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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

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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).

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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.

differentiated with respect to sex and age (<50/≥50) whereas on the district level information on age was not available.

Information on the proportion of land covered by sealed surfaces in each district was obtained from annual land-use data provided as well by the State Statistical Services of Berlin and Brandenburg. Sealed surfaces include data on built-up and undeveloped areas, as well as on industrial areas and areas used for transport.

The warmest period in each of the 17 years investigated was analysed with respect to its effects on mortality rates. Three methods were used to describe the thermal conditions and identify the warmest period in each year.

First, for each of the six stations, thresholds were determined by calculating the 95-percentile for daily maximum and minimum temperatures; days and nights exceeding these thresholds were classified as 'heat stressed'.

Second, for each of the six stations, the value at the lowest point of the regression line between temperature and mortality rate was defined for daily maximum and minimum temperature (breakpoint or hockey stick model; Rogot and Padget, 1976). Days and nights with a temperature observed above the breakpoint again were classified as 'heat stressed'.

As a third method, 'Perceived Temperature' was taken into account. Since 32 °C PT is the critical value above which the thermal perception is regarded as "hot" (VDI, 1998), days with data exceeding this value at 09:00, 12:00 or 15:00 h were classified as 'heat stressed'. For night time (00:00 or 03:00 h) the limit was set at 20 °C PT, as above that temperature thermal well-being is no longer certain.

Since all three methods recorded events with more than 14 consecutive days classified as 'heat stressed', a standard period of 3 weeks was used for this investigation. A shorter period would have excluded too many days classified as 'heat stressed', while a longer period would have included too many non-heat-stressed days.

In order to rank the 3-week periods according to their heat load, a binary system was introduced to code days and nights classified as 'heat stressed' with '1', and all other days with '0'. By adding up these 'stress points', a maximum possible total of 36 points can occur for each day:

$$\text{daily amount of 'stress} - \text{points'} = \sum_{s=1}^{6}\sum_{t=1}^{2}\sum_{m=1}^{3} \text{'stress} - \text{point'}_{mts}$$

with m = method (P95; regression; PT);

t = time of day (maximum; minimum);

s = station (Neuruppin; Angermünde; Berlin–Dahlem; Berlin–Tempelhof; Wittenberg; Cottbus).

Over a 3-week period therefore, a maximum total of 756 'stress points' can be accumulated, i.e. 36 × 21 days (Gabriel, 2010). The total number of 'stress points' was thus determined for each 3-week period from 1990 to 2006. The 3-week period with the highest number of points, and thus with the highest heat load, in each year was then chosen for further investigation.

Figures for the expected number of deaths per day were derived by conducting a time series analysis for each Federal State and for each district within those states. Since age information was not available for the district level mortality data, age standardisation was not possible. Our approach assumed that the raw data on mortality reflected the social situation within each district such that, for example, a high percentage of elderly people would result in a relatively high mortality baseline. First, the trend of long-term developments in population structure was determined. From trend-adjusted data seasonal variations were then determined by averaging the values for each day of the year over the entire 17-year period. Extreme values greater than three times the standard deviation were then replaced by this value. The result was smoothed using a 29-day period, as this eliminated daily fluctuations but preserved the seasonal characteristics. By adding the long-term trend to the seasonal variations the expected mortality figure was then derived. To investigate the differences in vulnerability between Germany's capital city and its rural surroundings, as well as between different districts within Berlin and in surrounding areas, the recorded number of deaths was compared to the expected number for each unit of area.

3. Results

3.1. Climatic conditions

The hottest 3-week period within the 17 years investigated occurred in 1994 (576 'stress points' between July 22nd and August 8th), followed by a period in 2006 (538 'stress points' between July 10th and July 30th) – see the *x*-axis of Fig. 2. During both of these periods the average daily maximum temperature was above 30.0 °C (Table 1), with absolute maxima of 38.2 °C in 1994 and of 36.6 °C in 2006. Although the average daily minimum temperature was well below 20.0 °C for both periods, some 'tropical nights' occurred in which temperatures did not fall below 20.0 °C. The highest frequency of 'tropical nights' was recorded in 1994 at the Tempelhof climate station (see Table 2).

The urban heat island within these two periods was especially distinct at night, when the average air temperature at the measuring stations in Berlin was 1.29 K (in 1994) and 0.83 K (in 2006) higher than at stations in the surrounding areas. Daytime measurements of air temperature within the city were, on average, lower than those from surrounding areas by 0.23 K and 0.35 K within the same periods in 1994 and 2006, respectively.

The coolest of the 3-week warm periods within the 17 years investigated (see *x*-axis of Fig. 2) occurred in 1993 (219 'stress points' between July 28th and August 17th). The average daily maximum temperature during this 3-week period was 23.5 °C, with 32.2 °C as the absolute maximum (Table 1); the average minimum temperature was 13.4 °C and there were no 'tropical nights'.

3.2. All-cause mortality

Out of all the 3-week heat-stressed periods, only those in 1994 and 2006 had mortality numbers that deviated from the expected number by more than 10% (see *y*-axis in Fig. 2). Within the 1994

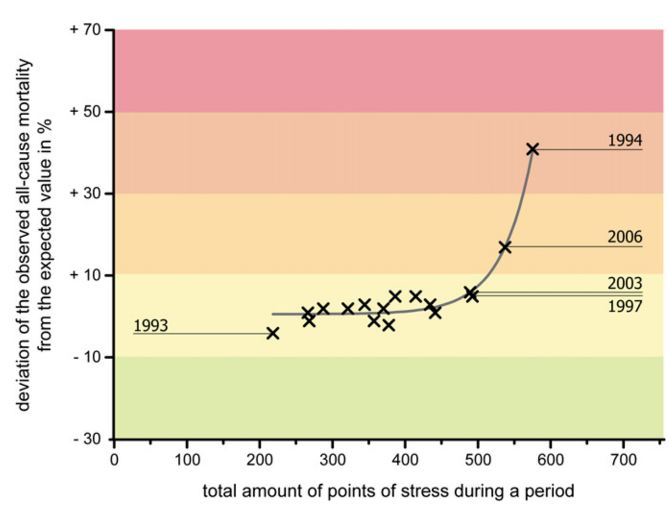

Fig. 2. Percentage deviation of recorded mortality rates from the expected values, for Berlin and Brandenburg during the hottest 3-week periods of each year between 1990 and 2006 [Data: Statistical Services of Berlin and Brandenburg].

Table 1
Average climatic conditions in Germany's Federal States of Berlin and Brandenburg during the investigated 3-week periods of 1994, 2006 and 1993 [Data: German Meteorological Service (DWD)].

		T_{max} [°C]	T_{av} [°C]	T_{min} [°C]	Water Vapour Press. [hPa]	Sunshine [h]	Clouds [1/8]	Global radiation [J/cm^2]	Windspeed [m/s]	$PT_{09/12/15}$ [°C] (day)	$PT_{00/03}$ [°C] (night)
1994	Ø	31.5	24.9	17.7	15.6	10.7	3.2	2137.4	1.5	32.0	14.9
2006	Ø	30.4	24.1	16.9	15.5	11.8	2.9	2402.6	1.8	31.1	13.2
1993	Ø	23.5	18.3	13.4	15.4	7.4	4.6	1627.7	2.2	22.1	10.6

period the expected number of deaths was exceeded by 1526, a positive deviation of 41% (Table 3), while on the hottest summer day (August 2nd) the number of recorded deaths exceeded the expected number by 151% (Fig. 3). Examining the number of deaths in different population groups over the whole 3-week period revealed that the number of deaths had a higher deviation from the expected number for people aged over 50 than it did for younger people, and that the deviation from the expected value was higher for women than it was for men. The number of deaths in Berlin for women aged over 50 exceeded the expected number by 54.9%, the strongest positive deviation of all sections of the population investigated.

The overall deviation in mortality figures for 2006 was less than for 1994, exceeding the expected number by 534, a positive deviation of 17%. A pattern of vulnerability similar to that of 1994 could not be observed within the various groups. The highest deviation from the expected mortality figures was for young men in Berlin (25.8% positive deviation). However, this result should be treated with caution as both the recorded and expected number of deaths for people aged less than 50 came to less than 100; the ratio of these two figures is thus very sensitive to a change in one of the values and a single case can have a marked effect on the deviation. Within the group of people older than 50, the number of deaths recorded for women and for people living in Berlin showed higher deviations from the expected number than those for men or people living in Brandenburg.

Since mortality numbers for the other 15 years did not show any variabilities greater than 10%, it would appear that, during average summers with no extreme heat waves, the population is coping quite well with the climatic conditions. During the relatively cool 3-week period in 1993, the recorded number of deaths in both Federal States even fell below the expected value.

3.3. Spatial distribution of mortality

For the 3-week heat-stressed periods in 1994 and 2006, and also for 1993, the deviation of the number of recorded all-cause mortalities from the expected number was also determined on a district level (Fig. 4).

For the 1994 period, every district in Berlin and Brandenburg showed a positive deviation from the expected number of deaths (Fig. 4a). The lowest deviation was recorded on the eastern border of the investigation area (+3.1%). Five districts showed a deviation greater than 50%, with four of these lying within the city of Berlin. The highest figure (+67.2%) was recorded in the city centre.

Table 2
Number [n] of 'tropical nights' ($T_{min} \geq 20$ °C) during the investigated 3-week periods of 1994, 2006 and 1993 [Data: German Meteorological Service (DWD)].

	1994	2006	1993
Neuruppin	1	1	0
Angermünde	4	0	0
Berlin–Dahlem	4	2	0
Berlin–Tempelhof	9	2	0
Wittenberg	3	2	0
Cottbus	4	5	0

In 2006, three districts showed negative deviations from the expected figures (Fig. 4b). All three are in the Federal State of Brandenburg, with a district in the western part of Brandenburg showing the greatest negative deviation (−26.3%). While all districts within the city of Berlin again showed a positive deviation from the expected figure, the highest deviation was recorded for a district in the northern part of Brandenburg (+34.2%).

While in both the 1994 and the 2006 heat-stressed periods the deviation from the expected figure was higher in the city of Berlin than in the Federal State of Brandenburg, it was actually lower during the relatively cool 3-week period of 1993. About two-thirds of the districts in the investigation area showed a negative deviation for the 1993 heat-stress period (Fig. 4c), with the greatest negative deviation occurring in the northern part of Berlin (−24.4%). The highest positive deviation for 1993 was observed in the Federal State of Brandenburg, in a district to the south-west of Berlin (+17.2%).

Correlating the deviation of recorded number of deaths from the expected number, with the proportion of land covered by sealed surfaces, on a district by district basis, it can be shown that the degree of correlation increases with increasing thermal stress (Fig. 5). The greater the thermal stress the greater the correlation between the number of deaths and the proportion of land covered by impervious surfaces. The effects of UHIs on mortality rates can therefore only be detected during the most extreme heat waves.

Our results show that

- mostly elderly people and especially women showed an increased vulnerability to heat stress,
- mortality rates are up to 67.2% higher during extreme heat waves, both in the city of Berlin and in the surrounding rural areas of Brandenburg,

Table 3
Absolute number [n] of recorded mortalities and of their expected values in Germany's Federal States of Berlin and Brandenburg and the percentage deviation, for the investigated 3-week periods of 1994, 2006 and 1993 [Data: Statistical Services of Berlin and Brandenburg].

			total	male		female	
				<50 years	≥50 years	<50 years	≥50 years
1994	Berlin	obs	3156	151	1026	55	1242
		exp	2181	119	784	52	1242
		dev	44.7%	27.4%	30.8%	6.2%	54.9%
	Brandenburg	obs	2088	131	800	37	1120
		exp	1579	117	623	42	789
		dev	32.3%	12.4%	28.5%	−12.7%	41.9%
2006	Berlin	obs	2044	96	826	34	1088
		exp	1715	76	736	33	905
		dev	19.2%	25.8%	12.3%	3.0%	20.3%
	Brandenburg	obs	1656	71	715	31	839
		exp	1428	72	641	28	743
		dev	16.0%	−0.9%	10.7%	10.4%	12.9%
1993	Berlin	obs	2083	105	751	50	1177
		exp	2288	122	792	54	1242
		dev	−6.5%	−14.1%	−5.2%	−6.6%	−5.2%
	Brandenburg	obs	1560	115	641	41	763
		exp	1612	120	631	45	789
		dev	−3.2%	−4.3%	1.6%	−8.3%	−3.3%

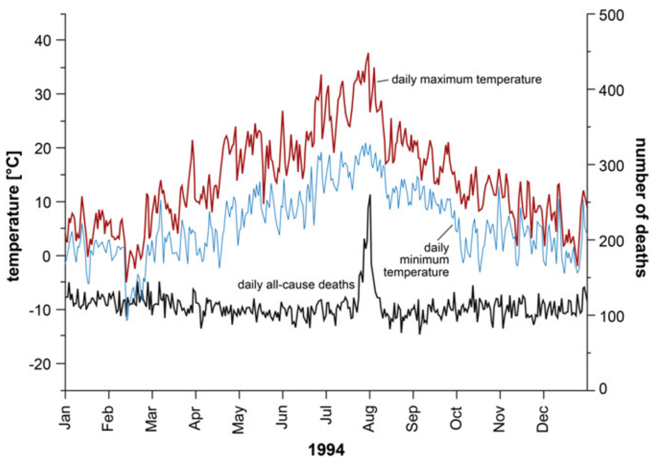

Fig. 3. Daily maximum and minimum temperatures, together with daily mortality rates for Berlin during 1994 [Data: German Meteorological Service, Statistical Services of Berlin and Brandenburg].

- no increase in the number of human mortalities was observed during average summers, either in Brandenburg or in Berlin; during unusually cool summers such as in 1993, the mortality was even reduced, and
- a clear relationship can be seen between the mortality rate and the density of urban structures within the city area during the most intense heat waves of 1994 and 2006.

4. Discussion

Our research has revealed a positive correlation between thermal stress and mortality rates within the study area. The observed increase in mortality rate corresponds well with results from other European (e.g. Huynen et al., 2001; Koppe et al., 2004; Sartor et al., 1997) and non-European (e.g. Nitschke et al., 2007; Smoyer, 1998) studies of heat-related mortality.

Although the investigation area is situated in north-eastern Germany, which has a temperate climate, episodes of heat-related mortality are not uncommon in this climatic zone. As noted by Keatinge et al. (2000) for Finland and Smoyer-Tomic et al. (2003) for Canada, unusual thermal conditions can affect people's health at even higher latitudes. Indeed, an increased vulnerability to adverse

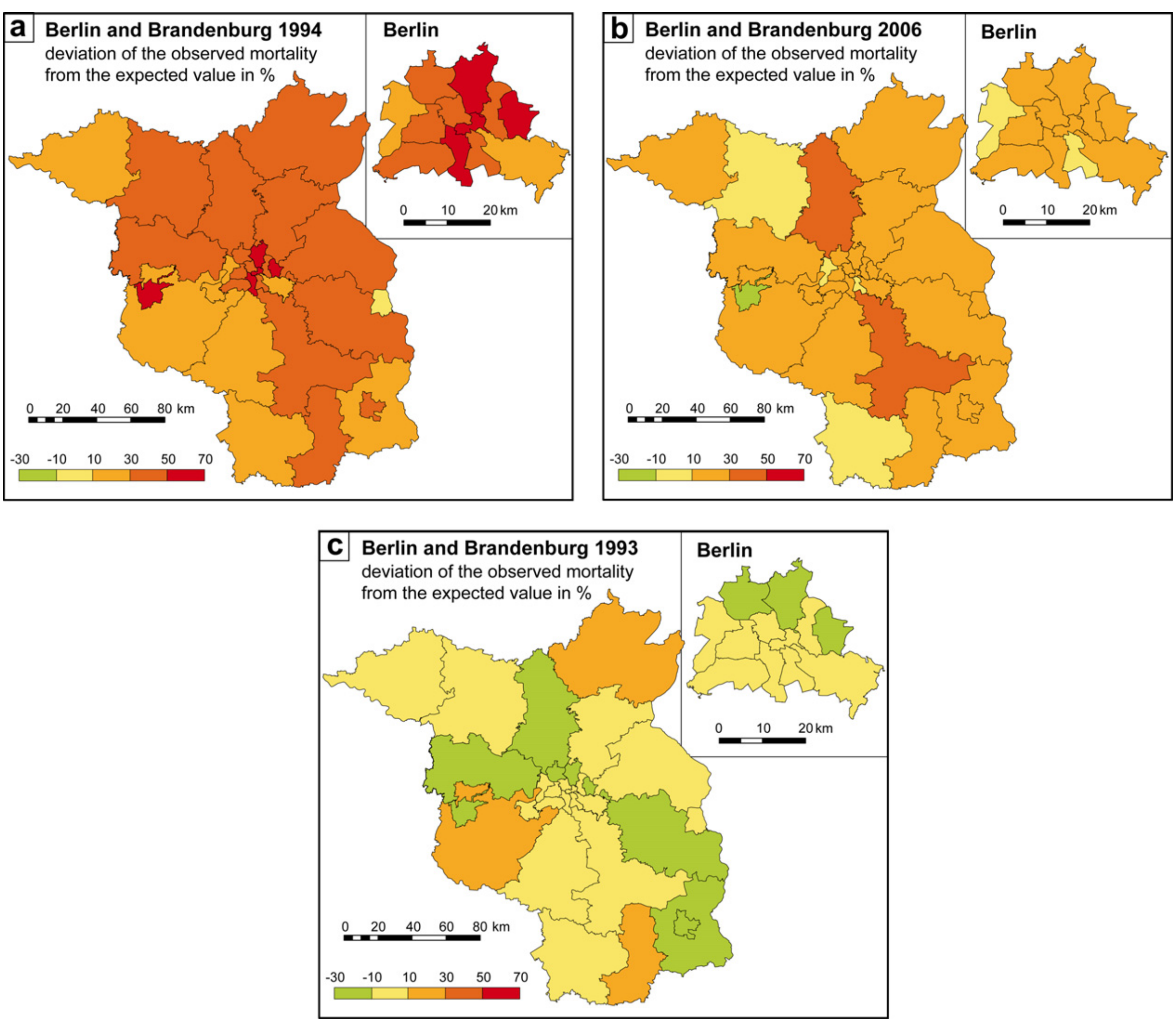

Fig. 4. Spatial distribution for the deviation [%] of recorded mortality rates from the expected values in Germany's Federal States of Berlin and Brandenburg during the investigated 3-week periods of (a) 1994, (b) 2006, and (c) 1993 [Data: Statistical Services of Berlin and Brandenburg].

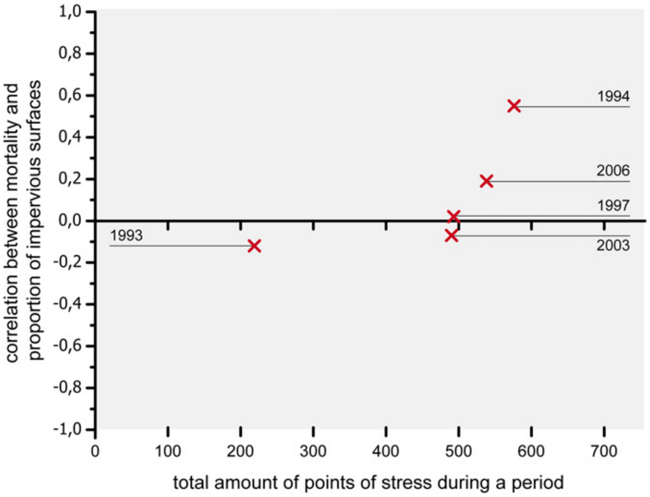

Fig. 5. Correlation between mortality rates and the proportion of land covered by sealed surfaces in Berlin and Brandenburg [Data: Statistical Services of Berlin and Brandenburg].

thermal conditions with increasing latitude has been reported in the United States (Medina-Ramón and Schwartz, 2007).

Within the investigation area, a heat-related increase in the mortality rate could only be observed in two of the 17 years: in 1994 and in 2006. This low frequency of heat-related increases in the mortality rate is in agreement with findings from the Czech Republic (Kyselý et al., 2000), France (Rey et al., 2007), and Spain (Díaz et al., 2002). While the summer of 2006 has been widely discussed in the scientific literature as a heat-stressed season (e.g. Fouillet et al., 2008), the summer of 1994 has attracted only minor attention (Huynen et al., 2001; Kyselý et al., 2000; Sartor et al., 1997). In 2003 however, which was a fatal year in many south-western European countries, the mortality rate within the area of investigation was only slightly above the expected value. This is in agreement with the results presented by Robine et al. (2007), who showed that thermal stress in that year affected only the south-western part of Germany.

During 1994 and 2006, deviations of more than 30% from the predicted value were observed in both the city of Berlin and the rural Federal State of Brandenburg. As Sheridan (2002) pointed out, heat-related mortality is “a rural problem, too”. However, with increasing heat load the correlation between high mortality rates and those districts with a high proportion of land covered by sealed surfaces becomes increasingly marked. A relationship between the mortality rate within the city of Berlin and the urban structures can be observed, especially during the heat-stressed period of 1994. The difference in night time temperatures between the city and its surroundings was more pronounced during the 1994 heat-stressed period than during the one of 2006. The inner urban differentiation of mortality rates due to the intensification of thermal stress as a result of the UHI effect has previously been proven for cities in the United States (Buechley et al., 1972; Schuman, 1972; Smoyer, 1998) as well as in China (Tan et al., 2010).

Although both heat-stressed periods had above average thermal conditions, the impact on overall mortality rates was much higher in 1994 than in 2006. The reasons for this difference can be found in the heat load itself, since the 1994 period reported higher values for both average and maximum temperatures, which is reflected in the higher total number of stress points. A more marked nocturnal UHI was developed as a result.

In addition to the observed thermal conditions, their temporal occurence must also be taken into account. The 1994 heat-stressed period developed 12 days earlier in the year than that of 2006. It was preceded by some single warm days, but these started only from the end of June. In 2006, however, the heat-stressed days had already started to appear by the beginning of June, with the result that some of the people most vulnerable to heat may have already died before the start of the investigated period. People also had less opportunity to develop short-term adaptation to thermal stress in 1994 than in 2006, especially since the preceding summer (in 1993) was exceptionally cool – in fact, it was the coolest summer in the whole period of investigation between 1990 and 2006. It should be borne in mind therefore, that the mortality rates of 1994 may also have been influenced by a long-term effect, since people who were vulnerable to heat would not have been affected during the previous summer.

The high vulnerability of elderly people to thermal stress is in agreement with international findings (Borrell et al., 2006; Díaz et al., 2006), as is the higher sensitivity of women to heat waves (Fouillet et al., 2006; Ishigami et al., 2008; Rey et al., 2007; Schuman, 1972).

5. Conclusion

In view of the increasing summer temperatures and more frequent hot periods predicted for most land areas by the IPCC (Solomon et al., 2007), mitigation of heat wave effects will need to take into account not only the thermal comfort inside buildings, but also the structures and land cover in urban areas. Although rural areas are affected in a similar way to urban agglomerations the need to reduce risk factors by urban planning is greater in cities, not only because heat waves are intensified in such agglomerations by the development of urban heat islands, but also because the risk factors are magnified by the large number of people that cluster together within such agglomerations (Brücker, 2005).

The superposition of a number of different factors – heat waves, thermal discomfort, rapid urbanisation, the growing number of elderly people, and global warming – precludes any simple solution. Nevertheless, adaptation measures are possible (Kirch et al., 2006) and intelligent short-term adaptation measures to cope with heat waves can be realised. In particular, Heat Health Warning Systems can be set up that take into account the actual weather as well as the forecast for the next few days (Kovats and Jendritzky, 2006). Long-term adaptation measures should relate to more advanced thermal comfort indices (e.g. the Universal Thermal Climate Index – UTCI – Jendritzky et al., 2007) as well as to urban planning and building design. Outdoor measures may include, for example, the creation of open green spaces, especially with trees (Endlicher et al., 2008), the facilitation of better ventilation in cities through cold air drainage flows at night, the enhancement of urban albedo by painting roofs and walls white, the reduction of thermal pollution, etc. Special emphasis must also be placed on indoor bioclimatic conditions.

Long-term adaptation measures require more time to be developed and introduced; such issues will, however, be further complicated by global climate change and by rapid urbanisation, especially the growing number of megacities. Finally, social aspects such as the proportion of elderly people and of women in each district will also need to be taken into account.

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