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RESEARCH ARTICLE

The protective effect of green space on heat-related respiratory hospitalization among children under 5 years of age in Hanoi, Vietnam

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Abstract

Combined effects of global warming and rapid urbanization replace green spaces with urban facilities. Children in urban areas are at a higher risk of heat-related adverse health effects. Our study aimed to examine the protective effect of urban green space on heat-related respiratory hospitalization among children under 5 years of age in Hanoi, the capital city of Vietnam. We estimated district-specific meteorological conditions from 2010 to 2014 by using a dynamic downscaling approach with a fine-resolution numerical climate model. The green space in each district was calculated using satellite data. The attributable fraction of heat-related respiratory hospitalization was estimated using a two-stage model, including a distributed lag non-linear model (DLNM) coupled with multivariate meta-analysis. The association between heat-related respiratory hospitalization and green spaces at the district level was explored using a linear regression model. The central districts were more crowded and hotter, with less green spaces than the outer districts. At temperatures > 34 °C (extreme heat threshold), the hospitalizations in the central districts increased significantly; however, in the outer districts, the hospitalization rate was insignificant. On average, extreme heat attributed 0.33% to citywide hospitalization, 0.35% in the center, and 0.32% in the outer region. Every 1% increase in the green space fraction will reduce heat-related respiratory hospitalization risk by 3.8%. Heat significantly increased the risk of respiratory hospitalization among children under 5 years in Hanoi, Vietnam. These findings are valuable for authorities to consider strategies to protect children's health against the effects of heat, including increasing green space.

Keywords Green space · The heat-related hospitalization · Children under 5 years old · Vietnam

Introduction

Global warming changes the frequency, duration, and intensity of extreme weather events such as heatwaves or heavy precipitation, increasing the harmful effects on human health (IPCC 2014). Children are vulnerable to these extreme conditions. Studies have shown that the risk of hospitalization in children under 5 years of age (< 5 years old) increases significantly from 10 to 24% during extreme heat events and with event duration (Kovats et al. 2004; Knowlton et al. 2009; Xu et al. 2017; Zhao et al. 2019).

In addition to climate change, urban residents are also subjected to the urban heat island (UHI) effect because urbanized areas often experience higher temperatures than surrounding

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areas. Urban warming due to the UHI effect can be considered as serious as global warming. Particularly in fast-growing cities, the rapid growth of urban structures from vegetative land has led to a reduction in evapotranspiration (Doan et al. 2019). Increasing green spaces is a practical solution for controlling UHI effects (Chatterjee et al. 2019). A systematic review found that the average temperature in a park was approximately 1 °C lower than those outside areas with less green space (Bowler et al. 2010). It is noteworthy to mention that an increase of 10% in green areas could reduce heat-related mortality by at least 6–12% (Mitchell and Popham 2008; Crouse et al. 2017). The adverse effects of extreme temperatures and the protective role of green spaces have been assessed separately in various studies (Mitchell and Popham 2008; Bowler et al. 2010; Crouse et al. 2017). However, the protective role of green space against heat-related health effects has been scantly investigated in megacities of developing countries, which have the highest vulnerability to the impacts of climate change and UHI.

A recent study in Ho Chi Minh City, the largest metropolis in Vietnam, showed that the UHI mortality-attributable fraction was 0.42%, and an increase of 1 km^2 of green space per 1000 population could prevent 7.4 deaths related to heat (Dang et al. 2018). Hanoi, the second largest and capital city in Vietnam, has been experiencing rapid urbanization, which is characterized by the replacement of green spaces with urban facilities (Nguyen et al. 2019); Doan et al. 2019). Therefore, local urbanization could play a significant role in urban warming in Hanoi, which is comparable to global warming. These global and local factors will place urban residents at a higher risk of adverse heat-related health effects, especially in children. Therefore, our study aimed to examine the protective effect of green space on heat-related respiratory hospitalization among children under 5 years of age (< 5 yeas old) in Hanoi, the capital city of Vietnam. The results of our study will be helpful for authorities planning urban green spaces to mitigate the negative impacts of climate change and UHIs on human health.

Materials and methods

We estimated district-specific meteorological conditions (i.e., temperature and relative humidity) from 2010 to 2014 using a dynamic downscaling model (for details, see the dynamic downscaled modeling below). The green space in each district was calculated using satellite images (see green space data processing). The attributable fraction of heat-related respiratory hospitalization was estimated using a two-stage model, including a distributed lag nonlinear model (DLNM) coupled with multivariate meta-analysis. The association between heat-related respiratory hospitalization and green spaces at the district level was explored using a linear regression model. This study focused on heat-related health effects; thus, we only performed analyses based on hot season data (from 1st May to 31st October in Hanoi, Vietnam).

Data sources and quality

Daily hospital admission records for children were collected from three national hospitals in Hanoi (National Children's Hospital, National Hospital for Tropical Diseases, and Bach Mai Hospital) from 1/2010 to 12/2014 with information about admission date, sex, age, resident location, and respiratory cause of hospitalization (ICD-10 codes J00-J99). The data used in this study were approved by the National Hospital of Pediatrics, Biomedical Research Ethics Committee (NHP, RICH, 15–014), and the University of Queensland School of Medicine Low Risk Ethical Review Committee (no. 2016-SOMILRE-0155).

Daily meteorological data were collected from the National Center for Hydro-Meteorological Forecasting (Noi Bai/Nguyen Van Cu station/Lang station), including temperature and relative humidity, from 1/2010 to 12/2014. These meteorological data were further used to evaluate the performance of the dynamically downscaled model.

Population data, including total population and population density, were collected from the Hanoi Statistical Yearbook (www.gso.gov.vn) and classified into 30 districts within Hanoi.

The meteorological data processing and dynamically downscaled model

Meteorological data at the district level were obtained using a dynamical downscaling approach with the state-of-the-art Weather Research and Forecasting (WRF) model. This is a mesoscale numerical atmospheric model primarily developed at the National Centre for Atmospheric Research (NCAR) that can be used for weather forecasting and atmospheric research. The WRF can simulate atmospheric phenomena at scales ranging from meters to thousands of kilometers if proper forcing of initial and boundary condition data (observations and analyses) is provided. In urban climate simulations, WRF is usually coupled with an urban canopy model (UCM), which allows it to represent the unique physical effects of urban areas (such as radiative effects or building friction) (Kusaka et al. 2001). WRF/UCM has been widely used to simulate UHI effects in large urban areas worldwide (Chen et al. 2011; Doan and Kusaka 2016). WRF has recently been used in studies on tropical cities, including large cities in Vietnam (Doan and Kusaka 2016; Doan et al. 2019).

In this study, we used the same model configuration as Doan et al. (2019), which showed an exemplary model's performance compared to in situ air temperature and relative humidity measurements. The final operational global analysis data (NCEP/FNL) from the National Centers for Environmental Prediction were used as initial and boundary conditions for the simulation. The model is configured using three nested domains. The inner most one has a horizontal resolution of 2×2 km, which is sufficient to capture inter-district differences in Hanoi. Up-to-the-date land use/cover and anthropogenic heat release data were used as surface forces. The simulation period was from 2010 to 2014, consistent with the period of available daily morbidity data. For the technical details of the WRF/UCM used in this study, it is suggested to refer to the previous publication of Doan et al. (Doan et al. 2019). We also tested the validity of the dynamically downscaled model by comparing the estimates from the model with the values from the three weather stations in Hanoi City (see the validity results in Fig. S2).

The green space data processing

Extracting green space is a key step in analyzing the impact of green spaces in reducing UHIs. Among the many satellite sources, photos captured by Landsat-8 were suitable for this task. Landsat-8, launched on February 11, 2013, is the eighth satellite in the Landsat program. It provides images (30×30 m pixel) of the Earth's land surface in the red–green–blue (RGB) and near-infrared (NIR) bands (Roy et al. 2014). These bands help to distinguish vegetation from other land cover types, because live green plants absorb red and blue light while reflecting near-infrared light (Jordan 1969).

In this study, we used USGS Landsat-8 surface reflectance images to classify the Hanoi Landscape into several classes. The dataset was atmospherically corrected to remove the impact of the Earth's atmosphere, such as clouds or aerosols. We selected all Landsat-8 scenes that covered Hanoi in 2014. The cloud pixels were removed using the pixel_qa bands provided in the product. Then, we combined all images into a single composite Landsat scene and used it as the data for our machine learning classification.

While there are many machine learning approaches to classify the Earth's land surface, the classification and regression tree (CART) is ideal for land classification according to several previous studies (ManojKumar et al. 2002; Xu et al. 2005). To prepare the training data for the model, we generated reference areas to identify water, vegetation, human construction, and others (see example in Fig. S1). Later, we applied the CART model to the reference data to generate a land classification map. We also generated sample areas for each land type to validate our map results. All image processing steps were performed using Google Earth engine.

Statistical methods

Descriptive statistics

For each district, we described the total respiratory hospitalization, average temperature, and the number of days at mild heat (temperature > 75th percentile), extreme heat (temperature > 99th percentile) in the hot season, population density, and green space fraction. For all variables, the average of eight central districts and 22 outer districts was calculated.

Attributable fraction (AF) and attributable number (AN) of respiratory hospitalization resulting from heat

The AF and AN of respiratory hospitalizations were estimated in two steps. (1) The association between the daily average temperature and daily respiratory illness-related hospital admission was estimated for each district following the two-stage model (described below). (2) AF and AN were calculated using an established method.

In the first stage, a distributed lag nonlinear model (DLNM) was used to estimate the exposure–time–response function. Specifically, DLNM is a useful approach in heat–time response when the exposure effect is delayed and nonlinear (Gasparrini et al. 2010). Standard time series quasi-Poisson regression linking daily hospitalization (i.e., outcome) with daily average temperature (i.e., exposure) was used to produce an overall exposure–response curve for each district (Bhaskaran et al. 2013):

$$\begin{aligned} &Y_t \sim quasi - Poisson(\mu_t) \\ &\mathrm{Log}(Y_t) = \alpha + \beta_1{}^{*}T_{t,l} \\ &+\beta_2{}^{*}DOW_t + \beta_3{}^{*}NCS_{(time,3df/halfyear)+\beta_4{}^{*}Year} \end{aligned} \quad (1)$$

where:

Y_t is the daily hospitalization count on day t.

l is the lag day.

$T_{t,l}$ denotes a matrix obtained by applying the cross-basis distributed lag non-linear model function to temperature (accounting for a potential non-linear relationship), which includes a 4° of freedom quadratic B-spline in the exposure–response dimension and a 5° of freedom natural cubic B-spline in the lag–response dimension (over lags from 0 to 21) (Guo et al. 2014).

DOW is the day of the week and was treated as categorical variable.

NCS represents the natural cubic spline function used to adjust long-term trends and seasonality with 3df for half a year, and time is a variable that takes consecutive numbers ranging from 1 on the day on which observations began to 915 on the final day of the observation period (from November 1st, 2010, to October 31st, 2014).

Year is the year of data (from 2010 to 2014) and was treated as categorical variable.

In the second stage, we reduced and pooled the estimated district-specific cumulative exposure–response curves using a multivariate meta-analytical model, separating the data into central districts (the center) and outer districts (the outer). This two-stage model has recently been used in multi-city, multi-country studies (Gasparrini et al. 2015). The central and outer districts were categorized based on their locations in the subdivisions of Vietnam (Fig. S3).

Commonly used in health impact assessment, the attributable number (AN) and attributable fraction (AF) represents the total number of cases and proportion of all cases, respectively, which can be attributed to a specific exposure in a population. In our study, AF and AN from the total, extreme, and mild heat were calculated using the method described by Gasparrini and Leone (Gasparrini and Leone 2014). A general definition of AF_x and AN_x for a given temperature exposure intensity x is as follows:

$$AF_x = 1 - \exp\left(-\beta_x\right) \quad (2)$$

$$AN_x = n^* AF_x \quad (3)$$

where n is the total number of cases and β denotes the risk associated with the exposed intensity x, compared with a reference value, x_0. The 75th percentile of temperature as x_0 and x ranging from the 75th to 99th percentiles was used to calculate the AF and AN of mild heat. The 99th percentile was used as x_0, and x ranging from the 99th to the 100th percentile was used to calculate the AF and AN of extreme heat. The sum of mild and extreme AF and AN is considered as the AF and AN of the total heat, respectively.

The green space protective effect to heat-related respiratory hospitalization

We conducted a linear regression analysis at the district level to examine the association between AF and green space fraction as the main effect and population density as confounding factors (WHO 2018). This model allows the estimation of the potential AF% reduction for each % green space fraction.

The model was constructed as follows:

$$Y = \beta_1 X_1 + \beta_2 X_2 + \alpha \quad (4)$$

where:
Y is the AF%
X_1 is the green space fraction
β_1 denotes the slope of X_1;
X_2 is the population density
β_2 is the slope of X_2
α represents the intercept

Results

Green space, urban, and temperature characteristics

Table 1 shows the green space, urbanization, and temperature characteristics of the central and outer areas of Hanoi. Overall, the center was more crowded, hotter, and had less green space than the outer areas.

The average green space fraction of the center is significantly lower than that of the outer space (i.e., 4.4% vs. 13.6%). To validate the green space data processing (see Methods), we compared the estimates from the CART model with a reference sample. The total accuracy of our classification is approximately 84.2%. The classification results demonstrate that the chosen algorithm effectively mapped water, vegetation, and urban areas with very high user's accuracies (100%, 94.3%, and 97.1%, respectively). The population density of the center was ten times higher than that of the outer area (23,959 people/km^2 vs. 2257 people/km^2). In particular, the center reached the lowest population density at 6086 people/km^2 and highest at 40,126 people/km^2, whereas the outer areas had the highest value of 6015 people/km^2. Exposure to high temperatures was also more frequent in the center than in the outer region. In the hot season, the average temperature of the central districts was 0.3 °C higher than that of the outer districts (28.7° C vs. 28.4 °C). Moreover, the central districts experienced a higher average number of hot days than that of the outer districts for every temperature threshold > 75th percentile and > 99th percentile (Table 1).

Attribution of respiratory hospitalization resulting from heat

The first-stage model time-series quasi-Poisson regression showed an association between temperature and hospitalization. The optimum temperature with minimum hospitalization risk was lower than mild heat threshold (Fig. 1). At temperatures higher than extreme heat threshold, the hospitalizations in the central districts increased significantly; however, this rise is insignificant in the outer districts. On average, extreme heat attributed 0.33% (95% CI, 0.24% to 0.39%) to citywide hospitalization, 0.35% (95% CI, −0.06% to 0.61%) in the center, and 0.32% (95% CI, −0.09% to 0.58%) in the outer region (Table 2). The heat attribution for each districts can be found in Fig. 2.

Protective effect of green space on heat-related respiratory hospitalization

The linear relationship between the green space fraction and heat-related respiratory hospitalization risk was statistically significant and is presented in Fig. 3. Overall, estimates suggest that every increase in the 1% green space fraction will reduce heat-related respiratory hospitalization risk by 3.8%. The estimations in the center were higher than those in the outer area (5.2%

Table 1 Respiratory hospitalization, temperature, population density, and green space characteristics of center and outer districts in Hanoi, Vietnam, 2010–2014

ID	Name	Category	915 days statistics for Hanoi's hot season (1st May to 31st Oct)				Population density people/km^2	Green space fraction, %
			Total respiratory hospitalized	Average temperature, °C (range)	Temperature > 75th percentile (day*)	Temperature > 99th percentile (day*)		
1	Hoan Kiem	Center	560	28.8 (18.4–36.0)	30.6 (293)	34.6 (25)	29,757	1.3
2	Dong Da	Center	2226	28.8 (18.5–36.0)	30.6 (300)	34.6 (28)	40,126	1.8
3	Thanh Xuan	Center	1786	28.7 (18.4–35.9)	30.4 (274)	34.4 (21)	28,182	2.7
4	Hai Ba Trung	Center	1002	28.8 (18.4–36.0)	30.6 (293)	34.6 (25)	30,941	3.0
5	Ba Dinh	Center	1408	28.9 (18.5–36.1)	30.6 (303)	34.8 (30)	26,725	3.7
6	Cau Giay	Center	2013	28.8 (18.6–36.0)	30.6 (293)	34.6 (26)	20,551	6.8
7	Hoang Mai	Center	1705	28.5 (18.3–35.5)	30.3 (250)	34.2 (11)	9303	7.8
8	Tay Ho	Center	727	28.5 (18.7–35.3)	30.2 (248)	34.0 (7)	6086	7.8
Center's average			**1428**	**28.7 (18.3–36.1)**	**30.5 (282)**	**34.5 (21)**	**23,959**	**4.4**
9	Thanh Oai	Outer	344	28.4 (18.4–35.4)	30.1 (233)	34.1 (9)	1457	6.8
10	Phu Xuyen	Outer	322	28.4 (18.3–35.4)	30.2 (242)	34.0 (9)	1113	7.2
11	Ung Hoa	Outer	219	28.4 (18.5–35.5)	30.1 (235)	34.1 (10)	1023	7.2
12	Thuong Tin	Outer	618	28.4 (18.3–35.3)	30.2 (237)	34.0 (8)	1847	7.5
13	Phuc Tho	Outer	247	28.5 (19.1–35.9)	30.2 (246)	34.6 (16)	1455	8.8
14	Long Bien	Outer	926	28.3 (18.4–34.8)	30.1 (225)	33.5 (5)	4450	8.9
15	Gia Lam	Outer	671	28.3 (18.0–35.0)	30.1 (227)	33.6 (5)	2153	9.5
16	Dan Phuong	Outer	297	28.5 (18.9–35.4)	30.2 (239)	34.1 (10)	1983	9.5
17	Me Linh	Outer	270	28.4 (18.7–35.2)	30.1 (230)	33.9 (7)	1476	10.0
18	Chuong My	Outer	543	28.4 (18.7–35.6)	30.1 (226)	34.4 (14)	1322	10.4
19	Thanh Tri	Outer	602	28.3 (18.5–35.1)	30.1 (227)	33.6 (6)	3487	11.0
20	Dong Anh	Outer	658	28.4 (18.3–35.1)	30.1 (231)	33.7 (6)	2056	11.2
21	Son Tay	Outer	199	28.3 (19.4–35.5)	30.0 (217)	34.1 (10)	1183	12.4
22	Ha Dong	Outer	1241	28.4 (18.5–35.4)	30.2 (237)	34.2 (11)	5486	13.8
23	Hoai Duc	Outer	800	28.5 (18.8–35.6)	30.2 (243)	34.2 (12)	2578	14.0
24	Bac Tu Liem	Outer	2394	28.7(18.8–35.7)	30.4 (267)	34.2 (17)	5922	14.8
25	Soc Son	Outer	351	28.4 (18.2–35.1)	30.2 (235)	34.1 (8)	1016	17.0

Table 1 (continued)

ID	Name	Category	915 days statistics for Hanoi's hot season (1st May to 31st Oct)				Population density people/km^2	Green space fraction, %
			Total respiratory hospitalized	Average temperature, °C (range)	Temperature > 75th percentile (day*)	Temperature > 99th percentile (day*)		
26	Quoc Oai	Outer	332	28.4 (18.8–35.7)	30.1 (227)	34.7 (17)	1169	17.2
27	Nam Tu Liem	Outer	477	28.5 (18.6–35.5)	30.3 (252)	34.2 (12)	6015	22.8
28	Thach That	Outer	499	28.3 (18.7–35.9)	30.0 (227)	34.8 (20)	1035	23.1
29	My Duc	Outer	201	28.3 (18.6–35.4)	29.9 (216)	34.1 (10)	796	27.9
30	Ba Vi	Outer	194	28.3 (18.9–35.9)	30.0 (218)	34.8 (18)	625	28.9
Outer's average			**564**	**28.4 (18.0–35.9)**	**30.1 (234)**	**34.1 (11)**	**2257**	**13.6**

*Compared to citywide threshold as the 75th percentile at 30.1 °C and the 99th percentile at 34.1 °C

and 3.8% reduction in heat-related respiratory hospitalization risk for every 1% increase in green space, respectively), and the relationship between total heat and green space fraction was still negative for both the center and outer areas (Fig. 3). Sensitivity analysis showed that population density was not correlated with heat-related respiratory hospitalization risk and was not a confounding variable (Fig. S3 and Fig. S4).

Discussion

Hanoi's urbanization characteristics

Our result recognizes the urbanization difference between the center and the outer. Population density is an urban classification criterion that exhibits significant differences. The central population density ranged from 6086 to 40,126 people/km^2, while the outer population density varied from 625 to 6015 people/km^2. The green space fraction average of the center is 4.4%, which is lower than that of the outer space by 13.6%. Previous studies have revealed that green spaces play a role in local temperature regulation (Bowler et al. 2010) (Dang et al. 2018). In Ho Chi Minh City, a previous study recognized that the temperature at the center is 0.9 °C higher than the outer temperature (Dang et al. 2018). Urbanization and a decrease in green spaces can lead to adverse heat-related health effects. A recent study noted that Hanoi is highly sensitive and poorly adaptive to heatwaves (Tran et al. 2020). Therefore, centers with a high population density and insufficient green space have a higher risk than Hanoi's general estimation. In the

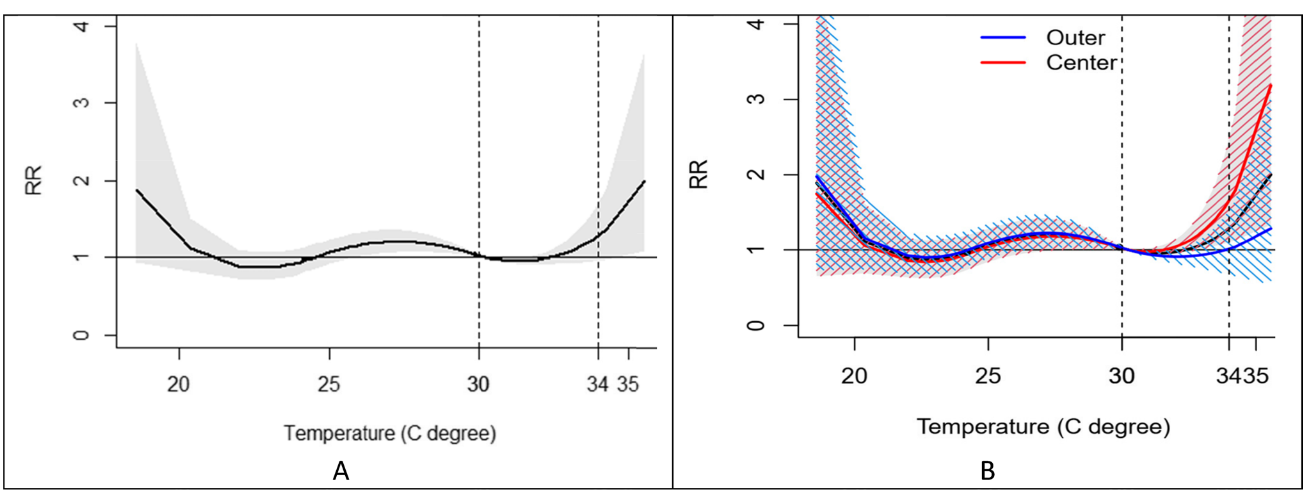

Fig. 1 Heat-related respiratory hospitalization risk functions in Hanoi, Vietnam, 2010–2014. **A** Pooled estimates for citywide. **B** Pooled estimates for center and outer

Table 2 Attributable fractions and 95% confidence intervals of center and outer

	Mild heat [75–99%]		**Extreme heat** [99–100%]		**Total heat** [75–100%]	
	AN (95% CI)	**AF (95% CI)**	**AN (95% CI)**	**AF (95% CI)**	**AN (95% CI)**	**AF (95% CI)**
Center	18 (− 195–195)	0.17% (− 1.72–1.74%)	40 (− 6–69)	0.35% (− 0.06–0.61%)	58 (− 194–259)	0.52% (− 1.73–2.30%)
Outer	− 6 (− 219–172)	− 0.14% (− 1.88–1.30%)	39 (− 9–69)	0.32% (− 0.09–0.58%)	33 (− 224–240)	0.19% (− 1.91%–1.86%)
Citywide	12 (− 85–96)	0.05% (− 0.35–0.40%)	79 (58–94)	0.33% (0.24–0.39%)	91 (− 34–184)	0.38% (− 0.14–0.77%)

* Mean (95% CI) of district average estimation

future, global warming combined with increasing construction density and decreasing green space will increase the vulnerability of Hanoi to heat effects (Yumino et al. 2015).

Exposure to heat

In our results, the hot season average temperature in Hanoi is found out to be 28.5 °C. The difference in the average hot season temperature of the center and the outer is 0.3 °C. The number of days in the hot season reaching high temperatures at the mild heat thresholds and extreme heat thresholds in the center was always higher than those in the outer region. During the 915 hot season days of the study period (2010–2014), the center had 282 days, and the outer had 234 days reaching temperatures higher than 75th percentile. Our study only used hot season data to focus on heat effect. However, other studies have revealed that cold weather is a more substantial cause of death than hot weather (Gasparrini et al. 2015; Schneider and Breitner 2016). The effect of cold effect and its associated factors should be explored in the future.

Attribution of respiratory hospitalization resulting from heat

Our study identified an association between temperature and respiratory hospitalization. High temperatures were associated with the increased risk of respiratory hospitalization (Fig. 1). Previous studies have documented the role of hot weather in health (Anderson and Bell 2009; Gasparrini et al. 2015; Ryti et al. 2016; Luong et al. 2019). Many previous studies have revealed that hospitalization by heat has a short lag effect (≤ 1 day) (Hansen et al. 2008; Ma et al. 2011; Lindstrom et al. 2013; Phung et al. 2016). In Vietnam, a multi-province study of 25 cities representing different ecological regions showed that heatwaves could increase hospitalization in the general population (Phung et al. 2017). It is also found out that children are vulnerable to heat (Kovats et al. 2004; Knowlton et al. 2009; Xu et al. 2017; Zhao et al. 2019). According to a study by Dung Phung et al., a 1 °C increase in the 2-day moving average temperature was significantly associated with an increased risk of 3.8% (95% CI, 0.4–7.2%) in respiratory admission of under 5-year children (Phung et al. 2015). The causes of heat-related hospitalizations have been noted in previous studies. Electrolyte imbalance, respiratory disease, fever, and renal disease are key pediatric diseases and conditions that are significantly affected by heat (Kovats et al. 2004; Leonardi et al. 2006; Knowlton et al. 2009; Nitschke et al. 2011; Guzman Herrador et al. 2015).

Protective effect of green space on heat-related hospitalization

Linear regression analysis in our study showed that green space is associated with heat-related hospitalization risk. If the green space ratio increases by 1%, the heat-related hospitalization risk decreases by 3.8% overall, and 5.2% and 3.8% heat-related

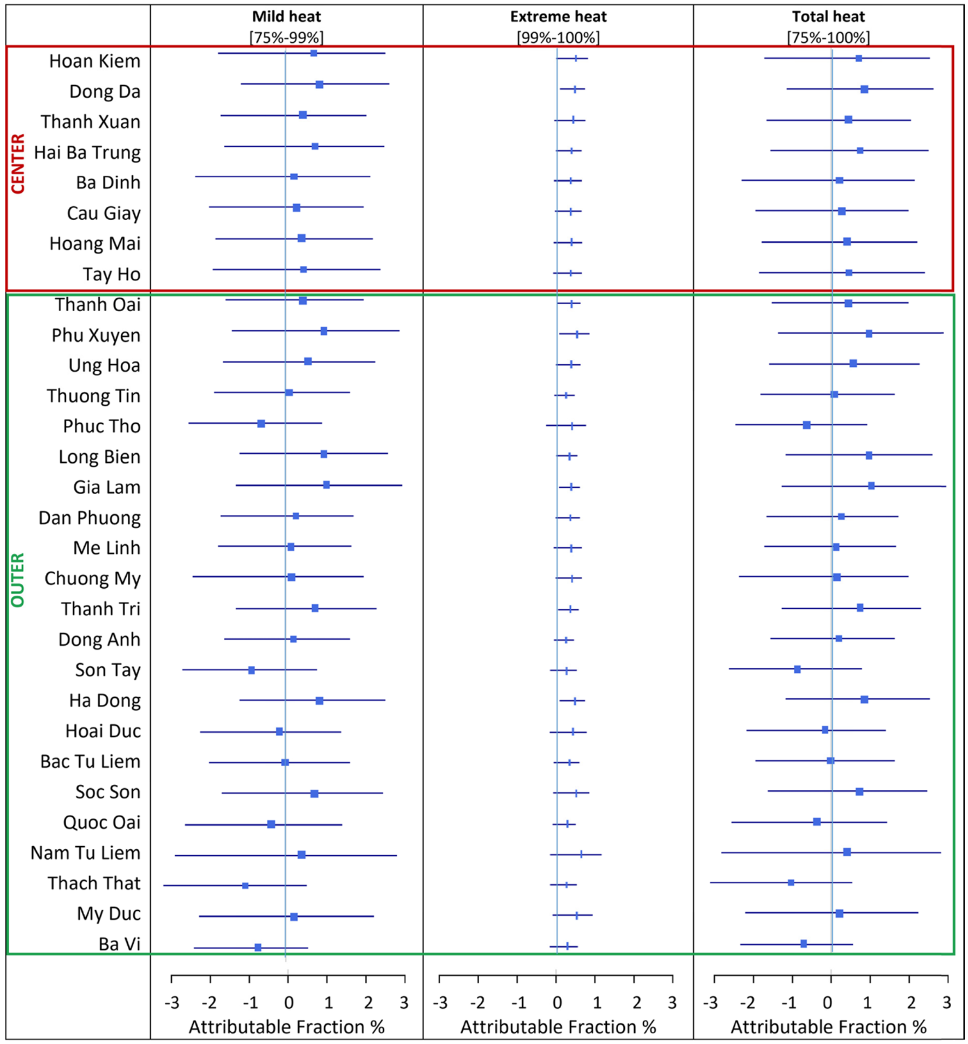

Fig. 2 Attributable fractions and 95% confidence intervals of districts separated for center and outer

hospitalization risk decrease for the center and outer areas, respectively (Fig. 3). Population density may affect population health conditions, leading to potential confounding or interaction (WHO 2018). However, the potential confounding or interaction of population density was eliminated because population density was not associated with hospitalization risk (Fig. S3 and Fig. S4).

These results provide evidence of the protective effect of green spaces, as they improve air quality, reduce stress, increase social cohesion and relaxation, and recover and promote physical activity, reduce overweight/obesity, boost mental health, and upgrade birth and developmental outcomes, as well as decrease cardiovascular mortality (Mitchell and Popham 2008; James et al. 2015; WHO 2016; Crouse et al. 2017).

Protective effects against heat have been recognized (James et al. 2015; Dang et al. 2018; Wang and Tassinary 2019). A 1% increase in the green space area is predicted to reduce all-cause mortality by 0.419% (95% CI 0.050–0.777%), with no effect on cause-specific mortality (Wang and Tassinary 2019). Every 1 km^2 increase in green space per 1000 people can prevent 7.4 deaths caused by heat (Dang et al. 2018). In children under 5 years of age, for the scope of literature, we have not found any previous studies on the protective effect of green space to heat-related hospital admission due to respiratory diseases (Lafortezza et al. 2009; Bowler et al. 2010; Trihamdani et al. 2015). Our results contribute to the data on the beneficial effects of green spaces on health, especially with extreme heat. In explaining the mechanism of increasing hospitalization in children < 5 years old, evidence has shown that green spaces can decrease the local temperature, which directly reduces the impact of heat on health. Additionally, there are indirect effects through improving air quality, promoting physical activity, and increasing relaxation efficiency, body recovery, and general health (Jenerette et al. 2011; WHO 2016).

Limitations and strengths

The ecological study design allows the estimation of the effect of heat and green space on morbidity within a specific area, alerting and motivating interventions to promote health.

In the scope of the data approach, the morbidity data used did not cover the overall under 5-year-old deaths in Hanoi. Three

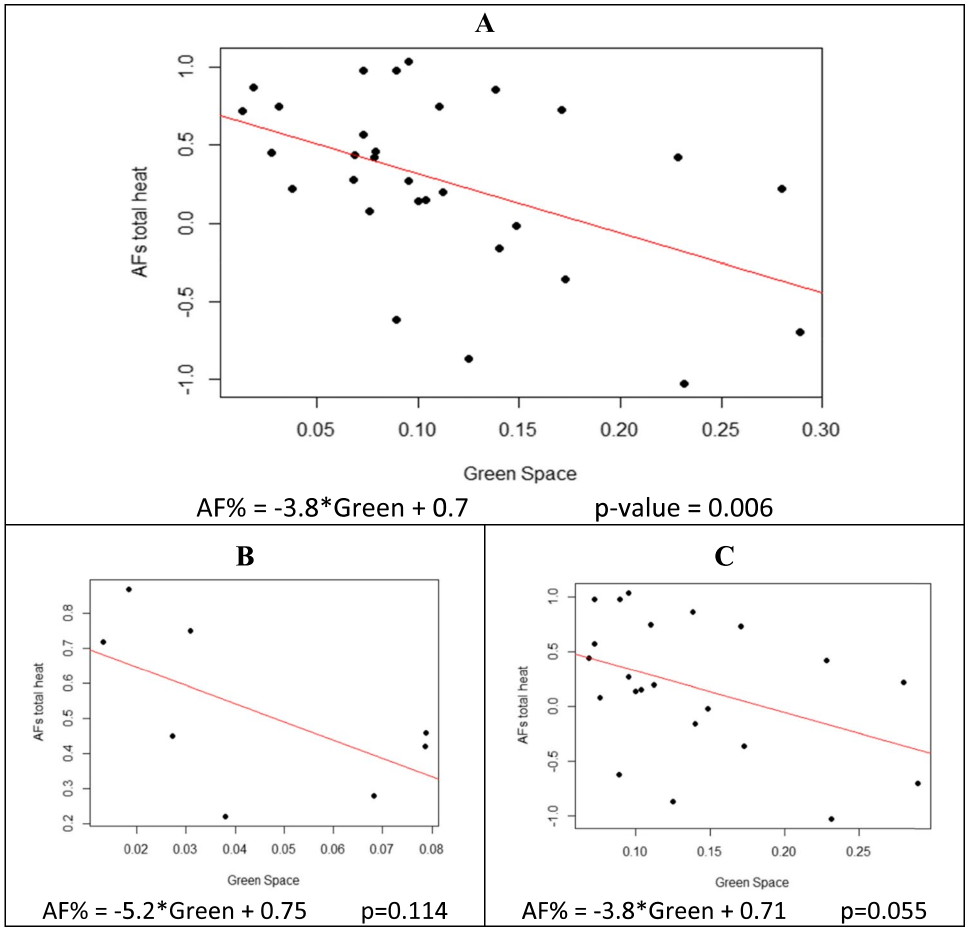

Fig. 3 Linear relationship among green space fraction and heat-related hospitalization **A** Relationship for citywide. **B** Relationship for center districts. **C** Relationship for outer districts

hospitals in our study were concentrated in the center, leading to omitted hospitalizations and deaths, especially in the outer districts. This limitation could lead to an underestimation of heat-related morbidity and mortality in the outer districts. For a better estimate in the future, it will be necessary to approach high-coverage data to represent Hanoi residents.

The meteorological data processed by the WRF model are simulation data that reflect temperature less precisely than the observed methods. The reliability of the WRF model was assessed by comparing it with data from three monitoring stations. Good reliability was achieved to eliminate deviations using the WRF model (Fig. S2).

Some factors such as population density, income, the standard of living, and the availability of local health services may also have confounding effect. However, in the scope of our study, we could only control the population density data at the district level due to the lack of other data sets.

Conclusion

This study confirmed the protective effect of green space on heat-related respiratory hospitalization among children < 5 years old in Hanoi, the capital city of Vietnam. It was observed that a 1% rise in the green space ratio decreases the heat-related hospitalization risk by 3.8%. These findings are valuable for authorities to consider strategies to protect children's health against the effects of heat, including increasing green space.

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Author contribution TND, QVD, and PKT came up with ideas and framework for the study. NNT, LTML, PMC, PKT, DP, and HTCHL collected the hospital and weather data. VTN and TND analyzed and interpreted the data. TND, VTN, and QVD were major contributors in writing the manuscript. All authors read and approved the final manuscript.

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Data availability The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate This study's ethical was approved by the National Hospital of Paediatrics, Biomedical Research Ethics Committee (NHP, RICH, 15–014), and the University of Queensland School of Medicine Low Risk Ethical Review Committee (no. 2016-SOMILRE-0155).

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

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