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Review

Effect modification of individual- and regional-scale characteristics on heat wave-related mortality rates between 2009 and 2012 in Seoul, South Korea

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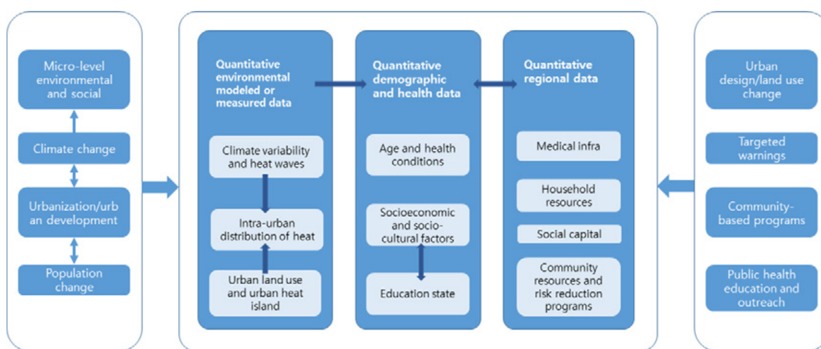
HIGHLIGHTS

- We studied heat wave mortality rates in Seoul between 2009 and 2012.
- Potential individual- and district-scale causative factors were investigated.
- Effect size of heat wave on mortality increased according to individual factors and regional level on heat wave day.
- More vulnerable individuals had low levels of education.
- Districts with higher mortality rates had less green space and fewer hospitals.

GRAPHICAL ABSTRACT



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ABSTRACT

Many studies have investigated the associations between heat waves, ambient temperature, cold spells, and mortality or morbidity. Some studies have utilized effect modification to reveal the factors that increase an individual's susceptibility to temperature extremes, which can then be used to reshape public policy. In this study, we used a time-stratified case-crossover technique to examine how individual- and regional-scale characteristics modified heat wave-related impacts on mortality rates in Seoul, South Korea, between 2009 and 2012. We defined a heat wave as having at least two consecutive days with a daily mean temperature greater than or equal to the 95th percentile recorded in each of Seoul's twenty-five districts. At the individual scale, citizens classified as belonging to a lower education group had a higher vulnerability to heat wave-related morbidity or mortality [odds ratio (OR) 1.261; 95% confidence interval (CI): 1.034–1.538]. At a regional scale, death during heat waves was more likely to occur in districts with a high deprivation index (OR = 1.194; 95% CI: 1.028–1.388). And a low proportion of green space around buildings (OR = 1.178; 95% CI: 1.016–1.366), a low proportion of rooftop green space (OR = 1.207; 95% CI: 1.042–1.399), or those that had fewer hospitals (OR = 1.186; 95% CI: 1.019–1.379). Our data show that mortality during heat waves is more likely where these individual and regional-scale vulnerabilities overlap. Our findings support evidence of mortality impacts from heat waves and provide a basis for selection to policy makers choose on the target groups to reduce the public health burden of heat waves.

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Contents

1. Introduction

The weather variability is a risk factor for mortality and many studies have been carried out in order to reveal the relationship between mortality and environmental variables, especially air temperature (Huynen et al., 2001; Curriero et al., 2002; Chung et al., 2009; Gasparrini et al., 2015). In addition, studies on the association between heat waves and health have been carried out with consideration of effect modifications as well as overall environmental factors such as weather and air pollution.

Many investigations into the links between heat waves and mortality rates have utilized effect modification (O'Neill et al., 2003; Goggins et al., 2012, and Ma et al., 2015) to study spatial variations and regional- to local-scale factors (Vaneckova et al., 2010; Yardley et al., 2011, and Hondula and Barnett, 2014). However, individual level characteristics other than these spatial variations and regional-to local-scale characteristics are also known to have a commanding influence on a person's health. It has long been known that heat waves increase the risk of mortality and morbidity, and the most vulnerable groups within any given population have been highlighted by several seminal studies. Previous works have suggested that the elderly, females, and/or people with chronic health problems are at the highest risk in all countries studied (O'Neill et al., 2003; Schwartz, 2005, and Chan et al., 2012). Although these characteristics are typically associated with high mortality rates, their severities of the mortality rates are expected to fluctuate over time according to meteorological conditions. Since factors such as age, gender, social status, and education level have no such climatic association, they are ideal for investigating whether they act as potential effect modifiers or not.

Many previous studies have investigated both the impact of heat waves on mortality, and the association between temperature and mortality rates in major cities in South Korea (Kim et al., 2006; Son et al., 2012). Heat waves in these studies have been defined differently in terms of their temperatures and durations, and these results are thus not directly comparable between different cities. In a previous study, one heat wave definition was applied to the 25 districts of Seoul and the association between heat waves and mortality at the individual level were examined. In this study, however, we investigated effect modification on heat wave days in Seoul at individual and regional levels based on the daily average temperature observed by 25 administrative districts. To our knowledge, there has been a lack of previous study into effect modification at the individual (i.e., personal) and regional scale. Our investigation took into account not only the individual level and the municipal administrative district, but also comprehensively evaluated the overall characteristics of the area at the local level. We estimated the effects that heat waves have on mortality in Seoul, South Korea, from 2009 to 2012, and evaluated effect modifications at the individual and regional scale in order to understanding their impacts. Our study focused on this urban area in order to allow comparisons of our results with (1) the reported effects of regional-scale characteristics, and (2) data reported for heat-related mortality rates within urban areas with similar characteristics.

The purpose of this study is to compare regional characteristics rather than conduct direct comparison by specific regions. In other words, we aim to compare the results of the study with the characteristics of the region and our results conducted in Seoul.

2. Material and methods

2.1. Study area and mortality data

The metropolitan area of Seoul—the capital of South Korea—had a total area of 605.21 km^2 in 2014, and a population of 9,631,482 in 2010 (identified via census data). Mortality data showing cause of death, age at the time of death, gender, marital status, employment type, and education level were obtained for twenty-five districts of Seoul from the Korea Bureau of Statistics. These data excluded those for accidental mortality, determined according to definitions provided by the International Classification of Disease (10th edition; ICD-10 codes A00-R99). In addition, we only considered deaths in Seoul that occurred during the warm season each year from 2009 to 2012, defined herein as the period between June 1 and August 31.

2.2. Environmental data

Daily weather data were obtained for each district from the Seoul Metropolitan Government records, which were based on data measured by the Korea Meteorological Administration. Meteorological data are observations of the Automatic Weather Station (AWS) provided by the Korea Meteorological Administration, which has one or more sites in each district. The data of observed weather conditions of 25 different districts were applied by matching the residence address of the deceased and the region where the observation equipment belongs. Air pollutant data for particulate matter <10 μm in aerodynamic diameter were obtained from the publically accessible Seoul air quality website (http://cleanair.seoul.go.kr/air_pollution.htm?method=average).

2.3. Effect modification

We categorized potential effect modifiers as those that operated at an individual (i.e., personal) or regional level. The former included gender, marital status, type of employment, and education status (obtained from mortality data), and the latter included economic status, environmental status, and the quality of medical infrastructure. We have investigated the integrated effects that a wide range of socio-economic (e.g., social status, income), demographic (e.g., gender, age), environmental (e.g., access to greenness), and medical infrastructure (e.g., the number of hospitals, medical man power) factors have on heat-related morbidity and mortality (cf. Yardley et al., 2011; Chan et al., 2012, and Margolis, 2014).

These regional-scale variables were categorized as 'high-level' or 'low-level' based on a quantile classification (see below). We modeled potential modifiers from each vulnerability category of economic status, environmental status, and medical infrastructure, at each level where they were available. Continuous effect modifiers were estimated by examining the effects that occurred among individuals in the 25th and 75th percentile of that modifier. The percentiles of each effect modifier were individually calculated for all variables in all 25 districts.

2.4. Definition of a heat wave

Heat waves occur when the temperature on a certain number of consecutive days exceeds a pre-determined fixed value (Robinson, 2001) or heat-stress index level (Smoyer-Tomic et al., 2003). This definition of a heat wave naturally differs between studies worldwide owing to variation in climatic conditions, in particular with regards the number of consecutive days that exceed a threshold temperature, the threshold temperature itself (Anderson and Bell, 2009), and whether or not heat waves are sub-divided according to their severity (Kinney et al., 2008).

We defined a heat wave to have occurred if two or more consecutive days between June and August had a daily mean temperature greater than or equal to the 95th temperature percentile in each of the twenty-five Seoul districts (Toloo et al., 2014). Heat wave characteristics are described herein in terms of their intensity and duration. The former was defined as the difference between the daily mean temperature during the heat wave and the districts' heat thresholds (zero on non-heat wave days).

2.5. Statistical analysis

We used a time-stratified case-crossover method for data analysis, which is a statistical technique suited to examine short-term exposures. The case-crossover study is a modification of the matched case-control study where each subject population controls their own time-invariant confounders, which were continually adjusted according to changes in the study design. Comparisons were made between the 'event' day (the day the case was died) and several referent 'non-event' days, with measured and unmeasured potential confounding factors such as age and education status controlled by design. The referent days were selected from the same month and year and matched by the day of the week to the health outcome. This time-stratified method of selecting comparison days ensures unbiased conditional logistic regression estimates and avoids bias resulting from time trends in examination of the environmental exposures (Levy et al., 2001, and Basu et al., 2015).

We also investigated how the effects of heat waves differed on a regional scale, and modeled whether these effects had consistent spatial and/or geographical correlations. Our analysis of geographical correlations utilized regional coefficients (β_4) for heat waves (see Model 1, below), alongside an assessment of regional-scale relationships using Moran's I (Moran, 1950; Fu et al., 2014) and local indicators of spatial association (LISA) for local-scale relationships.

Our regional-scale model 1 analysis was defined as follows:

$$\log\left(\frac{p_t}{1-p_t}\right) = \beta_0 \text{mean temperature} + \beta_1 \text{relative humidity} + \beta_2 PM_{10} + \beta_3 HW + \beta_4 (\text{HW} \times \text{City}),$$

where p_t be the probability that the person dies on day t, given that person is still alive at the beginning of that day. $\beta_0 \sim \beta_4$ are coefficients, PM_{10} is the daily mean concentration of particulate matter, and HW is a dummy variable that represented the number of days in which a heat wave occurred (or not) in each district.

Two separate models were used to determine the district-scale effects of heat waves on an individual and regional basis. Model 2 was used to investigate the degree to which any particular individual (personal) factor was a potential effect modifier:

$$\log\left(\frac{p_t}{1-p_t}\right) = \beta_0 \text{mean temperature} + \beta_1 \text{relative humidity} + \beta_2 PM_{10} + \beta_3 \text{heat wave} + \beta_4 \text{heat wave} \times \text{effect modifier} + \text{other individual factors},$$

where PM_{10} is the daily mean concentration of particulate matter. The regional-scale effects of heat waves on the calculated risk of mortality during both non-heat wave days and heat wave days varied significantly at an individual level. In order to investigate the effect that heat waves had on specific groups, we included an interaction term into the equation for model 2, thus defining that for model 3:

$$\log\left(\frac{p_t}{1-p_t}\right) = \beta_0 \text{mean temperature} + \beta_1 \text{relative humidity} + \beta_2 \text{mean } PM_{10} + \beta_3 \text{heat wave} + \beta_4 \text{heat wave} \times EM \times R\_EM + \text{other individual factors},$$

where *EM* is an individual effect modifier, and *R_EM* is a regional effect modifier.

3. Results

The total mortality count in Seoul within the 2009–2012 study period was 33,554, with the annual mortality rate in each district having increased each year. Of the deceased, 55.55% were male, 44.45% were female, and 50.38% were married (Table 1). Of the twenty-five districts considered, the highest mortality rate in 2009 was recorded in Gang buk, whereas Jong no-gu had the highest rates in 2010–2012 (Table 2). The 95th percentiles of the mean temperatures in each district—used herein to define the occurrence of a heat wave for each calendar year—are given in Table 3, alongside the number of heat wave days

Table 1
Demographic characteristics of the deceased in Seoul from June to August (2009–2012).

Variables	Categories	N (total: 33,554)	%
Sex	Male	18,640	55.55
	Female	14,914	44.45
Marital status	Single	2100	6.26
	Married	16,905	50.38
	Divorced	2343	7.01
	Bereavement	12,067	35.96
	Unknown	139	0.39
Education level	Uneducated	6503	19.38
	Elementary school	9170	27.33
	Middle school	4704	14.02
	High school	7357	21.93
	Colleges and university	4413	13.15
	Graduate school	745	2.22
	Unknown	662	1.97
Job	Executive, administrative, and managerial occupations	544	1.62
	Expert, engineer	885	2.64
	Office worker	963	2.87
	Service industry employees, salesperson	1550	4.62
	Agriculture, fishing industry	182	0.54
	Technician	400	1.19
	A machine assembler	156	0.46
	Labor worker	590	1.76
	House wife, student, unemployed	27,263	81.25
	Unknown	1021	3.04

Table 2
Mortality counts by 25 districts (2009–2012).

Year	2009			2010			2011			2012		
Districts (gu)	Mortality	Population	Mortality rate[a]	Mortality	Population	Mortality rate	Mortality	Population	Mortality rate	Mortality	Population	Mortality rate
Jong no	178	177,543	100.26	184	179,362	102.59	152	177,419	85.67	189	173,148	109.16
Jung	130	137,861	94.30	138	141,200	97.73	130	141,567	91.83	128	140,807	90.90
Yong san	206	251,200	82.01	251	257,143	97.61	229	259,288	88.32	234	255,294	91.66
Seong dong	249	316,064	78.78	236	316,892	74.47	288	308,767	93.27	264	306,868	86.03
Gwang jin	240	386,513	62.09	254	388,775	65.33	269	386,673	69.57	272	384,269	70.78
Dongdaemun	326	374,277	87.10	366	379,343	96.48	357	378,534	94.31	381	375,683	101.42
Jung nang	338	429,700	78.66	355	432,302	82.12	377	428,672	87.95	413	423,655	97.48
Seong buk	371	484,457	76.58	433	497,692	87.00	436	494,422	88.18	425	490,639	86.62
Gang buk	356	343,912	103.51	322	350,007	92.00	369	348,740	105.81	341	346,493	98.41
Do bong	315	372,398	84.59	328	370,734	88.47	329	367,949	89.41	331	364,454	90.82
No won	511	615,161	83.07	543	615,425	88.23	525	608,062	86.34	579	600,829	96.37
Eunpyeong	412	470,782	87.51	441	492,925	89.47	426	498,350	85.48	492	505,902	97.25
Seodae mun	282	336,649	83.77	301	333,871	90.15	276	324,529	85.05	328	324,733	101.01
Mapo	329	392,313	83.86	310	400,464	77.41	351	398,627	88.05	326	393,576	82.83
Yang Cheon	344	506,684	67.89	334	505,223	66.11	360	505,605	71.20	382	500,533	76.32
Gang seo	424	579,196	73.20	504	580,506	86.82	453	575,846	78.67	496	573,794	86.44
Guro	337	449,613	74.95	325	452,667	71.80	312	458,908	67.99	363	454,478	79.87
Geum Cheon	202	263,116	76.77	223	264,544	84.30	223	264,256	84.39	248	260,734	95.12
Yeong deungpo	322	441,747	72.89	361	445,648	81.01	324	439,555	73.71	358	426,876	83.87
Dong jak	316	407,973	77.46	316	413,814	76.36	322	413,658	77.84	341	416,268	81.92
Gwanak	385	547,311	70.34	441	549,736	80.22	420	546,350	76.87	398	540,520	73.63
Seocho	234	431,131	54.28	274	440,021	62.27	278	439,012	63.32	281	439,998	63.86
Gangnam	347	569,499	60.93	353	577,070	61.17	350	573,003	61.08	344	569,997	60.35
Songpa	433	689,296	62.82	448	693,144	64.63	448	690,466	64.88	473	680,150	69.54
Gangdong	351	489,655	71.68	389	496,939	78.28	377	500,516	75.32	418	492,728	84.83
Total	7938	10,464,051	75.86	8430	10,575,447	79.71	8381	10,528,774	79.60	8805	10,442,426	84.32

[a] Per 100,000.

recorded annually from June to August. These data show that both the annual number of heat wave days and the 95th percentile of the mean temperature in each district increased from 2009 to 2012 (Table 3).

Table 3
Heat wave days and temperature by 25 districts in Seoul according to heat wave definitions.

Year	2009		2010		2011		2012	
Districts	p95	HW days	p95	HW days	p95	HW days	p95	HW days
Jong no	29.1	2	29.8	0	30.2	3	32.1	2
Jung	27.6	1	28.6	1	28.8	3	31.1	3
Yong san	29	1	30	1	29.8	3	32	3
Seong dong	28.4	2	29.5	1	29.4	3	31.5	3
Gwang jin	28.4	2	29.7	2	29.5	3	31.3	3
Dongdaemun	28.6	2	29.4	2	29.3	3	31.2	3
Jung nang	28	3	29.4	2	29	3	30.7	3
Seong buk	28.1	2	29.2	1	28.7	2	30.8	3
Gang buk	28.6	2	29.7	2	29.4	3	31.4	3
Do bong	27.8	2	28.8	2	28.3	3	31	3
No won	28.3	3	29.3	3	29.4	3	31.4	3
Eunpyeong	28.1	2	29	2	29	3	31.1	3
Seodae mun	27.7	2	28.8	0	28.8	3	30.9	3
Mapo	28.3	1	29.1	1	29	3	31.3	3
Yang Cheon	28.7	2	29.8	3	29.7	3	31.7	3
Gang seo	28.4	1	29.1	1	28.7	3	31.6	3
Guro	28.5	1	29.8	1	29.4	3	31.6	3
Geum Cheon	28.6	2	29.8	1	29.3	3	31.5	3
Yeong deungpo	28.3	1	29.3	1	29.3	3	31.6	3
Dong jak	28.2	2	29.6	1	29.1	3	31.4	3
Gwanak	28.2	2	29.5	2	29.3	3	31.6	3
Seocho	28.7	2	29.9	0	29.9	3	32.1	3
Gangnam	28.3	2	29.3	1	28.7	3	30.9	3
Songpa	28.3	2	29.6	2	31.5	1	31	3
Gangdong	28.4	2	29.4	2	28.9	3	31.2	3
Total heat waves days		46		35		72		74
Average heat waves days by districts		1.84		1.4		2.88		2.96

Fig. 1 shows the district-based threshold temperatures used to define heat waves during each year's warm season. The 95th percentile temperature in each district was very similar to that recorded in adjacent areas each year, although Jong no, Yong san, and Seocho-gu districts were subjected to higher temperatures than other Seoul districts throughout the entire four-year study period (Fig. 1).

Fig. 2(A) shows a map of the spatial distribution of effect modifiers on heat waves using values estimated from model 3. Fig. 2(B) and (C) show the statistical significance of spatial autocorrelation within the map area, where darker regions represent high degrees of autocorrelation and white regions indicate that spatial autocorrelation was insignificant. Furthermore, LISA analysis performed on these twenty-five values showed that heat waves were not spatially associated with geographical features. Fig. 2(A) shows the effects of heat waves in each of the 25 districts, and Fig. 2(B) shows the degree of correlation among these effects according to location and distance (given as a statistical significance for each district). Our results were statistically significant in three districts, two of which showed low–high outliers and the other had high–low clusters (Fig. 2(C)). Based on these results, we analyzed whether the heat wave effects calculated in model 1 were more strongly influenced by individual or regional-scale characteristics. Our results showed that an individual's level of education was a key demographic factor that had a significant effect on heat wave-associated mortality rates, whereby those with lower levels of education were more at risk than those with advanced degrees. For regional-scale characteristics, a higher deprivation index also had a positive effect on heat wave-associated mortalities (Table 4). Our results show that in low-education groups, there is a high rate of mortality in areas with relatively high deprivation which are poor regions, (OR: 1.194, 95% CI 1.028–1.388) when compared to heat wave days and non- heat waves days. Likewise, green areas around public buildings (OR: 1.178, 95% CI: 1.016–1.366), rooftop green areas (OR: 1.207, 95% CI: 1.042–1.399), and the number of hospitals (OR: 1.186, 95% CI: 1.019–1.379), where OR is the odds ratio and CI is the confidence interval (Table 5).

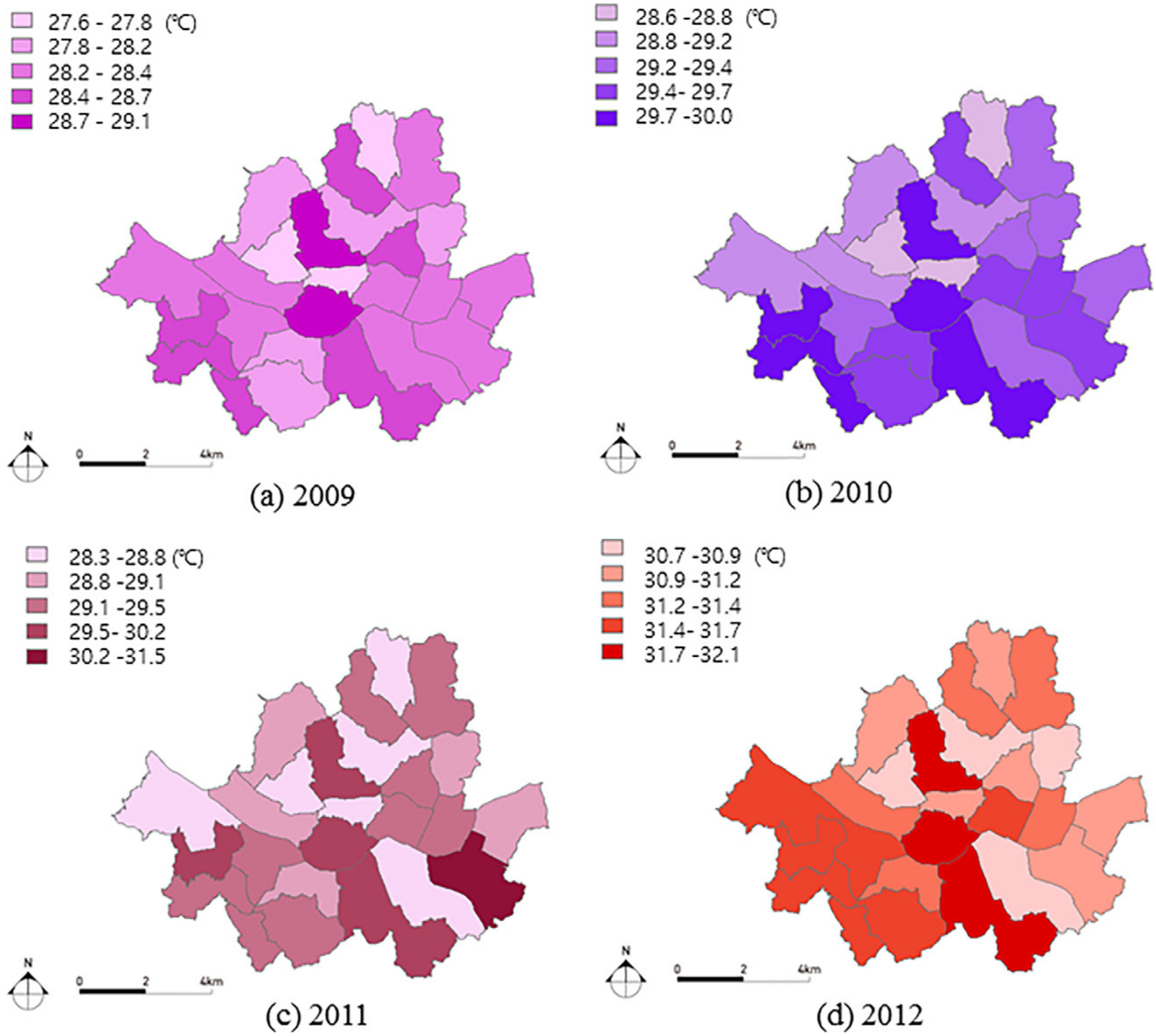

Fig. 1. Mapping of the mean temperature 95th percentile at each districts by yearly.

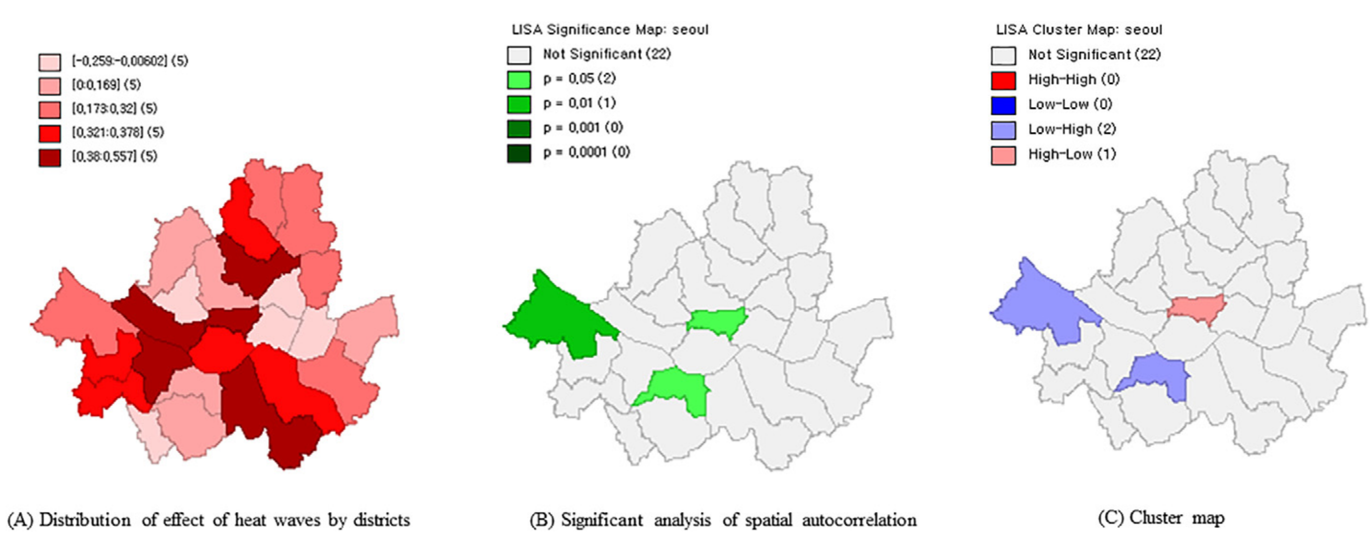

Fig. 2. Distributions of heat wave on mortality and results by the local indicators of spatial association local analysis.

Table 4
Results of individual level and region characteristics with univariate analysis.

Level	Categories	Variables	OR	95% CI	
Individual	Demographic factor	Sex (male)	0.996	0.861	1.153
		Marital state (married)	1.296	0.965	1.74
		Marital state (windowed/divorced)	1.104	0.821	1.485
		Job (outdoor)	0.901	0.679	1.196
		Education (lower)	**1.261**	**1.034**	**1.538**
Region	Economic status	Deprivation index (higher)	**1.191**	**1.029**	**1.379**
		Income level (lower)	1.048	0.906	1.211
		Financial independence rate	0.981	0.844	1.139
		Percentage of owner-occupation (%)	1.116	0.965	1.291
		Living floor area per person (%)	1.062	0.918	1.228
	Environmental status	Park area per 1person	1.009	0.873	1.166
		Green area	1.057	0.883	1.267
		Green area around public buildings	1.116	0.965	1.29
		Roof green area	1.119	0.967	1.293
	Medical infra	Number of hospitals	1.111	0.959	1.285
		Number of bed hospitals	1.177	0.911	1.522
		Medical man power	1.063	0.919	1.23

4. Discussion

Previous studies have shown that factors such as socio-demographic characteristics, biological mechanisms, policy, health protection behaviors, and habitat are known to influence a person's health. However, it is possible for an individual to control their exposure to heat, such that their actual exposure is lower than the temperatures measured at outdoor monitoring stations on a daily basis. Consequently, estimates of an individual's heat exposure reported in health-related studies are often imprecise (Bernhard et al., 2015; Kuras et al., 2015) as their actions and/or ability to reduce a perceived heat exposure are often determined by independent factors (e.g., socio-economic, cultural, and so on; Gronlund, 2014). Our study was based upon the hypothesis that these extraneous factors may impart key background controls on the effects of heat waves on human health. We considered a geographical correlation, and investigated the effects of individual and regional-scale characteristics, although showed that geography (location) exhibited no influence on heat wave mortality rates in Seoul between 2009 and 2012. Thus, we found that the mortality rate was affected by socio-environmental local characteristics in the low-education group. These socio-environmental factors were thus investigated in detail.

Our data showed that the heat wave hazard risk increased in groups with lower education levels on heat wave days compared non-heat wave days, which is consistent with the results of some previous work (O'Neill et al., 2003; Michelozzi et al., 2005; Bell et al., 2008, and Larrieu et al., 2008), but not all, where no correlation was observed (e.g., Medina-Ramón et al., 2006; Basu and Ostro, 2008; Bell et al., 2008; Ma et al., 2012; Yang et al., 2012, and Wang et al., 2014). Neighborhood-scale educational level has been correlated with heat-associated mortality, but results have been mixed when assessing the influence of education at the community scale (e.g., Gronlund, 2014). Individual level factors cannot rule out that each individual can influence the choice of a residential area. Therefore, this effect should be considered in a study that examines the relationship between the level of individuals and the level of the region and its relationship to the death of a heatwave day.

Education status may only be related to heat vulnerability. At the individual level, the education status indicated a vulnerable group in the heat wave in this study. Differences in heat-associated health outcomes by educational attainment are probably mediated by a variety of factors such as income disparities, occupational differences (work in climate-controlled settings is more likely to be performed by more highly educated individuals), cognitive deficits, other health-related barriers to education or lack of knowledge about heat-health risk (Gronlund, 2014). In the absence of information on the more proximate mechanisms, perhaps education should be accounted for when deciding which people and places to target for adaptation measures in areas where they have been identified as important characteristics of heat vulnerability. However, more proximate characteristics of vulnerability would probably more accurately identify vulnerable individuals, and public health measures targeting the more proximate mechanisms would likely be more effective (Gronlund, 2014). We analyzed the relationships between these factors at both the individual- and regional-scale in order to clarify this issue. In this study, we examined individual and local levels separately and examined which features of the region in the lower level of education, which is a significant variable at the individual level, affect the association in the heat.

At a personal level, we calculated a statistically significant increase in the odds ratio for a person to suffer heat-related health problems if they were relatively poorly educated.

A gender discrepancy in mortality rate was observed during the heat wave that affected mainland Europe in 2003, where there were relatively more female victims than male victims. In France, most deaths were among elderly women (Pirard et al., 2005). Our result for mortality rates in Seoul is consistent with that for Europe, with males having a lower risk than females, although the difference was not statistically significant (Table 4). Factors such as marital status and type of employment were inconsistent with previously reported trends for heat-related issues, whereby we found that single people do have a more general increased risk of health problems (or death), but are not specifically vulnerable during a heat wave. Mortality rate correlated with age and marital status (according to the categorizations single, married, and widowed/divorced). Our data showed that married and widowed/divorced individuals had an increased risk of non-accidental death during a heat wave, which is consistent with the results of a similar study undertaken in northern China (Zhang et al., 2016).

In a univariate analysis at the regional-scale, all investigated variables had positive effects on mortality rates, although only data for financial independence and the deprivation index were statistically significant (Table 4). We also investigated how these regional-scale characteristics affected mortality rates in the lower education group, which was identified as a statistically significant variable at the individual level. This showed that there were statistically significant effects on deprivation index (i.e., economic status), green areas around public buildings and rooftop green areas (i.e., environmental status), and the number of hospitals (i.e., availability of medical infrastructure) (Table 5). Although some variables were not statistically significant, their effect sizes had positive values; interestingly, within the environmental status category, the amount of green space in a district and the amount of living space both had positive effects on mortality rates, although general green space outside of population centers did not.

Table 5
The effects of region characteristics on heat wave related on mortality among lower education level group.

Level	Categories	Variables	OR	95% CI	
Region	Economic status	Deprivation index (higher)	**1.194**	**1.028**	**1.388**
		Income level (lower)	1.086	0.936	1.259
		Financial independence rate	1.01	0.864	1.18
		Percentage of owner-occupation (%)	1.078	0.929	1.251
		Living floor area per person (%)	1.109	0.958	1.284
	Environmental status	Park area per person	1.105	0.952	1.282
		Green area	1.085	0.895	1.315
		Green area around public buildings	**1.178**	**1.016**	**1.366**
		Roof green area	**1.207**	**1.042**	**1.399**
	Medical infra	Number of hospitals	**1.186**	**1.019**	**1.379**
		Number of bed hospitals	1.238	0.939	1.632
		Medical man power	1.139	0.984	1.318

There are studies that consider green factors in the study of heat and its health effects. Various types of data can be used to consider green space as a model. There are studies that use data such as NDVI indices obtained from satellite data to consider green area and distance. Instead, it is not easy to consider the types and distribution patterns of green spaces when using these indicators. In this study, it is possible to reflect the distance, form, and purpose in real human life or activity area by taking into account the model using various variables. These variables can be supplemented with qualitative information, such as the type of green space that has the specific purpose of park, the area of green space around the office building, and the area of green space on the roof. Analysis of the impact of the region in a specific vulnerable group showed a high impact on near-greenness variables in real life range (Table 5). Our data corroborate this link between mortality rate and green space proximity at the individual level: variables describing proximal outdoor activity space had a higher effect size on mortality rates than those describing distal outdoor activity space, and the amount of green space around public buildings and the proportion of rooftop green space both had statistically significant influences.

Future research should aim to investigate additional effect modifiers related to heat wave mortality rates and consider how hazard is measured and/or quantified (e.g., the temperature that defines a heat wave). Although our study was limited to the Seoul metropolitan area, our results showing the significance of individual- and regional-scale characteristics to susceptibility to the extreme temperatures should be applicable to any urban region, albeit with the following limitations. The extrapolation of individual- and regional-scale characteristics to predict patterns at a nationwide scale should be performed according to consistent criteria. For example, results produced in our modeling are evidently sensitive to the heat wave threshold values described above (i.e., 0 on non-heat wave days and 1 on heat wave days). Sensitivity analyses were performed by changing the temperature required to define a heat waves to the 95th, 97th, and 98th percentiles of each district's mean and maximum temperature. For our study, we used the 95th percentile daily mean temperature for district-specific values. Our heat wave definition considered a range of temperature indicators, intensity, and duration, although it is controversial as to which temperature indicator is best at predicting mortality. Previous studies have found that mean temperature is better than maximum and/or minimum temperature, as the former is more likely to represent the temperature level across a twenty-four hour period (Vaneckova et al., 2011, and Chen et al., 2015). Previous studies have defined heat waves by both relative and absolute temperature thresholds; in the former case, higher relative threshold values identified a stronger association between heat wave effects and mortality (Tong et al., 2010, and Tong et al., 2014). Previous environmental epidemiological studies that have demonstrated increased mortality and morbidity during heat waves have used percentile-based cutoffs for daily average temperatures, which were derived from nearby weather station datasets as the estimated timing of exposure. When using these data to investigate the individual-level effects of heat waves, it is important to note that any particular person may be subjected to a slightly different effective temperature than their neighbor (Maly, 2008), as heterogeneity is likely to exist within (or between) many (or all) neighborhoods in an urban center (Bernhard et al., 2015; Kuras et al., 2015).

Data concerning the temperatures experienced by individuals suggest that heterogeneous heat exposure is common within urban neighborhoods, and that outdoor temperatures may misrepresent the temperatures felt during both background-level summer conditions and heat waves. Further examination of the effect of personal characteristics on heat exposure may help to develop targeted strategies for preventing heat-related mortality.

There is no standard definition for a heat wave, yet most studies have used minimum temperature and durations as key criteria. In addition to comparing the number of heat-wave days with non-heat-wave days, some studies have examined individual heat-wave characteristics, such as intensity, duration, and timing during the year (Díaz et al., 2002; Hajat et al., 2002; Hajat et al., 2006; Anderson and Bell, 2009; Anderson and Bell, 2011) and have proposed various definitions based on different combinations of thresholds and durations., In this work, we chose to utilize three temperature thresholds (95th, 97th, and 98th percentiles) and three cutoffs for minimum durations (2 days) (Anderson and Bell, 2011; Son et al., 2012; Tian et al., 2013), as has been recommended by previous workers (Tian et al., 2013).

5. Conclusion

In our study, we investigated the effects that individual- and regional-scale characteristics had on heat wave-related mortality rates between 2009 and 2012 in Seoul, South Korea. We focused on twenty-five districts within the metropolitan area. Firstly, we investigated geographical relationships to mortality rates, and subsequently district-level factors. After identification of vulnerable groups based on the results of individual-level analyses, we analyzed the effect modification of regional-scale characteristics in these vulnerable groups. Our data show that heat-related mortality rates were strongly correlated with deprivation indices, the amount of green space around public buildings, education level, and the quality of medical infrastructure. Public health policy makers can utilize these data in order to control the effects of heat waves on mortality rates, with changes that can be tailored for both individual- and regional-scale characteristics. Policy makers can use our data and results to discern which demographic groups or regions are most vulnerable during heat waves; for example, we highlight key local- and regional-scale factors (e.g., the amount of green space around public building) that may alleviate heat wave-related mortality rates. These data allow policy makes to enact informed choices in the future, for example when undertaking new community-scale construction projects and city planning.

Competing financial interests

The authors declare they have no actual or potential competing financial interests.

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