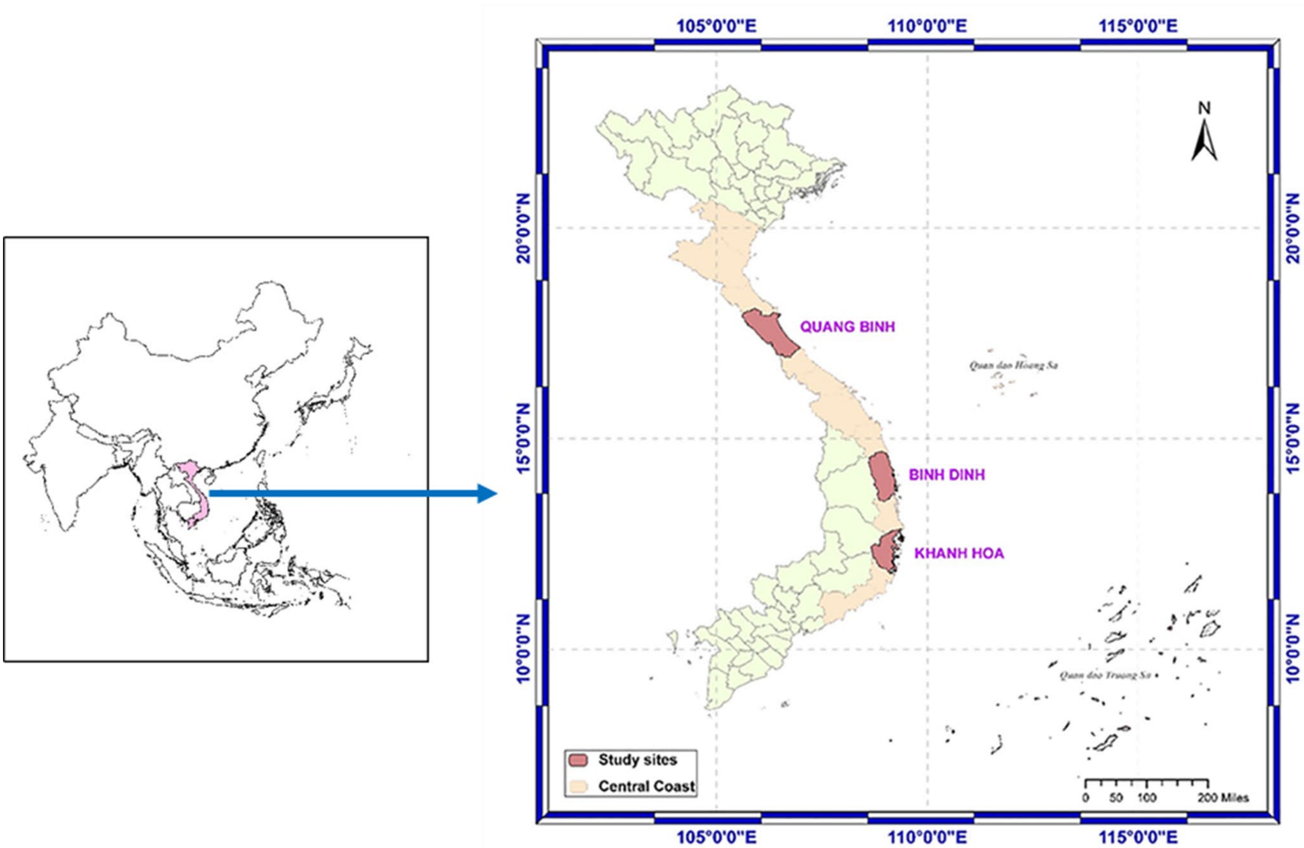

Fig. 1 The study sites in the Central Coast of Vietnam

Table 1 Characteristics of hospital admissions and meteorological data

Province	Study period	The average daily hospitalization (SD)			DTR (°C)						Relative humidity % (SD)	Disaster occurrence (days)
		All causes	CVDs	Respiratory diseases	Mean (SD)	Min	P25	P50	P75	Max		
Khanh Hoa	2008–2020	150.9 (53.7)	16.3 (6.7)	21.9 (10.1)	5.6 (1.5)	0.6	4.7	5.7	6.5	14.1	77.5 (5.7)	500
Binh Dinh	2008–2019	155.8 (65.6)	23.9 (14.2)	22.2 (12.9)	5.5 (1.8)	0.4	4.4	5.5	6.6	15.8	77.2 (8.5)	536
Quang Binh	2010–2020	81.6 (33.1)	6.8 (3.6)	8.4 (5.4)	5.7 (2.2)	0.7	4.2	5.7	7.1	19	80.5 (10.0)	61

crucial core data on over 22,000 mass disasters worldwide from 1900 to the present day. The Centre for Research on Epidemiology of Disasters collects this global disaster data through the EM-DAT (Tin et al. 2024), while the NOAA provides monthly land surface temperature datasets (Lawrimore et al. 2011; Menne et al. 2018). Both resources are widely recognized and freely accessible (Tschumi and Zscheischler 2020; Wang Lu et al. 2020). A natural disaster was defined based on specific criteria such as at least ten deaths (including dead and missing), at least 100 people affected (including injured, or homeless), a call for international assistance or an emergency declaration. We recorded only natural hazard-triggered disasters including riverine floods, tropical cyclones, flash floods, droughts, and convective storms.

Statistical analysis

We applied standard time-series regression models, which are widely used to quantify short-term associations between temperature and hospital admissions (Bhaskaran et al. 2013). The analysis approach was conducted in two stages to examine the association between DTR and hospitalization for all causes, cardiovascular diseases (CVDs) and respiratory diseases. First, province-specific effects were estimated using a single model for each community. Second, these estimates were pooled using a random-effect meta-analysis method to calculate the relative risk (RR) measurements associated with exposure to DTR.

Stage 1

We utilized Generalized Linear Models with a Poisson distribution to assess the association between DTR and hospitalization admissions (Bhaskaran et al. 2013). The analysis assumed a non-linear relationship between DTR and admissions, as observed in previous studies (Ngo et al. 2021; Zhai Zhang et al. 2021). We used a 6-day lag (0–6) to capture the delayed effects of DTR on admissions. The effect observed in previous studies typically reflects the immediate effects of DTR, usually within a week (Luong et al. 2019; Ngo et al. 2021; Wang Zhou et al. 2020). The model controlled for the effects of days of the week, relative humidity, and official holiday. Relative humidity was adjusted using a natural cubic spline with 4 degrees of freedom (Bhaskaran et al. 2013), as previous research indicates that humidity significant modifies the relationship between temperature and health outcomes (Zeng et al. 2017).

To explore the seasonal pattern of the relationship between DTR and hospital admissions, data were divided into the rainy season (May to October) and the dry season (November to April of the following year). Subgroup analyses were then conducted to identify vulnerable populations based on gender (male and female) and age (below 64 years and 65 years or above). Furthermore, a stratified analysis was also performed to assess potential modifying effects based on the occurrence of a natural disaster.

To explore the short-term impact of DTR on hospital admissions in each province, single-lag models with 0 to 6 days were used to test delayed effects. The Poisson model is outlined in the following equation:

$$Y_t \sim \ Poisson\ (\mu_t)$$

$$Log\,(\mu_t) = \alpha\ + \beta\ (DTR_l) + ns\,(RH,\ 4df) + \ ns\,(time,\ 4df) + \gamma\ DOW_t + holiday$$

Herein, t is the day of the observation, Y_t is the count of daily hospitalization admissions in each province, following a Poisson distribution for each day t. α is the intercept in specific-region, ns() is the natural cubic spline. RH is average relative humidity with 4 degrees of freedom (df); Time is a continuous variable throughout the study period. A natural cubic function with 4 degrees of freedom within each year was constructed to adjust for seasonal variations and long-term trends in hospitalization. DOW represents the days of the week (ranging from 1 to 7). Holiday was treated as a binary variable to control the confounding effect. The effect of DTR was determined by calculating the relative risk (RR) per 1°C increase of the DTR value on days.

Stage 2

We applied a random-effect meta-analysis using restricted maximum likelihood (REML) to calculate the pooled effect across the three provinces. We performed subgroup analyses to identify populations sensitive to DTR, consisting of gender, age group, season, and natural disaster occurrence. Results were presented with 95% confidence intervals, considering a *p*-value of < 0.05 as statistically significant.

Several sensitivity analyses were conducted to assess the robustness of the models by altering the degrees of freedom (3 degrees/year and 4 degrees/year) and removing humidity from the province-specific models. The best model was selected based on the Akaike Information Criterion (AIC), which involved choosing the model with the smallest AIC values (Bozdogan 1987). The results indicated that the models with 4 degrees/year were the most suitable for this study, as reported in Supplementary Materials (Table S2). All analyses were performed using STATA software (Version 16.0) for statistical computing.

Ethical approvals

The work received approval from the Human Research Ethics Committee of Hue College of Medicine and Pharmacy (Vietnam) and the Queensland University of Technology Research Ethics Committee (Approval number: H2021/016).

Results

Descriptive analysis

During the study period, the total number of all-cause hospitalizations recorded in the database of the three studied hospitals was 1,701,736. Of these, 234,980 cases were CVDs and 255,222 cases were respiratory diseases. The average daily hospitalizations for all causes ranged from 81.6 cases in Quang Binh to 155.8 cases in Binh Dinh. For CVDs, the daily average ranged between 6.8 and 23.9 cases, while for respiratory diseases, it ranged from 8.4 to 22.2 cases across the provinces (Table 1).

Meteorological data showed that the average daily DTR ranged from 5.5°C in Binh Dinh to 5.7°C in Quang Binh, slightly rising from the South to the North. The relative humidity ranged from 77.2 to 80.5% for Binh Dinh and Quang Binh, respectively. Additionally, numerous natural disaster events occurred during the study period, with total

61 disaster days in Quang Binh, 500 days in Khanh Hoa and 536 days in Binh Dinh.

Province-level effects of DTR on hospitalization

The effects of DTR on all-cause and cause-specific hospital admissions were most pronounced at lag 0 (Table 2). The impact of DTR on hospitalizations varied across the provinces. In Binh Dinh, for instance, a 1 °C increase in DTR was associated with a 1.5% [0.6-2.4%] increase in CVD admissions at lag 0. This association varied across gender, age, and season subgroups in this province, with the highest risk observed during the dry season, resulting in a 4.8% [3.3–6.2%] increase at lag 0.

For respiratory diseases, the effect of DTR was also significant, with increases ranging from 0.9% [0.0-1.7%] in Binh Dinh to 2.2% [1.3-3.0%] in Khanh Hoa. Gender-specific analysis revealed a slightly higher risk for female patients (2.6% [1.5-3.7%]) compared to males (1.8% [0.6-3.0%]) in Khanh Hoa. Age-specific analysis showed that patients aged 65 and above were more affected than those under 65. For each 1 °C increase in DTR, there was a 2.5% [1.4-3.7%] increase in admissions for the ≥ 65 age group, compared to a 1.8% [0.6-3.0%] increase for those under 65. Additionally, the effect of DTR was also more pronounced in the dry season, with a peak increase of 4.1% [2.7-5.5%] in Binh Dinh.

For all-cause admissions, higher DTR was significantly associated with an increased the hospitalization risk in all provinces, particularly in Binh Dinh, where a 1 °C increase in DTR resulted in a 2.4% [1.8–3.0%] increase in admissions. The relationship between DTR and hospitalizations was observed across all subgroups, with the highest risk seen in the dry season, among females, and in those aged 65 and above. For an increase of 1 °C DTR, the most significant adverse effect of DTR on all-cause admissions in Khanh Hoa was in female patients (3.1% [2.1-4.1%]) and during the dry season in Binh Dinh (3.7% [2.8-4.6%]).

Pooled effects of DTR on hospitalization

The pooled effect of DTR on hospitalizations across different diseases and regional subgroups is displayed in Fig. 2a. The combined estimate indicated a 1.5% [1.2-1.8%] increase in all-cause hospitalization for every 1 °C rise in DTR. For respiratory hospitalizations, a 1 °C increase in DTR resulted in a 0.5% [0.0–1.0%] increase. However, no significant association was found between DTR and the risk of hospital admissions for CVDs.

Figure 2b and c, and 2d show the area-combined effects of DTR on hospitalizations for all causes and specific causes, stratified by season, gender, age, natural disaster occurrence. Across all subgroups, DTR was associated with an increased risk of all-cause hospitalizations. During the dry season, the risk increased by 1.8% [1.4-2.1%] for every 1 °C rise in DTR. Furthermore, the risk was higher in the < 65 age group (1.7% [1.3-2.1%]) and with natural disaster occurrence (1.7% [0.3-3.1%]), compared to the ≥ 65 age group (1.3% [1.0-1.5%]) and being unaffected by natural disaster events (0.6%[0.2-0.9%]) (Fig. 2b).

Regarding the combined effect of DTR on respiratory disease hospitalizations, we observed a 2.4% [2.1-2.7%] increase during the dry season. Although the analysis showed that a 1 °C rise in DTR led to increased admissions across age and gender subgroups, no significant differences were found between males and females or between

Table 2 The relative risk (%) of DTR on admissions along the lag day 0 for causes, gender, age, disaster occurrence, and seasons subgroup

%RR (95%CI)	Location	Cause admission	Gender		Age		Disaster occurrence		Season	
			Male	Female	0–64 years	65 + year	Yes	No	Dry	Rainy
CVDs	Khanh Hoa	0.2 (-0.5-1.0)	0.8 (-0.2-1.8)	-0.3 (-1.3-0.7)	-0.4 (-1.6-0.8)	0.6 (-0.4-1.6)	2.6 (-0.7-6.0)	**1.9 (1.1–2.8)**	0.9 (-0.2-2.1)	-0.5 (-1.5-0.6)
	Binh Dinh	**1.5 (0.6–2.4)**	**1.9 (0.8–2.9)**	1.0 (-0.1-2.1)	**2.1 (0.9–3.2)**	**1.1 (0.1–2.2)**	0.3 (-7.1-8.3)	**1.3 (0.1–0.3)**	**4.8 (3.3–6.2)**	-0.2 (-1.5-1.1)
	Quang Binh	0.2 (-0.6-1.0)	0.2 (-0.9-1.3)	0.2 (-0.7-1.1)	0.6 (-0.4-1.6)	-0.1 (-1.1-1.0)	1.5 (-7.0-1.9)	0.2 (-0.5-1.0)	**1.1 (0.1–2.1)**	-0.4 (-1.7-0.8)
Respiratory diseases	Khanh Hoa	**2.2 (1.3-3.0)**	**1.8 (0.7–2.8)**	**2.6 (1.5–3.7)**	**1.8 (0.6-3.0)**	**2.5 (1.4–3.7)**	-0.3 (-1.0-0.4)	**2.9 (0.1–5.9)**	**2.5 (1.3–3.8)**	**1.3 (0.1–2.4)**
	Binh Dinh	**0.9 (0.0-1.7)**	**1.1 (0.1–2.1)**	0.6 (-0.5-1.6)	0.5 (-0.6-1.5)	1.2 (0.1–2.3)	1.8 (-5.0-9.1)	**1.9 (0.3–3.6)**	**4.1 (2.7–5.5)**	-0.6 (-1.8-0.6)
	Quang Binh	**2.0 (1.2–2.9)**	**1.6 (0.5–2.8)**	**2.4 (1.4–3.5)**	**1.6 (0.5–2.7)**	**2.5 (1.3–3.7)**	7.2 (-1.2-6.4)	**2.0 (1.1–2.8)**	**3.1 (2.0-4.2)**	0.4 (-1.0-1.7)
All causes	Khanh Hoa	**2.1 (1.6–2.6)**	**2.1 (1.4–2.9)**	**2. (1.2–2.8)**	**3.1 (2.1–4.1)**	**1.3 (0.5–2.1)**	3.0 (-0.3-6.3)	**1.7 (1.3–2.2)**	**1.9 (1.1–2.7)**	0.2 (-0.3-0.7)
	Binh Dinh	**2.4 (1.8-3.0)**	**2.2 (1.4-3.0)**	**2.6 (1.7–3.4)**	**2.4 (1.4–3.4)**	**2.4 (1.5–3.2)**	3.1 (-1.6-8.0)	**1.1 (0.2-2.0)**	**3.7 (2.8–4.6)**	0.6 (-0.2-1.5)
	Quang Binh	**1.2 (0.8–1.6)**	**1.9 (1.3–2.5)**	0.5 (-0.2-1.2)	**1.8 (1.0-2.6)**	**0.8 (0.1–1.4)**	2.9 (-1.1-7.1)	**1.2 (0.8–1.6)**	**1.6 (1.1–2.1)**	-0.1 (-0.6-0.5)

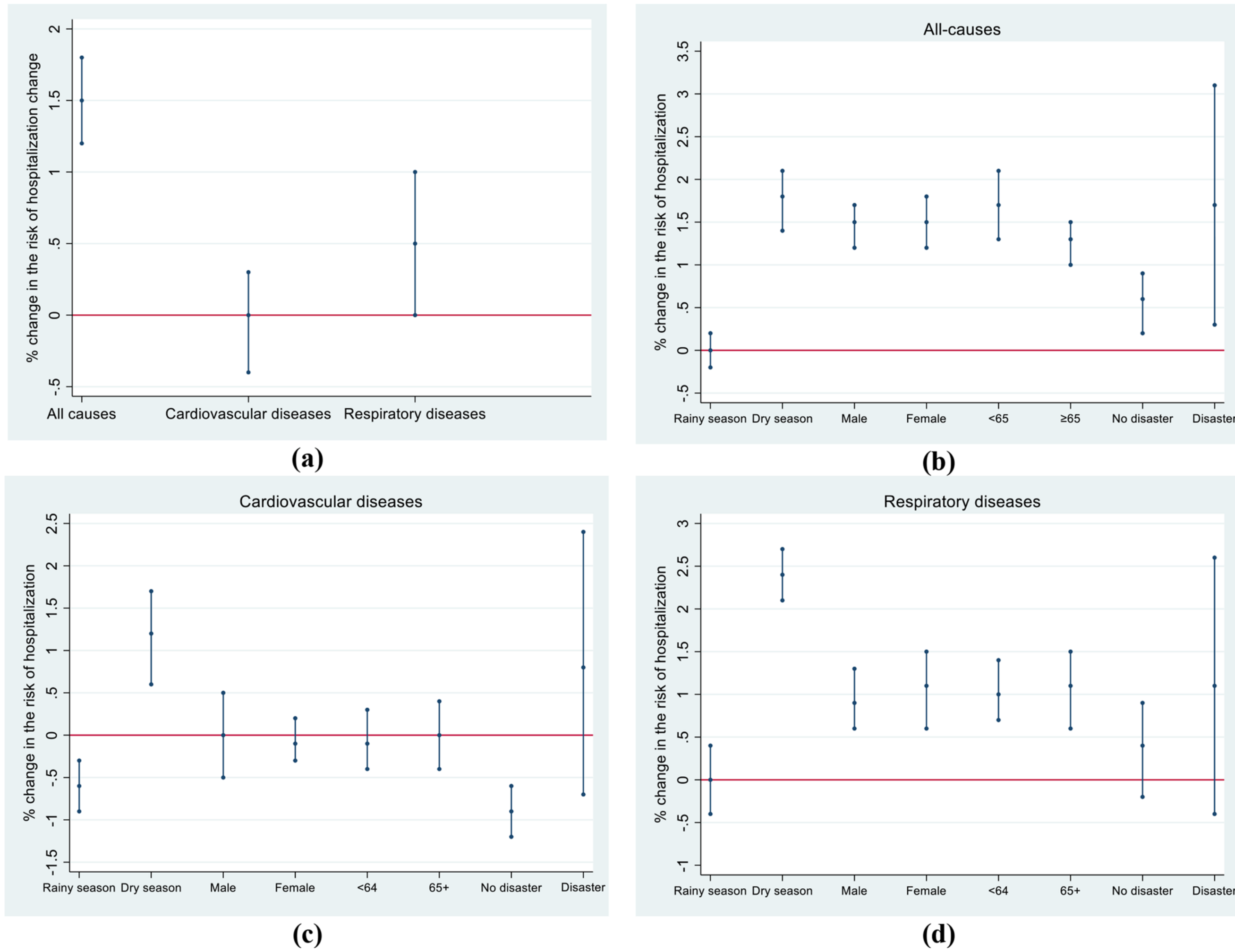

Fig. 2 The pooled effect of DTR on admissions by subgroups. (**a**) Shows the area-combined effects of DTR on hospitalization for all causes, cardiovascular and respiratory diseases. (**b**, **c**, **d**) Show the area-combined effects of DTR on hospitalization for all causes and cause-specific stratified by season, gender, age, disaster occurrence

the younger and older groups. Furthermore, the association between DTR and respiratory hospitalizations considering natural disaster occurrence was not significant (Fig. 2c).

Females and individuals aged 65 and above experienced slightly higher rates of respiratory disease admissions related to high DTR compared to males and younger individuals. Additionally, the study revealed that an increase in DTR during the dry season was associated with a 1.2% [0.6–1.7%] increase in CVD admissions per 1 °C rise in DTR. However, the exposure-response relationships between DTR and CVD admissions were not significant across different age and gender groups (Fig. 2d).

Discussion

This is the first comprehensive study to assess the impacts of DTR on hospitalization risks across provinces in Vietnam's Central region. These findings highlight the effect of DTR on hospital admissions for all causes, CDV and respiratory diseases, stratified by gender, age, season, and the occurrence of natural disasters across three provinces. The pooled estimates revealed that an increase of 1 °C in DTR was associated with an increased risk of hospitalization for all causes and respiratory diseases within a short-term exposure period of 0–6 days. Nevertheless, the association between DTR and CVD admissions was not statistically significant.

In our study, the combined effect of DTR was associated with a 0.5% [0.0–1.0%] increase in the risk of respiratory hospitalization. Previous studies have reported elevated risks of hospitalization for exacerbation of chronic respiratory diseases (9% [8-11%]) associated with an increase in DTR at lag 0–6 (Wang Zhou et al. 2020). Similarly, a 1 °C increase in the 8-day moving average of DTR (lag 0–7) corresponded to a 2.08% (95% CI: 0.88-3.29%) increase in respiratory emergency room admissions (Wang et al. 2013b). However, other studies have shown contrasting findings, suggesting that an increase in DTR could lead to higher daily hospitalization for certain heart and respiratory diseases. For example, the area-combined effects of DTR on cardiac failure and asthma were significantly increased by a 1 °C increment of DTR, at 3.0% (95% CI, 1.4–4.6) and 1.1% (95% CI, 0.1–2.0), respectively (Lim et al. 2012).

The overall estimated effects of DTR on CVDs were found to be insignificant in our study. Similar results were observed in a previous multi-province study on high-temperature effects on cardiovascular admissions in Vietnam's tropical Mekong Delta Region (Phung et al. 2016). Additionally, a study in China determined that low DTR had a significantly greater detrimental effect than higher DTR on the risk of CVD admissions (Zhai Zhang et al. 2021). A possible explanation for this finding is that the DTR effects could vary depending on the subclasses of CVDs, as suggested in previous studies (Lin et al. 2020; Wang Zhou et al. 2020; Zhai Qi et al. 2021). Further studies should focus on examining the influence of DTR on specific CVD subtypes.

Our study also examined the effect of DTR during both dry and rainy seasons. During the dry season, the pooled effect of DTR on hospitalization increased for both allcauses and specific causes. The maximum combined estimate of DTR on the risk of respiratory disease hospitalizations could go up to 2.4% [2.1-2.7%]. These findings were consistent with a study in Guangdong Province, South of China, where the effect of DTR rapidly increased in the relatively low DTR observed during the hot season (May to October) (Wang Zhou et al. 2020). Similarly, a nationwide time-series study in England and Wales reported that high DTR exhibited a more significant adverse effect during the hot season (Zhang et al. 2018). Nevertheless, some publications have identified DTR as a protective factor for children under 5 years old, with varying levels depending on the season and region in Vietnam (Luong et al. 2019; Ngo et al. 2021). In the North of Vietnam, a 1 °C increase in DTR was associated with a 1.4% reduction in the risk of hospitalization for all causes for children under 3 years old (Luong et al. 2019). Meanwhile, in the South, a rise of 1 °C DTR was significantly associated with a 2.0–2.5% decrease in the risk of hospitalization for ALRI among children under 3 years old in the rainy season (Ngo et al. 2021). These differences can be attributed to distinct patterns of the DTR distribution according to the climate of each region, with the highest mean DTR observed during summer (Katavoutas et al. 2023). The increased impact of DTR during the dry season was more noticeable, which is crucial evidence for public health protection planning.

The associations of hospitalization for all causes, respiratory diseases and DTR were identified when the data were stratified by age and sex. Province-level effects of DTR on hospitalization for all causes were similar between genders whereas the effect estimates were higher for the younger group compared to the older group. We speculated that the younger group experienced more frequent sudden temperature variations due to increased outdoor activities and responsibilities, regardless of weather conditions, while older people tend to stay indoors. Our findings also showed that females and the elderly were significantly more vulnerable to higher DTR in terms of respiratory disease incidences. A possible explanation is that the elderly might not be adequately equipped to handle sudden temperature changes with suitable behavioral responses. Besides, they are more vulnerable to ventilatory failure during high-demand states and possible poor outcomes (Sharma and Goodwin 2006). Moreover, women have less pulmonary capacity for gas exchange during hypoxic conditions, making them more susceptible to respiratory issues (Bouwsema et al. 2017; Guzman and Summers 1973; Paolo and Yannick 2022).

Notably, DTR caused greater adverse effects on all-cause hospitalizations within six days following on a natural disaster happen, resulting in a 1.7% [0.3-3.1%] increase compared to non-disaster days (0.6% [0.2-0.9%]). A systematic review indicated that patients with chronic diseases are particularly vulnerable during disasters, experiencing exacerbated symptoms, increased hospital admissions and a greater need for ventilators and oxygen therapy. For instance, conditions such as diabetic ketoacidosis and hypoglycemia contribute to higher mortality rates among patients with diabetes (Ghazanchaei et al. 2021). Additionally, the risk of all-cause hospital admissions increased by 4% in the thirty days following the 2011 Super Outbreak, which was one of the largest tornado-related natural disasters in US (Bell et al. 2018).

Regarding the impact of DTR on hospital admissions at the provincial level, the association between CVDs and DTR's RR varied among gender, age, and season subgroups. The most significant adverse effect of DTR on CVD risk was 4.2% [0.6-8.0%)], with higher effects observed in females (5.1% [1.1-9.1%]), and younger adults (8.3% [3.0-3.9%]) (Zhai Qi et al. 2021). DTR also significantly affected respiratory disease admissions. In Korea, increases in DTR were associated with significant increases in total respiratory hospital admissions, with a 1.3% [0.3-2.4%] increase in Seoul and a 2.6% [1.3-4.0%] increase in Incheon, respectively (Lim et al. 2012). The relationship between DTR and hospitalization for respiratory diseases (COPD and asthma), was especially pronounced in female bronchiectasis patients (6.0% [3.0-10.0%]) (Wang Zhou et al. 2020).

Higher DTR was found to significantly increase the risk of hospitalization for all causes in all provinces. Subgroup analysis revealed significant differences between males and females, younger people and the elderly, and seasonal variations in hospital admissions. The reasons behind these differences remain uncertain and require thorough investigation. However, previous studies have suggested that variations in specific age groups, gender, and seasonal observations could be influenced by population diversity, activity patterns, socioeconomic factors, and geographical locations (Basu 2009; Ding et al. 2015).

Elderly individuals are particularly susceptible to temperature changes due to age-related declines in thermoregulation, making it difficult to maintain stable body temperature and increasing the risk of adverse effects (Salam et al. 2023; Zhou et al. 2023). Sudden temperature shifts can lead to rapid changes in heart rate and circulation, raising the risk of cardiopulmonary issues and other diseases, even potentially fatal outcomes (Liu et al. 2015; Rusticucci et al. 2002). Additionally, sudden temperature changes may trigger pathophysiological responses in the respiratory system, such as bronchospasms and inflammatory responses (Graudenz et al. 2006). Reduced sweating and skin blood flow further contribute to heat-related illnesses (Balmain et al. 2018; Holowatz et al. 2010). These results seem consistent with our study, which showed increased morbidity in individuals aged 65 and above following daily temperature fluctuations, especially during the dry season. We hypothesize that elderly individuals with pre-existing medical conditions may struggle to adapt to sudden temperature variations due to weakened immune function and organ decline. Gender-related differences in hormonal influence also play a role in temperature regulation. Women's fluctuating hormone levels throughout the menstrual cycle can affect thermoregulation (Stephenson and Kolka 1993). Estrogens typically promote vasodilation and heat dissipation, while progesterone and progestins have the opposite effect. Estrogens and progesterone/progestins can interact with androgens, affecting thermoregulatory responses across the lifespan (Charkoudian and Stachenfeld 2014). Moreover, behavioral differences between sexes, such as women's tendency to dress more lightly, including wearing skirts, may increase their exposure to temperature fluctuations (Honda et al. 2016). This might partly explain our findings that females, especially female elderly people, were more vulnerable to DTR.

This study has several strengths. While a few previous studies have primarily focused on the effects of DTR on children's health (Luong et al. 2019; Ngo et al. 2021), this is the first multi-city study to examine the short-term effects of DTR on hospitalization among older populations across diverse climate zones in Vietnam. Additionally, most prior studies have focused on the health impacts of high and/or cold temperature (Linh Tran et al. 2023). Our study broadens this scope by highlighting the health risks associated with significant fluctuations between day and night temperatures, not limited to extreme conditions, and by exploring the interactions of diverse climate-related hazards including DTR and natural disasters. Our findings provide evidence that it is crucial during periods of high DTR for females and individuals aged 65 and over to minimize exposure to temperature fluctuations, particularly during the dry season and in the context of environmental disasters.

However, we acknowledge that our study has several limitations. First, health data was collected only from the biggest hospital in each province for this study, which means that cases seen at local health stations or private facilities might not have been included. The largest hospitals, typically tertiary care centers, primarily admit severe cases, potentially missing moderate and minor cases that are managed in lower-level hospitals or clinics. This could result in an overrepresentation of more critical cases in our dataset. However, lower-level facilities often face challenges with incomplete outcome data due to the limited implementation of electronic hospital management systems, which further complicates data collection from these sources (Dat et al. 2022). Second, this research was unable to investigate the relationship between DTR and cause-specific differences. Previous studies have shown that the DTR effects may vary depending on the specific cardiovascular condition. For instance, a former study reported that high DTR might trigger initial strokes in the summer and winter, with cerebral infarction being more susceptible to DTR than intracerebral hemorrhage (Lin et al. 2020). Therefore, pooling all CVDs might have reduced the sensitivity to DTR effects in this research. Another limitation of this study is the lack of information on the duration of a disaster's effects. Consequently, we were unable to determine how long these effects persist and influence health outcomes for the purposes of our analysis. Lastly, our analysis did not include personal characteristics comprising of socio-economic status, behaviors related to air-conditioning use or medical history, which could potentially introduce some measurement bias.

Conclusions

This multi-province study demonstrated a significant association between rising DTR and increased risks of hospital admissions in Vietnam's central region. Our findings indicated that the region-combined effects of DTR on all causes and respiratory diseases were statistically significant, with more pronounced impacts during the dry season. The presence of natural disasters further amplified the effect of DTR, leading to an increase in all-cause hospitalizations. These results suggest that DTR should be considered an important indicator of climate variations when building effective adaptation plans aimed at mitigating DTR-related health risks among residents in response to climate change.

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Author contributions H.K.T.N and T.T.C.T conducted data analysis and were involved in draft writing and editing. T.A.T.D was responsible for the conceptualization, supervision, funding acquisition, draft reviewing and editing. D.P contributed to the conceptualization, data analysis, draft reviewing and editing. T.N.D, K.D.N, M.H.D.N and H.C.T focused on reviewing and editing the draft, with K.D.N also involved in funding acquisition. P.K.T participated in supervision, funding acquisition, draft reviewing and editing.

Data Availability The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest The authors declare that they have no conflicts of interest.

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