Socio-demographic vulnerability to heatwave impacts in Brisbane, Australia: a time series analysis

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Abstract

Objective: Examining the association between socioeconomic disadvantage and heat-related emergency department (ED) visits during heatwave periods in Brisbane, 2000–2008.

Methods: Data from 10 public EDs were analysed using a generalised additive model for disease categories, age groups and gender.

Results: Cumulative relative risks (RR) for non-external causes other than cardiovascular and respiratory diseases were 1.11 and 1.05 in most and least disadvantaged areas, respectively. The pattern persisted on lags 0–2. Elevated risks were observed for all age groups above 15 years in all areas. However, with RRs of 1.19–1.28, the 65–74 years age group in more disadvantaged areas stood out, compared with RR=1.08 in less disadvantaged areas. This pattern was observed on lag 0 but did not persist. The RRs for male presentations were 1.10 and 1.04 in most and less disadvantaged areas; for females, RR was 1.04 in less disadvantaged areas. This pattern persisted across lags 0–2.

Conclusions: Heat-related ED visits increased during heatwaves. However, due to overlapping confidence intervals, variations across socioeconomic areas should be interpreted cautiously.

Implications: ED data may be utilised for monitoring heat-related health impacts, particularly on the first day of heatwaves, to facilitate prompt interventions and targeted resource allocation.

Key words: socioeconomic disadvantage, vulnerability, heatwaves, emergency departments, temporal analysis

Globally, heatwaves and high temperatures kill thousands of people and adversely affect the health of many more every year.[1] With the frequency and intensity of heatwaves expected to increase as a result of global climate change, further increases in mortality and morbidity are projected to occur,[2,3] and the impacts are more severely felt in urban areas.[4,5] Some groups are at higher risk, such as people with low socioeconomic position, pre-existing respiratory or cardiovascular diseases, the elderly and young children.[1,6-8]

Harm minimisation strategies including heat warning systems and protective measures are used to reduce the negative health impacts of heatwaves,[9] but, little is known about their effectiveness for vulnerable populations.[10] Studies indicate that high-risk areas involve higher concentrations of vulnerable groups. These include: the elderly, who may live alone; the urban poor; people with chronic health conditions; and those living in poorly designed dwellings.[11-13] While some studies suggest that hospitalisations do not increase on hot days,[14] there is evidence that emergency presentations and admissions increase significantly during heatwaves.[15-19] The volume and type of presentations to emergency departments (EDs) can also be used as surveillance tools to monitor the evolving impacts of extreme weather events, which can assist relevant local agencies to monitor and respond as required.[20]

As the impacts of high temperatures vary, location-specific research is required to provide relevant information to facilitate prompt interventions and targeted resource allocation. However, knowledge of socio-demographic vulnerability to heatwave impacts is limited. This paper is the first to examine the relationship between neighbourhood disadvantage and heat-exacerbated ED presentations in Brisbane, Australia. ED-presentations data encompass a wide cross-section of people who may be affected by heat but have not died or may not need to be admitted. Consequently, we can explore the potential use of these data to monitor the immediate impacts of heatwaves in this region.

Methods

Data

All data were collected for the period 1 July 2000 to 30 June 2008 for Brisbane, Australia (27° 30′ south and 153° 00′ east).

The health data, in the form of public hospital ED presentations, were provided by Queensland Health. The data included patient's arrival date, residential postcode, age and diagnosis (using International Classification of Diseases [ICD] versions 9 and 10). The diagnostic assessments for

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non-external causes (NEC) were grouped as respiratory disease (ICD–9, 460–519; ICD–10, J00–J99), cardiovascular disease ([CVD]: ICD–9, 390–459; ICD–10, I00–I99), and Other NEC (ICD–9, 001–390 and 520–799; ICD–10, A00–H95 and K00–R99). Age was grouped as 0–14, 15–64, 65–74, and 75+. Matching data for private EDs were not available.

The health data included patients' residential postcodes. The Index of Relative Socioeconomic Disadvantage (IRSD) for postcodes was obtained from the Australian Bureau of Statistics (ABS) to assess patients' neighbourhood socioeconomic disadvantage. IRSD is part of a suite of indexes called Socio-Economic Indexes for Areas (SEIFA).[21] The IRSD summarises 17 measures about the economic and social resources of people within an area, including percentage of households with low income, low education, high unemployment and unskilled occupations. The areas are scored and ranked into percentiles and deciles. A low rank means highly disadvantaged. For the purposes of this study, we re-grouped IRSD deciles into quintiles (1= Most disadvantaged; 5= Least disadvantaged). Figure S1 (supplementary material) visualises the level of disadvantage of the study areas according to IRSD.

To calculate the mean number of daily ED presentations per 100,000 persons, we downloaded the population data (Census data for 2001 and 2006, and estimates for other years) from the ABS by IRSD, age and gender. For each year, we used as the denominator the total population numbers for disease categories, and sub-population numbers for IRSD, age and gender categories.

Meteorological data, consisting of daily minimum and maximum temperatures (over 24 hours after 9 am) and relative humidity were obtained from the Bureau of Meteorology. Air pollution data were obtained from Department of Science, Information Technology, Innovation and the Arts, and consisted of observations of ozone (O_3) and particulate matter less than 10μm (PM_{10}). The data were collected from seven meteorological and nine air pollution observation stations in Brisbane. For each measure, the daily mean was calculated.

Heatwave definition

Since there is no official heatwave threshold for Brisbane, we have defined a heatwave event as two or more consecutive days with daily mean temperatures above the 95th percentile. We selected this conservative threshold because we were interested in the potential use of ED data for monitoring acute and early impacts of heatwaves, and this was previously shown to be associated with an increase of about 3% in emergency hospital admissions in Brisbane; higher percentiles were associated with higher admission rates.[15] The daily mean temperature was also shown to be a better predictor of heat-related mortality in this city than other measures.[22] To test the sensitivity of the heatwave definition and its suitability and implication for monitoring purposes, we applied a lower and a higher threshold of 90th and 98th percentiles in accord with the literature.[15,23-25]

Analysis

To analyse the cumulative effect and individual lagged effects of temperature and heatwaves on the number of ED visits in association with socioeconomic disadvantage, we examined the relationship between heatwaves and daily number of ED presentations using a generalised additive model, which assumed a quasi-Poisson distribution for daily ED presentations to allow for over-dispersion. Daily mean temperature was modelled using a natural cubic spline with 'X' degrees of freedom, while the added effects of heatwaves were captured using an indicator variable, which identified heatwave days according to the definition. For the lagged effects of heatwaves, we used the lag time of 0–3 days as our preliminary analysis showed no statistically significant increases beyond this period. Other studies have also found that, unlike cold, heat health effects are acute and continue only for a few days.[16,26] Natural cubic splines for day of season and year were incorporated to control for regular seasonal effects and longer term trends, while day of the week was adjusted for by using a categorical variable. We controlled for PM_{10}, O_3 and relative humidity using natural cubic splines. To capture lagged effects of humidity and air pollutants, moving averages over the previous seven days were used. All cubic splines were modelled using four degrees of freedom, which was chosen based on previous research.[27]

To examine sensitivity to changes in the model parameters, additional analyses were performed to check the reliability of the findings by changing the degrees of freedom (3–6) used for air pollutants, relative humidity, seasonal and long-term trends. We also tested the sensitivity with a longer lag time (10–15 days) for air pollutants and relative humidity consistent with previous studies,[28,29] which did not change the results.

Effect estimates of an added heatwave effect were calculated as the relative risk (RR) of presentation to ED on heatwave versus non-heatwave days by disease categories, age groups, gender and IRSD quintiles, separately.

All analyses were performed using SPSS 19.0 and R 3.0.1 'mgcv' package. MapInfo Professional 10.5 was used for spatial presentation of the results.

Results

ED presentations for all NEC increased from 336 cases on 1 July 2000 to 477 on 30 June 2008; or from a total of 136,603 cases in 2000/01 fiscal year to 163,232 in 2007/08 (Figure S2 in the supplementary material). The presentations fluctuated fairly regularly with increases around warmer months (November to March). We selected this period for further analysis to present a more accurate picture of the impact of heatwaves and avoid the effect of cold temperatures on ED attendances.

During the study period, the daily mean temperature ranged between 17°C and 34.5°C. The threshold for determining heatwaves was 27.0°C at 95th percentile for two or more consecutive days. We identified 112 heatwave days with an average 28.4°C temperature. The non-heatwave periods were on average 4.4°C cooler (for further details see Table S1 in the supplementary material).

Table 1 shows the mean number of daily ED presentations per 100,000 persons by disease groups, IRSD, age and gender. Respiratory and CVD presentations increased 2% and 1%, and Other NEC 12% during heatwaves. While the IRSD areas 1–5 contained 3.5%, 3.9%, 6.1%, 44.1% and 42.4% of the population, they comprised 5.7%, 6.3%, 6%, 48.5% and 33.4% of all NEC-related ED presentations, respectively. In the most disadvantaged areas, the attendances during heatwave periods increased by 12% compared to non-heatwave days, but in the least disadvantaged locations the ED presentations increased by 6%. The presentations increased by 7% among the youngest age group during heatwaves, while it was 13% among the elderly. Both females and males had an elevated rate of attending EDs (around 8.5%) during heatwaves. This pattern remained mostly consistent with either of the 90th and 98th percentiles (see Supplementary Table S2).

Table 2 shows the results of the multivariable analysis of the relationship between ED attendance and heatwaves by disease categories across the five IRSD groups adjusted for relative humidity, PM_{10} and O_3. While respiratory visits were not overall affected by heatwaves significantly, a statistically significant decline of 7%–9% was observed on lag days 1–3 in less disadvantaged areas. Similarly, only when lag effects were analysed, the CVD-related attendances increased significantly by 9%–10% on lags 0–1 in less disadvantaged areas. ED presentations for Other NEC increased significantly in all IRSD areas except IRSD 2. However, the increase was more pronounced in the most disadvantaged areas (RR 1.11, 95% Confidence Interval [CI] 1.02–1.20) than the least disadvantaged areas (RR 1.05, 95%CI 1.02–1.08). Looking at the lagged effects, Other NEC presentations persisted from lag 0 to lag 3, with more pronounced effects in the most disadvantaged areas. However, the confidence intervals overlapped across IRSD subgroups, and the differences were not statistically significant.

Regarding age (Table 3), no significant effect was observed for the 0–14 years age group even after lag effects were considered. For the 15–64 years age group, an overall significant increase was observed in IRSD 4 areas (RR= 1.04, 95%CI 1.02–1.08). However, after lag analysis, we observed that visits by 15–64 year olds increased 8%–9% on lags 1–2 in the most disadvantaged areas. The highest effects were identified in the 65–74 years age group living in the more disadvantaged areas with RR 1.19 (95%CI 1.02–1.40) in IRSD 1, and RR 1.28 (95%CI 1.09–1.50) in IRSD 2. These increases mainly occurred on lag 0. There was also an elevated risk of 6%–7% in IRSD 4 that persisted between lags 0–3. For the oldest age group (75 years and above), an overall increased risk was mainly observed in IRSD 4 areas (RR 1.08, 95%CI 1.03–1.14); the risk lasted for two days (lags 0–1). Additionally, in the least disadvantaged areas, ED visits by this age group increased on lag 1 (RR 1.10, 95%CI 1.03–1.17) and lasted till lag 3. Due to overlapping confidence intervals, the differences across IRSD subgroups were not statistically significant.

Considering gender (Table 4), ED visits increased for both females and males in IRSD 4 areas (RR 1.04, 95%CI 1.01–1.07). The lagged effects were approximately at the same rate between lags 0–2. However, males in the most disadvantaged areas had an increased risk of attendance (RR 1.10, 95%CI 1.02–1.19). The effects persisted at similar rates between lags 0–2. Despite considerable differences across IRSD areas, the confidence intervals overlapped, making the differences statistically non-significant.

We modified the degrees of freedom for air pollutants, relative humidity and seasonal and long-term trends, but the results did not

Table 1: Mean number of daily ED presentations per 100,000 persons on heatwave and non-heatwave days in Brisbane: Nov-Mar 2000–2008.

	95th percentile		
	NHW	HW	HW/NHW Ratio
Disease			
Respiratory	3.2	3.3	1.02
CVD	1.5	1.5	1.01
Other NEC	30.7	34.4	1.12
ALL NEC	35.5	39.3	1.11
IRSD			
1	78.2	87.8	1.12
2	77.0	86.5	1.12
3	47.0	51.2	1.09
4	52.6	57.3	1.09
5	37.8	40.3	1.06
Age			
0–14	60.9	65.0	1.07
15–64	42.5	46.1	1.08
65–74	48.3	53.7	1.11
75+	69.8	79.2	1.13
Gender			
Female	44.2	47.8	1.08
Male	51.6	56.2	1.09
Total	47.1	51.0	1.08

HW, Heatwave days; NHW, Non-Heatwave days; CVD, Cardiovascular diseases; NEC, Non-External Causes; IRSD, Index of Relative Socioeconomic Disadvantage (1= Most disadvantaged, 5=Least disadvantaged)

Table 2: Association between ED presentations and heatwaves according to geographic socioeconomic disadvantage and diseases in Brisbane (95th percentile).

Disease	Respiratory	CVD	Other NEC	All NEC
	RR (95% CI)	RR (95% CI)	RR (95% CI)	RR (95% CI)
IRSD		**Cumulative effect**		
1	0.93 (0.78, 1.10)	0.98 (0.79, 1.20)	**1.11 (1.02, 1.20)**	**1.08 (1.00, 1.17)**
2	0.93 (0.78, 1.11)	0.84 (0.66, 1.09)	1.09 (0.99, 1.20)	1.08 (0.98, 1.18)
3	1.08 (0.94, 1.23)	0.97 (0.79, 1.20)	**1.07 (1.01, 1.13)**	**1.07 (1.01, 1.13)**
4	0.97 (0.92, 1.03)	1.03 (0.95, 1.11)	**1.07 (1.04, 1.10)**	**1.06 (1.03, 1.09)**
5	0.96 (0.90, 1.03)	0.92 (0.83, 1.02)	**1.05 (1.02, 1.08)**	**1.04 (1.01, 1.07)**
		Lag 0		
1	0.94 (0.79, 1.11)	1.06 (0.86, 1.31)	**1.08 (1.00, 1.17)**	1.06 (0.98, 1.15)
2	0.93 (0.77, 1.11)	0.90 (0.70, 1.16)	1.09 (0.99, 1.20)	1.07 (0.98, 1.18)
3	1.07 (0.93, 1.23)	1.04 (0.84, 1.29)	1.03 (0.97, 1.09)	1.04 (0.98, 1.10)
4	0.97 (0.92, 1.03)	**1.10 (1.01, 1.19)**	**1.06 (1.03, 1.09)**	**1.05 (1.02, 1.08)**
5	0.96 (0.90, 1.03)	0.99 (0.90, 1.10)	**1.04 (1.01, 1.07)**	**1.03 (1.00, 1.06)**
		Lag 1		
1	0.93 (0.79, 1.11)	0.98 (0.79, 1.21)	**1.10 (1.01, 1.19)**	1.08 (0.99, 1.16)
2	0.89 (0.74, 1.07)	0.97 (0.76, 1.24)	1.05 (0.95, 1.16)	1.04 (0.94, 1.14)
3	1.01 (0.87, 1.16)	1.00 (0.81, 1.25)	1.04 (0.98, 1.10)	1.03 (0.98, 1.09)
4	**0.93 (0.88, 0.99)**	**1.09 (1.01, 1.18)**	**1.05 (1.02, 1.08)**	**1.04 (1.01, 1.07)**
5	0.95 (0.89, 1.02)	0.94 (0.85, 1.05)	**1.04 (1.01, 1.07)**	1.02 (0.99, 1.06)
		Lag 2		
1	0.91 (0.76, 1.08)	1.08 (0.88, 1.34)	**1.10 (1.01, 1.19)**	**1.08 (1.00, 1.17)**
2	0.88 (0.73, 1.06)	0.86 (0.67, 1.11)	1.06 (0.96, 1.17)	1.04 (0.94, 1.15)
3	0.99 (0.86, 1.15)	1.04 (0.84, 1.29)	**1.07 (1.01, 1.13)**	**1.06 (1.00, 1.12)**
4	**0.93 (0.87, 0.98)**	1.02 (0.94, 1.11)	**1.05 (1.02, 1.08)**	**1.04 (1.01, 1.07)**
5	**0.91 (0.85, 0.98)**	1.00 (0.90, 1.11)	**1.04 (1.01, 1.08)**	**1.03 (1.00, 1.06)**
		Lag 3		
1	0.91 (0.77, 1.09)	1.09 (0.88, 1.34)	1.06 (0.98, 1.15)	1.05 (0.97, 1.14)
2	0.88 (0.73, 1.07)	0.87 (0.67, 1.13)	1.06 (0.96, 1.17)	1.04 (0.94, 1.15)
3	0.89 (0.77, 1.04)	0.94 (0.75, 1.18)	1.04 (0.98, 1.10)	1.02 (0.96, 1.08)
4	**0.91 (0.86, 0.97)**	1.01 (0.93, 1.10)	**1.04 (1.01, 1.07)**	**1.03 (1.00, 1.06)**
5	**0.91 (0.85, 0.97)**	1.03 (0.93, 1.14)	1.03 (1.00, 1.06)	1.02 (0.99, 1.05)

Results adjusted for relative humidity, PM10 and O3.

Statistically significant differences at P<0.05 are highlighted in bold.

Abbreviations: RR, Relative Risk; HW, Heatwave days; NHW, Non-Heatwave days; CVD, Cardiovascular diseases; NEC, Non-External Causes; IRSD, Index of Relative Socioeconomic Disadvantage (1= Most Disadvantaged; 5= Least Disadvantaged) change substantially. Also, a longer lag time (10–15 days) for air pollutants and relative humidity did not alter the findings. The results from the sensitivity analysis with 90th and 98th percentiles produced similar pattern of associations, but the magnitudes varied as expected. At 90th percentile, the associations were generally weaker than the 95th percentile, while at the 98th percentile they were stronger (results not presented).

Discussion

Heatwave effects vary in magnitude by location, disease type, demographic characteristics and heatwave duration. Our study showed that on heatwave days, CVD presentations increased 9%–10% only in IRSD 4 areas on lags 0–1; Other NEC-related attendances increased 7%–10% in IRSD 1–3 areas on lags 0–2, and by 4%–6% in other areas. Regarding age, in more disadvantaged areas (IRSD 1-2), ED attendances by the 15–64 year age group increased around 7%–9% on lags 0–2 and 18%–32% on lags 0–1 by the 65–74 year age group. On the other hand, in IRSD 4–5 areas, an increase of around 4%–10% was recorded for all age groups above 15 years on lags 0–2. Male presentations in IRSD areas 1 and 4 increased 10% and 4%, respectively, while for females the increased presentations were only in IRSD 4 areas. However, due to overlapping confidence intervals, the differences across IRSD areas were not statistically significant.

Previous studies in this city showed that the likelihood of hospital admissions increased significantly during heatwaves for NEC, particularly renal diseases among older people (65 years and above) but not for CVD and respiratory diseases.[15,30] Other studies show mixed results in relation to the impacts of heat on CVD and respiratory morbidities.[6,31,32] Factors such as differences in socio-demographic characteristics, biological mechanisms, health protection behaviors and habits during heatwaves such as the notable Australian 'Slip, Slap, Slop, Seek, Slide' sun protection campaign[33] and urban heat island may account for the differences.

Research on heat-related morbidity and its association with socioeconomic disadvantage is limited. Existing literature identifies the poor, particularly in urban areas, as among

Table 3: Association between ED presentations and heatwaves according to geographic socioeconomic disadvantage and age in Brisbane (95th percentile).

Age Group	0-14	15-64	65-74	≥75
	RR (95% CI)	RR (95% CI)	RR (95% CI)	RR (95% CI)
IRSD	**Cumulative effect**			
1	1.05 (0.93, 1.18)	1.07 (0.99, 1.15)	**1.19 (1.02, 1.40)**	1.04 (0.88, 1.21)
2	1.06 (0.93, 1.22)	1.08 (0.98, 1.18)	**1.28 (1.09, 1.50)**	1.07 (0.90, 1.28)
3	1.02 (0.94, 1.11)	1.05 (0.99, 1.11)	0.90 (0.77, 1.05)	1.04 (0.93, 1.17)
4	1.01 (0.97, 1.05)	**1.04 (1.02, 1.08)**	**1.08 (1.02, 1.14)**	**1.08 (1.03, 1.14)**
5	1.02 (0.97, 1.06)	1.02 (0.99, 1.05)	1.04 (0.97, 1.12)	1.06 (0.99, 1.13)
		Lag 0		
1	1.03 (0.92, 1.16)	1.07 (0.99, 1.15)	**1.18 (1.00, 1.39)**	1.01 (0.86, 1.19)
2	1.07 (0.94, 1.23)	1.08 (0.98, 1.19)	**1.32 (1.12, 1.54)**	1.08 (0.91, 1.29)
3	1.02 (0.94, 1.10)	1.04 (0.98, 1.10)	0.87 (0.75, 1.02)	1.01 (0.90, 1.13)
4	1.01 (0.97, 1.05)	**1.05 (1.02, 1.08)**	**1.07 (1.01, 1.14)**	**1.08 (1.03, 1.14)**
5	1.01 (0.97, 1.06)	1.02 (0.99, 1.05)	1.05 (0.97, 1.13)	1.06 (0.99, 1.12)
		Lag 1		
1	1.03 (0.91, 1.16)	**1.09 (1.01, 1.17)**	1.08 (0.91, 1.27)	1.01 (0.86, 1.18)
2	1.01 (0.88, 1.16)	1.05 (0.95, 1.16)	1.17 (0.99, 1.38)	1.06 (0.89, 1.27)
3	1.02 (0.94, 1.11)	1.01 (0.95, 1.07)	0.92 (0.79, 1.08)	1.02 (0.91, 1.15)
4	1.00 (0.96, 1.04)	**1.04 (1.01, 1.07)**	**1.07 (1.01, 1.14)**	**1.06 (1.00, 1.12)**
5	0.98 (0.94, 1.02)	1.01 (0.98, 1.04)	1.07 (0.99, 1.15)	**1.10 (1.03, 1.17)**
		Lag 2		
1	1.04 (0.92, 1.17)	**1.08 (1.00, 1.16)**	1.12 (0.95, 1.32)	1.11 (0.94, 1.29)
2	1.03 (0.90, 1.18)	1.04 (0.94, 1.15)	1.15 (0.97, 1.37)	0.97 (0.80, 1.16)
3	1.00 (0.92, 1.09)	1.04 (0.98, 1.10)	0.99 (0.85, 1.15)	1.12 (1.00, 1.25)
4	0.99 (0.95, 1.03)	**1.05 (1.02, 1.08)**	**1.06 (1.00, 1.13)**	1.04 (0.98, 1.10)
5	0.99 (0.94, 1.03)	1.02 (0.99, 1.05)	**1.08 (1.00, 1.16)**	**1.10 (1.03, 1.17)**
		Lag 3		
1	1.04 (0.92, 1.17)	1.05 (0.97, 1.13)	1.11 (0.94, 1.32)	1.07 (0.91, 1.26)
2	0.99 (0.86, 1.14)	1.05 (0.95, 1.16)	1.14 (0.96, 1.35)	0.85 (0.70, 1.03)
3	0.99 (0.91, 1.08)	1.00 (0.94, 1.06)	0.98 (0.84, 1.14)	1.08 (0.97, 1.22)
4	0.97 (0.93, 1.01)	**1.04 (1.01, 1.07)**	**1.06 (1.00, 1.13)**	1.05 (0.99, 1.11)
5	0.98 (0.93, 1.02)	1.01 (0.98, 1.04)	1.06 (0.98, 1.14)	**1.07 (1.00, 1.14)**

** IRSD: 1= Most Disadvantaged; 5= Least Disadvantaged.*
Results adjusted for relative humidity, PM10 and O3.
Statistically significant differences at P<0.05 are highlighted in bold.
Abbreviations: RR, Relative Risk; IRSD, Index of Relative Socioeconomic Disadvantage (1= Most Disadvantaged; 5= Least Disadvantaged)

Table 4: Association between ED presentations and heatwaves according to geographic socioeconomic disadvantage and gender in Brisbane (95th percentile).

Gender	Female	Male
	RR (95% CI)	RR (95% CI)
IRSD	**Cumulative effect**	
1	1.03 (0.95, 1.13)	**1.10 (1.02, 1.19)**
2	1.09 (0.98, 1.21)	1.07 (0.98, 1.18)
3	1.03 (0.96, 1.10)	1.04 (0.98, 1.10)
4	**1.04 (1.01, 1.07)**	**1.04 (1.01, 1.07)**
5	1.02 (0.98, 1.05)	1.02 (0.99, 1.06)
	Lag 0	
1	1.03 (0.94, 1.13)	**1.10 (1.01, 1.19)**
2	1.10 (0.99, 1.22)	1.08 (0.98, 1.19)
3	1.01 (0.94, 1.08)	1.03 (0.97, 1.10)
4	**1.04 (1.01, 1.07)**	**1.04 (1.01, 1.07)**
5	1.02 (0.98, 1.05)	**1.03 (1.00, 1.06)**
	Lag 1	
1	1.04 (0.95, 1.14)	**1.09 (1.01, 1.18)**
2	1.07 (0.96, 1.19)	1.03 (0.93, 1.14)
3	1.02 (0.96, 1.09)	0.99 (0.93, 1.05)
4	**1.03 (1.00, 1.07)**	**1.03 (1.00, 1.06)**
5	1.01 (0.98, 1.05)	1.02 (0.98, 1.05)
	Lag 2	
1	1.06 (0.96, 1.16)	**1.09 (1.00, 1.18)**
2	1.04 (0.93, 1.16)	1.05 (0.95, 1.16)
3	**1.07 (1.00, 1.14)**	1.00 (0.94, 1.07)
4	**1.03 (1.00, 1.07)**	**1.03 (1.00, 1.07)**
5	1.03 (0.99, 1.06)	1.02 (0.98, 1.05)
	Lag 3	
1	1.03 (0.94, 1.14)	1.06 (0.98, 1.15)
2	1.03 (0.92, 1.14)	1.03 (0.93, 1.14)
3	1.04 (0.97, 1.11)	0.97 (0.91, 1.04)
4	1.02 (0.99, 1.06)	1.02 (0.99, 1.06)
5	1.02 (0.98, 1.05)	1.00 (0.97, 1.04)

** IRSD: 1= Most Disadvantaged; 5= Least Disadvantaged.*
Results adjusted for relative humidity, PM10 and O3.
Statistically significant differences at P<0.05 are highlighted in bold.
Abbreviations: RR, Relative Risk; IRSD, Index of Relative Socioeconomic Disadvantage (1= Most Disadvantaged; 5= Least Disadvantaged)

the most vulnerable groups.[6,31,34] While our results were mostly consistent with these studies, we also found that ED presentations increased during heatwaves in the less disadvantaged areas, albeit at noticeably lower rates. Many factors may explain these findings. For instance, although Brisbane's inner-city suburbs are rated high in terms of IRSD, they are also home to a number of low-socioeconomic-status people living in public housing facilities and welfare services. These areas are also likely to be hotter than outer suburbs due to the concentration of high-rise buildings and other infrastructure, which may create an urban heat island. The elderly and those living in these circumstances may have limited cooling facilities and insulation. Even when these facilities are available, the costs of accessing or using them may be a concern.[35] Furthermore, the differences in ED visits in different IRSD areas may reflect health disparities associated with spatial patterns of temperature and air pollution.[36,37] However, we were unable to assess this with our data.

We found that in the most disadvantaged areas, men's chances of attending an ED on heatwave days increased 10% compared with non-heatwave days, while this was 4% for women and men in the less disadvantaged areas. Higher exposure to heat due to working outdoors or inadequate ventilation may at least partly explain the difference. Lower socioeconomic position is also associated with other factors such as poorer general health, lifestyle risk factors, difficulties in receiving timely information, lower social support particularly for the elderly living alone and inability to access alternative health and medical services. These and other bio-psycho-social factors such as lifestyle, ethnic background and biological make-up may explain why the risk of attending EDs increases during heatwaves in the more disadvantaged areas particularly. Further research using environmental health disparities and environmental justice frameworks may shed light on how socioeconomic position, heat and health interact.[36,38]

Overall, our findings show that even relatively modest temperature increases are associated with an elevated number of ED attendances in this subtropical city, where one may assume that people are relatively accustomed to warm weather. However, with mild temperatures most days (75% of days with a daily mean ≤24.1°C), an ageing population and growing number of migrants to Brisbane,[39] this cannot be taken for granted. These groups may be more vulnerable to heatwave impacts,[7,40] and measures need to be implemented to protect people, especially high-risk groups in the more disadvantaged areas. It may even be necessary to use lower thresholds of heatwave definition in order to prepare the resources and respond to the increasing demand for emergency health services during hot periods.

To alleviate heat-related health impacts, each locality's climatic, geographic and socioeconomic conditions, population characteristics and preparedness, and individuals' perceptions need to be considered. These factors significantly affect the way in which risk management and prevention programs are developed, delivered and utilised.[12,31,41,42] Consistent with the literature,[16,26,32] our findings showed acute short-term increases in ED presentations during heatwaves in different areas that varied by diseases and demographic characteristics. These may have significant policy implications for improving access to health and cooling services, and promoting targeted health messages for high risk groups and locations. As previously suggested,[16,20,43,44] ED data in conjunction with other surveillance methods can provide a sensitive tool to monitor the heat effects in real-time, and facilitate the allocation of resources and management of the ED surge capacity in each area.

From a public health policy perspective, the findings are significant as they show that the more disadvantaged suburbs are mainly concentrated close to each other (see Figure S1), and only make up 12% of the presentations. This should make it easier to provide necessary assistance during heatwaves. On the other hand, a large proportion of the patients live in the rest of the city and even a small percentage increase as a result of high temperature translates to a high demand for emergency health services including a rapid surge in ED presentations. It is important to assess the needs of each population and their vulnerability when developing prevention and mitigation strategies. Also, vulnerable individuals living in less-disadvantaged areas should not be forgotten, and broad community messaging should occur as well as targeted programs aimed at vulnerable groups.

Our study has several major strengths. It is the first study to examine the impact of heatwaves on ED visits according to geographic socioeconomic disadvantage in a subtropical climate. In addition, the study contributes to the development of a simple and easy-to-use marker to identify and monitor heat effects in vulnerable areas and groups in Brisbane. It demonstrates that heatwaves are associated with substantial increases in ED usage, particularly in the more disadvantaged areas. Finally, our findings provide a foundation for further investigation on how to improve public health services and messages during heatwaves.

These findings should be considered with the study limitations. First, as we used administrative data, we were unable to confirm individual exposures to heat and to explore the relation with other factors such as individuals' education, employment and income. Second, our study was based on data for one city and from public hospitals only. Third, the IRSD is not a definitive measure of socio-economic status, and the climatic factors (e.g. temperature and air pollution) may vary across the city and IRSD areas. Finally, IRSD analysis was based on residential postcodes. Some patients may not have been at home when suffering heat exposure. Additionally, postcodes are of low resolution due to their extent of coverage. Some postcodes cover large areas of land and park with small population, while others apply to small but densely populated areas. More precision can be achieved if suburb or Statistical Local Area data are available.

Conclusions

Different locations have different degrees of tolerance and vulnerability to hot temperatures. Living in socioeconomically disadvantaged areas may further expose the population and increase the chances of falling ill as a result. As the health effects of heatwaves are acute and short-term, the use of readily available ED and high-resolution geographic socioeconomic data in conjunction with other syndromic surveillance tools can provide a simple and timely indicator of the rising level of heat impacts, inform health resource allocation strategies, and alert the activation of response measures in affected areas.[4,11,34]

Future location-specific research is required on community vulnerability to heat hazards linking emergency health services and other locally specific data. These may include population density, urban heat island, demographic and socioeconomic characteristics, and access to health care facilities. Furthermore, individuals' perceptions, beliefs and actions in relation to heat and its impacts have not been studied in this region. More studies are recommended to enhance our awareness of the population needs and sensitivities, and advance the development of appropriate measures to protect their health.

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Supporting Information

Additional supporting information may be found in the online version of this article:

Supplementary Table 1: Mean daily temperature on heatwave vs. non-heatwave days in Brisbane: Nov-Mar 2000–2008 (°C).

Supplementary Table 2: Mean number of daily ED presentations per 100,000 persons on heatwave and non-heatwave days in Brisbane: Nov-Mar 2000 –2008.\
Supplementary Figure 1: Map of study areas according to the Index of Relative Socio-economic Disadvantage (IRSD)- 2006 Census.

Supplementary Figure 2: ED presentations for non-external causes between 1 July 2000 and 30 June 2008.