Science of the Total Environment 592 (2017) 288–294

Contents lists available at ScienceDirect

Science of the Total Environment

journal homepage: www.elsevier.com/locate/scitotenv

Small-area spatiotemporal analysis of heatwave impacts on elderly mortality in Paris: A cluster analysis approach

Tarik Benmarhnia [a,*,1], Wahida Kihal-Talantikite [b,1], Martina S. Ragettli [c,d], Séverine Deguen [b]

[a] Department of Family Medicine and Public Health, Scripps Institution of Oceanography, University of California, San Diego, CA, USA
[b] EHESP School of Public Health–Rennes, Sorbonne-Paris Cité, France
[c] Swiss Tropical and Public Health Institute, Basel 4002, Switzerland
[d] University of Basel, Basel 4003, Switzerland

HIGHLIGHTS

- We found a spatial aggregation of death cases during heat wave days in the city of Paris.
- Spatial variation in heat-related vulnerability can be explained by PM_{10} levels, some social factors and micro-heat islands.
- Living in an area with high proportion of elderly people may reduce risks for heat-related mortality among elderly people.
- This study can be useful for designing interventions targeting more vulnerable areas and reduce the burden of heat waves.

GRAPHICAL ABSTRACT

ARTICLE INFO

Article history:
Received 3 January 2017
Received in revised form 21 February 2017
Accepted 10 March 2017
Available online 17 March 2017

Editor: D. Barcelo

Keywords:
Heat waves
Spatiotemporal analysis
Heat-related mortality
Green space
Urban Heat Island
Vulnerability

ABSTRACT

Background: Heat-waves have a substantial public health burden. Understanding spatial heterogeneity at a fine spatial scale in relation to heat and related mortality is central to target interventions towards vulnerable communities.
Objectives: To determine the spatial variability of heat-wave-related mortality risk among elderly in Paris, France at the census block level. We also aimed to assess area-level social and environmental determinants of high mortality risk within Paris.
Methods: We used daily mortality data from 2004 to 2009 among people aged >65 at the French census block level within Paris. We used two heat wave days' definitions that were compared to non-heat wave days. A Bernoulli cluster analysis method was applied to identify high risk clusters of mortality during heat waves. We performed random effects meta-regression analyses to investigate factors associated with the magnitude of the mortality risk.
Results: The spatial approach revealed a spatial aggregation of death cases during heat wave days. We found that small scale chronic PM_{10} exposure was associated with a 0.02 (95% CI: 0.001; 0.045) increase of the risk of dying during a heat wave episode. We also found a positive association with the percentage of foreigners and the

* Corresponding author at: Department of Family Medicine and Public Health, Scripps Institution of Oceanography, University of California, San Diego, 9500 Gilman Drive, La Jolla, 92093, CA, USA.
E-mail address: tbenmarhnia@ucsd.edu (T. Benmarhnia).
[1] These 2 authors equally contributed to this work.

http://dx.doi.org/10.1016/j.scitotenv.2017.03.102

Air pollution
Social inequalities in health

percentage of labor force, while the proportion of elderly people living in the neighborhood was negatively associated. We also found that green space density had a protective effect and inversely that the density of constructed feature increased the risk of dying during a heat wave episode.
Conclusion: We showed that a spatial variation in terms of heat-related vulnerability exists within Paris and that it can be explained by some contextual factors. This study can be useful for designing interventions targeting more vulnerable areas and reduce the burden of heat waves.

1. Introduction

Heat wave days have a substantial public health burden with increased risk of health responses ranging from heat exhaustion to death (Basu, 2009; Gronlund et al., 2014). Many studies have documented the health impacts of extreme heat events worldwide with some heat waves that were particularly deleterious such as the 1995 heat wave in Chicago that caused 700 excess deaths within a week (Semenza et al., 1996), or more recently in India (Azhar et al., 2014). Europe experienced a devastating heat wave in 2003, with France being particularly affected by heat-related mortality. A total of 15,000 excess deaths were reported during in the first week of August 2003 (Robine et al., 2012). In addition, climate change predictions indicate higher frequency of severe heat waves that are likely to increase heat-related health impacts (Huang, 2011; Li et al., 2013).

To prevent the burden related to such extreme events, public health authorities have developed policies aimed at reducing heat wave-related health effects, including heat warning systems (HWS) or heat action plans (HAPs) (Boeckmann and Rohn, 2014; Lowe et al., 2011; McGregor et al., 2015). Such HWS include early alerts and advisories combined with emergency public health measures to reduce heat-related burden during heat wave days. HAPs are activated when meteorological conditions meet local criteria for classification of heat wave days, each jurisdiction having its own precise criteria (Tong et al., 2010). In general, each local public health authority has developed its own criteria at which the HWS is triggered (Lowe et al., 2011). In France, the 2003 heat wave forced the French public health authorities to develop a HWS at the municipality level in 2004 (Pascal et al., 2006).

Various sub-populations can have a disproportionate public health burden from heat-related mortality. Studies have shown that temperature-mortality effect estimates can vary by age (Åström et al., 2011), social deprivation (Bell et al., 2008; Gronlund, 2014), or air pollution exposure (Benmarhnia et al., 2014). Particularly, a recent meta-analysis (Benmarhnia et al., 2015) has identified that the elderly constitute the main vulnerable group. Information about potential factors associated with increased vulnerability to heat-related mortality is used to develop targeted interventions to reduce heat-related health inequalities (Price et al., 2013). Yet, in addition to individual vulnerable characteristics, it is also important to understand the spatial distribution of the burden of heat waves in order to target precisely areas at higher risk during heat waves.

Spatial heterogeneity (or variability) in relation to heat and related mortality has been broadly studied in the last years through different approaches. A study conducted in Philadelphia (Hondula et al., 2012), showed that there exists some fine-scale spatial variability in the mortality response to high apparent temperatures. Another study conducted in Australia (Vaneckova et al., 2010) used a cluster analysis to identify the locations with a significant increase in mortality risk, in order to identify regions where mortality is significantly higher on anomalously hot days only. A study conducted in the US showed the existence of clustering of heat mortality at as small scale (Stone et al., 2014). More recently, Chen et al. (2015) employed a spatial point pattern analysis to explore the risk of heat waves on stroke mortality at a sub-city level in Nanjing, China. These studies are particularly important as they can help local policy makers identify areas at higher risk for mortality during heat wave days comparing to non-heat-wave days.

In this study, we propose an innovative approach that simultaneously assesses the risk of dying during a heat-wave day (compared to non-heat wave days) while identifying small-area clusters where the risk of dying during a heat wave is higher. We conduct our analysis in the city of Paris, where the heat waves impacts are well documented (Fouillet et al., 2006; Le Tertre et al., 2006; Rey et al., 2009; Vandentorren et al., 2004) and where the HWS is managed at the municipality level, and thus information on spatial vulnerability at a small-area level would be useful and could directly be integrated in the local public health policy (Pascal et al., 2006).

1.1. Objectives

The overall objective of this paper was to determine the fine scale spatial variability of heat-wave-related mortality risk among elderly in Paris. As a secondary analysis, we aimed at quantifying the contribution of neighborhood characteristics such as chronic air pollution exposure, socioeconomic and demographic variables to explain the spatial variability of heat-wave-related mortality at the small-area level.

2. Material & method

2.1. Study setting

The study was carried out in Paris, the capital city of France, with 2.25 million inhabitants (2006 census). Analyses were conducted at the French census block level (called IRIS by, the French National Statistics Institute, INSEE), the smallest spatial unit in France. The city of Paris is subdivided into 992 census blocks/IRIS, with a mean population of 2199 inhabitants and a mean area of 0.11 km^2 (range from 0.009 to 5.4 km^2).

2.2. Data source

2.2.1. Health data

Daily mortality data including information on the individuals such as date of death and census block of residence was provided by the death registry by the city of Paris. We restricted our analyses to elderly individuals based on previous studies in this city (Benmarhnia et al., 2014). Thus, we considered all deaths that occurred in the city of Paris for residents older than 65 years from January 2004 to December 2009 (only summer months from June to September). For confidentiality reasons it was not possible to distinguish causes of deaths, thus we used all-cause deaths. Yet, the proportion of accidental causes of death is marginal among the age group considered in the present study (Meslé and Vallin, 1996; Aouba et al., 2011). Ethical approval was obtained from the French commission on data privacy and public liberties (CNIL—Commission Nationale de l'Informatique et des Libertés).

2.2.2. Meteorological and air pollution data

The daily maximum (Tmax) and minimum temperatures (Tmin) were obtained from the Météo-France Montsouris station in Paris. The urban air pollution including annual concentration of NO_2, PM_{10} and $PM_{2.5}$ was modeled and provided by AirParif (the regional association for the surveillance of air quality: http://www.airparif.asso.fr/). The dispersion models (ESMERALDA) were used to produce annual mean