Environmental Pollution 159 (2011) 2044–2050

Contents lists available at ScienceDirect

Environmental Pollution

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

Urban and rural mortality rates during heat waves in Berlin and Brandenburg, Germany

Katharina M.A. Gabriel [a,b], Wilfried R. Endlicher [a,*]

[a] Geography Department, Humboldt-Universität zu Berlin, Climatology Chair, Unter den Linden 6, 10099 Berlin, Germany
[b] Leibniz Institute of Freshwater Ecology and Inland Fisheries, Berlin, Germany

ARTICLE INFO

Article history:
Received 6 August 2010
Received in revised form
29 December 2010
Accepted 8 January 2011

Keywords:
Urban climate
Heat waves
Thermal stress
Human mortality rates
Adaptation measures

ABSTRACT

In large cities such as Berlin, human mortality rates increase during intense heat waves. Analysis of relevant data from north-eastern Germany revealed that, during the heat waves that occurred between 1990 and 2006, health risks were higher for older people in both rural and urban areas, but that, during the two main heat waves within that 17-year period of time, the highest mortality rates were from the city of Berlin, and in particular from its most densely built-up districts. Adaptation measures will need to be developed, particularly within urban areas, in order to cope with the expected future intensification of heat waves due to global climate change.

1. Introduction

Of all natural disasters heat waves often claim the largest number of fatalities. In the United States several hundred people lost their lives during the heat waves of 1980 (Smoyer, 1998) and 1995 (Klinenberg, 2002; Semenza et al., 1996). This is a far greater loss of life than occurs during blizzards, floods, and cyclones combined (National Weather Service, 2007). Large numbers of fatalities also occurred in southern and western Europe during 2003, when a prolonged and exceptionally intense heat wave resulted in 70,000 heat-related deaths (Robine et al., 2007). There is also evidence that morbidity increases together with mortality rates during extreme heat events (Dolney and Sheridan, 2006; Golden et al., 2008; Mastrangelo et al., 2007).

Simulations of the future climate indicate that the frequency of extreme weather events is very likely to increase (Solomon et al., 2007). Heat phenomena such as that of the summer in 2003 are thus expected to become more common in the near future (Schär et al., 2004; Meehl and Tebaldi, 2004; Kalkstein and Greene, 1997). Beniston (2004) suggested that the extreme thermal situation experienced in Europe during the summer of 2003 could be quite normal by the end of this century. The number of hot days per year is therefore likely to increase over nearly all land areas.

The most important human impact on the local climate of cities is known as the urban heat island (UHI) effect, reflecting the temperature difference between an urban area and the rural surroundings. Since the first evidence presented by Luke Howard (1833) in London, many investigations have shown the importance of this phenomenon, which is largely due to heat storage in buildings and sealed roads. The UHI effect is especially important during the summer months and is usually more evident at night. The intensity of a city's heat island is dependant on the size of the city and the building density. Maximum differences of about 10 K or more between city centres and rural areas have been recorded on clear summer evenings (Oke, 1973). During heat waves the local effect of an UHI is superimposed on the regional temperature, producing an even more extreme event.

According to United Nations projections, urban populations will continue to grow over the next decades (UN, 2008, 2010). The combined effect of global warming and worldwide increases in urban populations means that thermal stress in cities is likely to become an increasingly important issue, even in the more temperate climate of central Europe (50–55°N). Further investigation was therefore considered to be warranted into whether or not thermal stress is enhanced in large cities, especially during extreme weather events, and thus leads to higher mortality rates in

* Corresponding author.
E-mail address: wilfried.endlicher@geo.hu-berlin.de (W.R. Endlicher).

0269-7491/$ – see front matter
doi:10.1016/j.envpol.2011.01.016

urban areas than in the rural surroundings. It was also considered important to establish whether variations in UHI effects due to differences in building density within large cities (i.e. Urban Heat Archipelagos) result in similar variations in human mortality rates.

The high proportion of vulnerable people assembled in these urban areas has resulted in the observation that "Urban heat waves are among the deadliest of all weather emergencies" (Stéphan et al., 2005, p. 39). It is therefore important to investigate the specific patterns of heat stress and associated health risks for urban populations.

This study has been centred on Berlin, which is Germany's largest city with 3.5 million inhabitants. The objectives were to investigate whether an urban–rural differentiation of heat wave mortality rates can be seen between the city of Berlin and the rural surroundings of Brandenburg, and also whether an intra-urban differentiation exists between the various districts of Berlin. The hypothesis to be tested was that rural districts with no enhancement of thermal stress, and urban districts with relatively low population densities and correspondingly moderate thermal discomfort due to weak UHI development, would record lower heat-related mortality rates than urban districts with high population densities and high levels of thermal discomfort.

2. Area of investigation, data, and methods

The area investigated covers the two German Federal States of Berlin – which is the capital of Germany – and Brandenburg, in the north-eastern part of the country. The entire area covers 30,370 km^2 with maximum dimensions of 291 km N–S and 244 km E–W, centred approximately at 52° 31′ N and 13° 24′ E. The urban agglomeration of Berlin is encircled by the rural State of Brandenburg (Fig. 1). Areas of settlement and those used for transport (roads, railroads, airfields) cover 70% of Berlin, but only 9% of Brandenburg where land-use is dominated by agriculture (49%) and forestry (35%). These differences are also reflected in the population densities which, in 2009, averaged 3860 inh./km^2 for the city of Berlin but only 86 inh./km^2 for the Federal State of Brandenburg.

For this investigation climate and mortality data, as well as data on land-use, were available over a period of 17 years from the year of Germany's reunification, i.e. from 1990 to 2006. The meteorological data included thermal conditions (T_{max}, T_{av}, T_{min}) as well as water vapour pressure, global radiation, hours of sunshine, and wind speed, on a daily basis. Also available was a figure for 'Perceived Temperature' (PT) with a 3-hourly resolution, taking into account air temperature, radiation fluxes, humidity, and wind velocity (Jendritzky et al., 2005). The data were obtained from the German Meteorological Service (DWD) for a total of six stations, two of which were located in the city of Berlin and four in smaller towns within the surrounding area with between 14,500 and 101,500 inhabitants. These smaller towns (Neuruppin to the north-west, Angermünde to the north-east, Wittenberg to the south-west and Cottbus to the south-east) are all situated within 60–70 km of the Berlin city centre. The selection criteria took into account the availability of continuous data over the 17 years covered by the investigation, for both the measured values and the calculated PT index.

Mortality data, obtained from the State Statistical Services of Berlin and Brandenburg, provided a record of daily all-cause mortality totals. On the Federal State level the daily totals were

Fig. 1. Location of the investigation area: the Federal State of Berlin (the city of Berlin) and the surrounding Federal State of Brandenburg, in north-eastern Germany.