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Spatial analysis of hospital admissions for respiratory diseases during summer months in Berlin taking bioclimatic and socio-economic aspects into account

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Abstract
International environmental health studies of the past years have discussed the impacts of heat stress on human health. In particular, respiratory morbidity has shown significant heat effects in European cities. Metropolitan areas such as Berlin are characterised by an intra-urban spatial variability in socio-economic and bioclimatic conditions that is assumed to result in spatial differences in respiratory health risks. In essence, the elderly, children and people with chronic diseases suffer most from heat stress. A spatial epidemiological approach was chosen to map elevated risks for hospital admissions among > 64-year-olds with respiratory diseases (RD) during the summer months (June–September) from 2000 to 2009 and to link respiratory health risks to bioclimatic and socio-economic conditions in Berlin. The study aims to detect significant clusters with elevated relative risks for hospital admissions among > 64-year-olds with RD in due consideration of socio-economic conditions as a covariate for health outcomes. The findings from the purely spatial analysis show significant intra-urban disparities in the relative risks for hospital admissions among > 64-year-olds with RD. The highest relative risks within significant clusters were basically detected in the north-western and south-eastern city centre based on the study period 2000–2009 and also during the hot months of July and August in 2003 and 2006. The correlation analysis depicted significantly positive relationships between relative risks for hospital admissions among > 64-year-olds with RD and population density, socio-economic conditions and the annual mean number of days with heat loads on the basis of the period 1971–2000 and the average of the periods 1971–2000 and 2021–2050 at the zip code level in Berlin. To specifically implement health care intervention and prevention strategies into urban planning and to apply a directed practice of telemedicine for patients with chronic obstructive pulmonary diseases, spatial epidemiological analyses are an important approach to identifying heat-vulnerable urban areas.

Zusammenfassung
In den vergangenen Jahren zeigten internationale Studien zu Umwelt und Gesundheit Auswirkungen von Wärmebelastung auf die menschliche Gesundheit auf. In europäischen Städten wurden signifikante Hitzeeffekte besonders bei Krankenhausaufnahmen für Atmungssystemerkrankungen identifiziert. Großstädte wie Berlin sind durch eine innerstädtische Variabilität an sozioökonomischen wie bioklimatischen Bedingungen gekennzeichnet, von der anzunehmen ist, dass sie in räumlichen Unterschieden beim Risiko für Atemwegserkrankungen resultiert. Vor allem ältere Menschen, Kinder und chronisch Kranke leiden unter Hitzestress. Zur Darstellung erhöhter Risiken für Krankenhausaufnahmen bei > 64-Jährigen mit Atmungssystemerkrankungen (AS) während der Sommermonate (Juni-September) 2000-2009 in Berlin wurde ein räumlich-epidemiologischer Analyseansatz gewählt. Dabei werden gesundheitliche Risiken für AS in Verbindung zu bioklimatischen und

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sozioökonomischen Faktoren gesetzt. Ziel der Studie ist es, räumlich signifikante Cluster erhöhter Risiken für Krankenhausaufnahmen bei > 64-Jährigen mit AS zu ermitteln und sozioökonomische Faktoren als Kovariate für Gesundheitseffekte zu berücksichtigen. Die Ergebnisse der ausschließlich räumlichen Analyse zeigen signifikante innerstädtische Disparitäten beim relativen Risiko einer Krankenhausaufnahme bei > 64-Jährigen mit AS. Für den Zeitraum 2000-2009 wurden höchste relative Risiken innerhalb signifikanter Cluster hauptsächlich im nordwestlichen und südöstlichen Stadtzentrum Berlins und für die heißen Monate Juli und August der Jahre 2003 und 2006 identifiziert. Das relative Risiko einer Krankenhausaufnahme bei > 64-Jährigen mit AS in Berlin korreliert auf Postleitzahlebene positiv signifikant mit der Bevölkerungsdichte, mit sozioökonomischen Faktoren und dem Jahresmittel der Anzahl der Tage mit Wärmebelastung (auf der Basis der Daten für 1971-2000 und dem Durchschnitt der Zeiträume 1971-2000 und 2021-2050). Um spezifische Interventions- und Präventionsstrategien im Gesundheitswesen in die Stadtplanung zu integrieren und eine gezielte telemedizinische Versorgung von Patienten mit chronisch obstruktiven Lungenerkrankungen zu implementieren, sind räumlich-epidemiologische Analysen ein wichtiger Ansatz, um hitzevulnerable Stadtgebiete zu identifizieren.

Keywords Urban health, spatial epidemiology, respiratory diseases, heat load, Berlin, Germany

1. Introduction

International studies of the past years reveal substantial impacts of heat stress on health, especially for the hot summers in 2003, 2006 and 2010 in Europe (*Barriopedro* et al. 2011; *Fouillet* et al. 2008; *Robine* et al. 2008; *Schär* and *Jendritzky* 2004). Investigations focus above all on heat impacts on mortality, but human health responses during heat expositions already start at the level of well-being, followed by aggravation of pre-existing illnesses, appearance of symptoms, increased emergency calls and increased hospital admissions. An epidemiological study of high temperature impacts on morbidity in 12 European cities shows that extreme heat events increase hospital admissions for respiratory diseases (RD), particularly in the elderly population (*Michelozzi* et al. 2009).

The first investigation of weather impacts on mortality in Berlin was conducted by *Turowski* and *Haase* in 1987 based on death certificates from 1958 to 1967. Their findings show an increase in mortality from April to August when air temperature values exceeded averages. Thereby, respiratory mortality indicates higher impacts than cardiovascular mortality (*Turowski* and *Haase* 1987). The respiratory tract is physically closely related to environmental conditions. Physiological responses to heat are vasodilatation, sweating, an increase in heart beat and higher respiratory rates to transport more oxygen. Acute respiratory episodes are associated with airways and systematic inflammation as well as with cardiovascular comorbidity (*Michelozzi* et al. 2009). Extreme heat events are also accompanied by increased air pollution (IPCC 2007; *Stedman* 2004), which exacerbates the impacts of heat on human health (*Confalonieri* et al. 2007; *Harlan* and *Ruddell* 2011; *Knowlton* et al. 2008). The findings from an all-cause mortality study in Berlin that took the short-term effects of air pollution and meteorological conditions into account suggest that interactive effects exist between ozone and particulate matter (PM10) and equivalent temperature (*Burkart* et al. 2013). During the summer months, pollen has a crucial impact on the respiratory tract as well. High concentrations of various pollen taxa aggravate the symptoms of asthma, wheezing and allergies that increase respiratory morbidity and mortality (*Brunekreef* et al. 2000; *Darrow* et al. 2012). An investigation of urban and rural all-cause mortality in the city of Berlin and the federal state of Brandenburg depicts increases in mortality during the heat waves in 1994 and 2006 (*Gabriel* and *Endlicher* 2011). In particular, elderly people show an increased vulnerability to heat, and mortality rates correlate positively with the proportion of land covered by sealed surfaces in 1994 and 2006 (*Gabriel* and *Endlicher* 2011).

However, human health is not only determined by weather, air quality and pollen. Crucial factors are genetic predisposition, lifestyle, age, pre-existing diseases and socio-economic conditions (*Klinenberg* 2002; *Koppe* et al. 2004). In aspects of environmental justice, socio-economic factors are especially fundamental in environment and health research. A project called 'Environmental justice in Berlin' analyses the socio-spatial distributions of different environmental strains, e.g., air pollution, bioclimatic aspects and noise (*Klimeczek* 2011). Within this context, *Lakes* and *Klimeczek* (2011) note the high relevance of environmental justice. Berlin's inner city shows considerably increased multiple environmental strains at the same time as a low social status, whereas in the periphery, the correlation is inverse (*Lakes* and *Klimeczek* 2011).

Concerning heat and health issues, the urban population is particularly at risk because features of heat waves are strongly correlated with urban heat island (UHI) effects (*Champiat* 2009). The urban climate is mainly characterised by UHIs, which imply significantly higher air temperatures in urban areas in comparison with rural areas. UHIs arise from modified energy and radiation fluxes attributable to anthropogenic impacts (*Kuttler* 2010; *Oke* 1995). Heat waves present special problems in urban areas because buildings retain heat if ventilation for cooling at night is inadequate (*Clarke* 1972; *Koppe* et al. 2004). Prolonged heat stress during summer nights prevents the necessary recovery of the human body. Metropolitan areas such as Berlin exhibit a heterogeneous mosaic of heat islands (intensely sealed surfaces) and cool islands (green spaces). Berlin's Senate Department for Urban Development and Environment, in collaboration with the German Weather Service, uses an urban bioclimate model to evaluate bioclimatic conditions on a large scale. The resulting bioclimatic maps provide the basis for further implementations, e.g., in the Urban Development Climate Plan (Stadtentwicklungsplan Klima – StEP Klima), which considers the spatial and urban planning aspects of Berlin's climate to ensure urban life quality in times of climate change (SenStadt 2011). The long-term strategy of StEP Klima aims to also integrate health issues. Therefore, spatial epidemiological information with different specifications on meso- and micro-scales and in relation to bioclimatic conditions is needed. Berlin is characterised by a multifaceted urban bioclimate and respective urban social structures. Thus, spatial differences in health impacts due to varying environmental and social conditions are very likely. In addition to urban development aspects, spatial health and environment data provide short- and long-term strategies for health care issues. Elderly people, children and people with chronic diseases suffer particularly from heat stress (*Koppe* et al. 2004). Chronic obstructive pulmonary disease (COPD) is one of the leading causes of mortality and morbidity worldwide (*Lopez* et al. 2006; WHO 2004), and exacerbations of COPD are one of the most common reasons for hospital admissions for respiratory causes in the elderly population (*Michelozzi* et al. 2009). Heat stress may trigger these acute episodes (*Ferrari* et al. 2012). Medical studies indicate that telemedicine technology can help to prevent hospital admissions for COPD (*Holland* 2013; *Pedone* et al. 2013). COPD patients in telemedical treatment send physiological parameters from home to physicians, and in the case of declining parameters, an immediate intervention is possible. However, a spatially inclusive and comprehensive practice of telemedicine technologies is still in progress in Germany (BMG 2013). Thus, the detection of areas with increased respiratory morbidity risks helps to apply the directed practice of telemedicine. Given the approximately 4000 Euros per hospital treatment in Berlin (*Goppolt* 2011), avoiding and reducing hospital admissions are fundamental for patients and financial issues in public health care.

This study aims to analyse hospital admission data for respiratory diseases among > 64-year-olds in Berlin on a large scale to detect city quarters where elderly people are at increased risk for respiratory hospital admissions. As such, the analysis considers spatial differences in population and social factors as well as bioclimatic conditions and relates spatial variability in relative risks for respiratory diseases among > 64-year-olds to population, social and heat load structures.

2. Methodology

2.1 Study area

The research area covered the federal state of Berlin, the capital of Germany. Berlin spans approximately 890 km^2, with a population of 3.5 million in 2013, and is located in the north-eastern part of Germany, characterised by a temperate climate in transition from maritime to continental climate. Berlin's zip code areas (n = 190) were chosen as spatial units in the analysis. Since the year 2000, the hospital diagnosis statistics have provided patients' zip codes in addition to the official municipality key. Because of missing values in the population and morbidity data for zip code area 14053, the spatial analysis includes 189 zip code areas.

2.2 Study subjects

2.2.1 Hospital admissions for respiratory diseases

Hospital admission data were acquired from the Research Data Centre of the Federal Statistical Office and the Statistical Office of Berlin. The data provide diagnoses classified by ICD-10 code, age, admission date and residence broken down by zip codes. Respiratory system diseases (RD) with ICD-10[1] code J00-J99 for > 64-year-olds from 2000 to 2009 were obtained. Since 1993, every hospital in Germany has been obliged to report hospital diagnosis statistics annually to federal statistical offices. The residence is categorised by the official municipality key and, only since 2000, by zip codes derived from postal addresses. Zip codes are not a reviewed feature. Thus, failures in declarations lead to elimination and missing data. Because of data privacy protection, high spatial resolution in hospital data restricts high temporal resolution. Temporal analysis in daily resolution, as is common in epidemiological studies concerning the impacts of heat stress on health, is not accessible with hospital data at the zip code level. Therefore, hospital admissions were obtained in monthly resolution from June to September to provide sufficient cases per zip code area. The purely spatial analysis considered admission averages for the period 2000-2009 and also admissions during the hot summers of 2003 and 2006.

2.2.2 Heat load in Berlin

Due to the purely spatial analysis approach, a representative distribution of heat load in Berlin was required. For the research period 2000-2009, no bioclimate data in spatial resolution were available. Therefore, the annual mean number of days with heat load based on 1971-2000 and the annual mean number of days with heat load based on 2021-2050 were obtained from Berlin's Senate Department for Urban Development and Environment (SenStadtUm 2010). The average for both time periods was additionally calculated to fit within the research period. The spatial distribution of urban heat load was modelled by an urban bioclimate model (UBIKLIM). UBIKLIM was developed by the German Weather Service (DWD) and evaluates the urban environment, taking into account land use, types of urban structures, sealing, elevation, air temperature, humidity, wind speed, radiation and radiation temperature (SenStadtUm 2010). The human physiological response is based on the 'Klima-Michel-Modell' (*Jendritzky* et al. 1990; *Jendritzky* and *Nübler* 1981) which considers all thermo-physiologically relevant parameters such as air temperature, humidity, wind speed, water vapour pressure, mean radiant temperature, physical activity (metabolic rate) and clothing. UBIKLIM was combined with the annual number of days with heat load as an average over 30 years based on synoptical weather data from Berlin. A day with heat load is defined by a perceived temperature (*'gefühlte Temperatur'*) that exceeds 32 °C at least three times a day between 9 am and 3 pm UTC (SenStadtUm 2010). These conditions are thermo-physiologically relevant and describe a heat stress warning situation. The output of the bioclimate model is expressed in raster units of 25 × 25 m, which were converted to zip code units by calculating average values in a geographic information system (GIS).

2.2.3 Population and socio-economic data

Annual population data at the zip code level were acquired from the Statistical Office of Berlin. The annual population data from 2000 to 2009 contained the total population and the number of > 64-year-olds. To assess socio-economic conditions in Berlin that were relevant for health issues, social index 1 (edition 2008) from Berlin's Senate Department for Health was chosen (SenGUV 2009). The spatial units of social index 1 (SI1) are expressed as urban planning areas (n = 447) and were converted to zip code units by calculating average values in Arc GIS. The SI1, based on data from 2002 to 2006, includes the parameters unemployment, education, poverty, income, children, type of residential area, migration and health indicators (mortality, life expectancy). Thirty planning areas did not provide SI1 data. Thus, the corresponding data were missing at the zip code level (see *Fig. 7*). SI1 strongly correlates with chronic diseases such as COPD and acute upper respiratory tract infections. Morbidity rates increase with decreasing social status (SenGUV 2011).

2.3 Methodology of the spatial analysis

The spatial analysis of hospital admissions for respiratory diseases (RD) was run by the free software SaTScan v9.1.1 (www.satscan.org). SaTScan performs geographical surveillance of diseases to detect spatial disease clusters and indicates their statistical significance (*Kulldorff* 2005). The purely spatial analysis was set up by using a discrete Poisson model and scanning for clusters with high rates. The maximum spatial cluster size expressed 50 % of the population at risk. The model used a maximum likelihood ratio test statistic, and the p-value was obtained through Monte Carlo hypothesis testing. Under the null hypothesis, and when there were no covariates, the expected number of cases (E) in each area (zip code) was proportional to its population size (Pop) and calculated using indirect standardisation. For each location and size of the scanning window, the alternative hypothesis was that there was an elevated risk within the window compared with the outside. The expected number of cases and the relative risk (RR) in each zip code area or scanning window was calculated as:

$$E[RD] = \frac{Pop \times RD_{sum}}{Pop_{sum}}$$

$$RR = \frac{RD / E[RD]}{(RD_{sum} - RD)/(RD_{sum} - E[RD])}$$

E[RD]	Expected number of cases
RD	Hospital admissions for RD in zip code area
RD_{sum}	Sum of hospital admissions for RD
Pop	Population in zip code area
Pop_{sum}	Sum of population
RR	Relative risk

The relative risk (RR) was expressed by the expected risk within a zip code area or window divided by the expected risk outside of the zip code area or window. A relative risk (RR) below 1 expressed a lower risk for hospital admissions within a zip code area or cluster compared with outer zip code areas or clusters. An RR of 1 implies that the risks were similar; an RR above 1 indicates that the risk was higher within a zip code area or cluster compared with outer zip code areas or clusters (e.g., for two times higher: RR = 2).

Socio-economic variables are strongly predictive for disease occurrence and are also associated with areas that exhibit high levels of environmental pollution. The way that this confounding effect was addressed was to adjust for socio-economic deprivation on the small-area scale (*Elliott* and *Wakefield* 2000). With covariate adjustment, the expected number of cases in the spatial analysis was:

$$E[RD] = \sum_i E[RD_i] = \sum_i Pop_i \times (RD_{sum})_i / (Pop_{sum})_i$$

E[RD]	Expected number of cases
RD	Hospital admissions for RD in zip code area
RD_{sum}	Sum of hospital admissions for RD
Pop	Population in zip code area
Pop_{sum}	Sum of population
i	Social index 1 (SI1)

The results of the spatial analysis were processed in ArcGIS 10. After the RR was calculated for each zip code area in SaTScan, a correlation analysis (Spearman-Rho) was run with the software IBM SPSS Statistics 19. The parameters heat load (based on 1971-2000 and the average of 1971-2000 and 2021-2050), population density and social index 1 (SI1) were correlated before and after adjustment for the covariate SI1. To set up a comprehensive framework for a spatial epidemiological analysis, three key pillars provided by *Grübner* et al. 2011 were suggested: exposure mapping, disease mapping and spatial epidemiological modelling (*Grübner* et al. 2011).

3. Results

3.1 Exposure mapping – spatial distribution of heat loads in Berlin

Spatial variability in urban structures with regard to sealed surface, building density, 3-dimensional structures and urban green and water spaces results in differences in the urban climate and in the bioclimatic evaluation of the urban environment in Berlin. The annual number of days with heat load on the basis of 1971-2000 ranged from 6.3 to 18.1 (mean and median = 13.2) at the zip code level in Berlin (see *Fig. 1*). The annual number of days with heat loads on the basis of 2021-2050 ranged from 8.7 to 25.4 (mean and median = 18.5) at the zip code level (see *Fig. 2*). The annual number of days with heat load on average for the periods 1971-2000 and 2021-2050 ranged from 7.4 to 21.7 (mean and median = 15.8) at the zip code level (see *Fig. 3*). Spatial distributions of days with heat loads for all periods (1971-2000, 2021-2050 and 1971-2050) were similar because land-use changes were not provided in the urban bioclimate model (SenStadtUm 2010). Fifty percent of the zip code areas above the median in 1971-2000 covered urban structures with a high amount of sealed surface, building density and lack of green and water spaces. Thus, heat load strongly correlated with the population density (r = 0.86; see *Tab. 1*), which is an indicator of building density. The highest number of days with heat loads (upper quartile: 15.2-18.1 heat load days per year) from 1971 to 2000 resulted in 43 zip code areas within the following quarters[2] (in alphabetical order with districts in brackets):

- Charlottenburg (Charlottenburg-Wilmersdorf)
- Friedrichshain (Friedrichshain-Kreuzberg)
- Gesundbrunnen (Mitte)
- Kreuzberg (Friedrichshain-Kreuzberg)

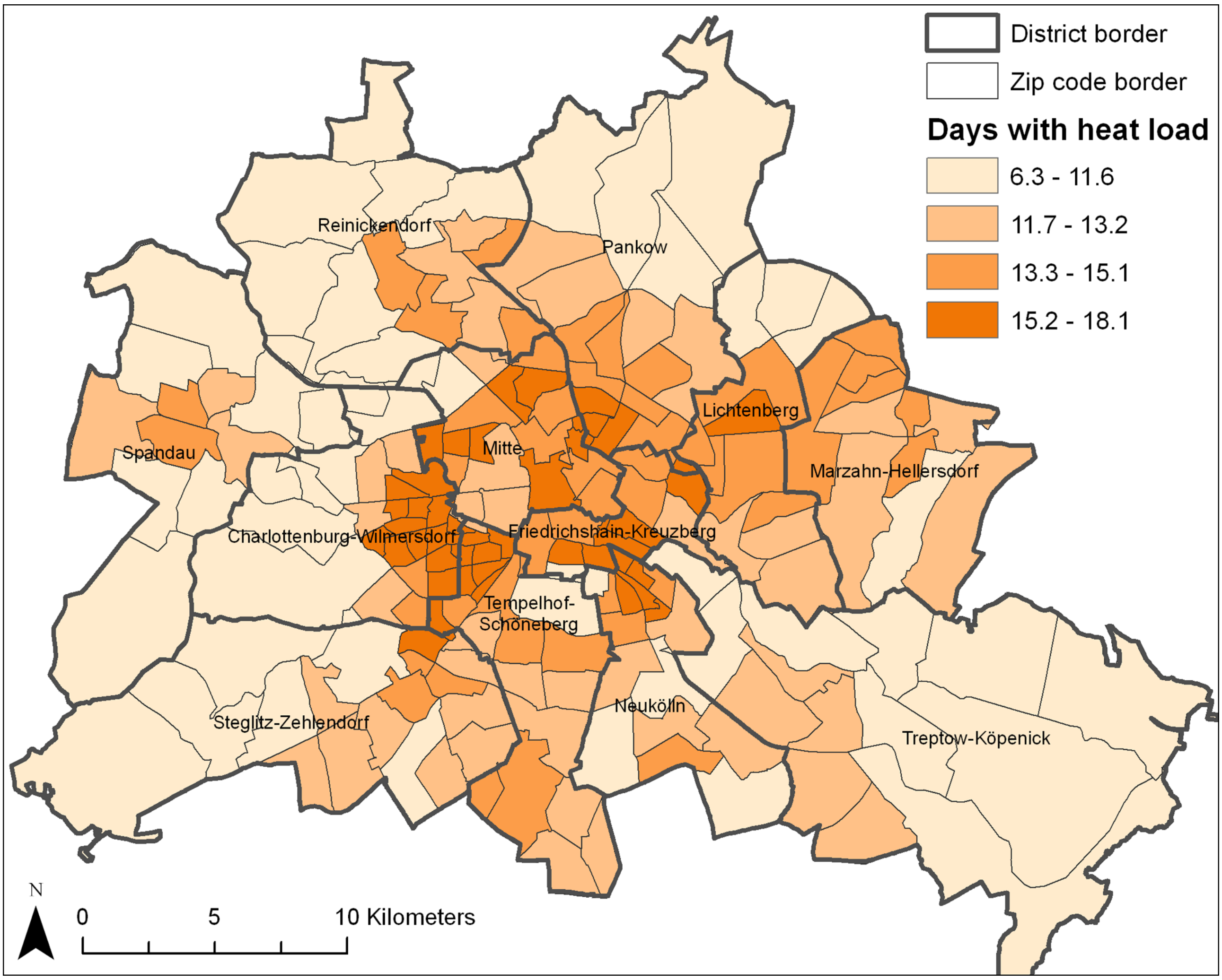

Fig. 1 Annual mean of days with heat load in quartiles on zip code level 1971-2000 in Berlin. Data basis: Information System City and Environment of the Senate Department for Urban Development and the Environment Berlin

- Mitte (Mitte)
- Moabit (Mitte)
- Neukölln (Neukölln)
- Prenzlauer Berg (Pankow)
- Schöneberg (Tempelhof-Schöneberg)
- Wilmersdorf (Charlottenburg-Wilmersdorf).

In the zip code areas of the upper quartile for days with heat loads, population density ranged from 3749 to 30843 (mean = 16193) inhabitants per km^2, which mainly corresponded with population density levels roughly in the upper quartile in Berlin (see *Fig. 4*). The spatial distributions of heat load and population density corresponded to each other.

In contrast, the elderly population (> 64-year-olds) correlated significantly negatively with population density (r = -0.47; see *Tab. 1* and *Fig. 5*). Thus, the heat-vulnerable population group basically lived outside the city centre, with lower heat loads, in the western, south-western and south-eastern quarters.

3.2 Disease mapping – spatial distribution of relative risks for hospital admissions among > 64-year-olds with respiratory diseases in Berlin

The spatial distribution of relative risks for hospital admissions among > 64-year-olds with respiratory diseases (RD) was calculated for the study periods 2000-2009 (June–September) and for the hot summer months (July and August) in 2003 and 2006. Approximately 600,000 elderly people (> 64 years) live in Berlin (see *Tab. 2*). In the study period 2000-2009, more than 40,000 elderly people with RD who resided in Berlin were admitted to approximately 70 hospitals during the summer seasons. In 2003 (July-August) 1898, and in 2006 (July-August) 2146 elderly people with RD were

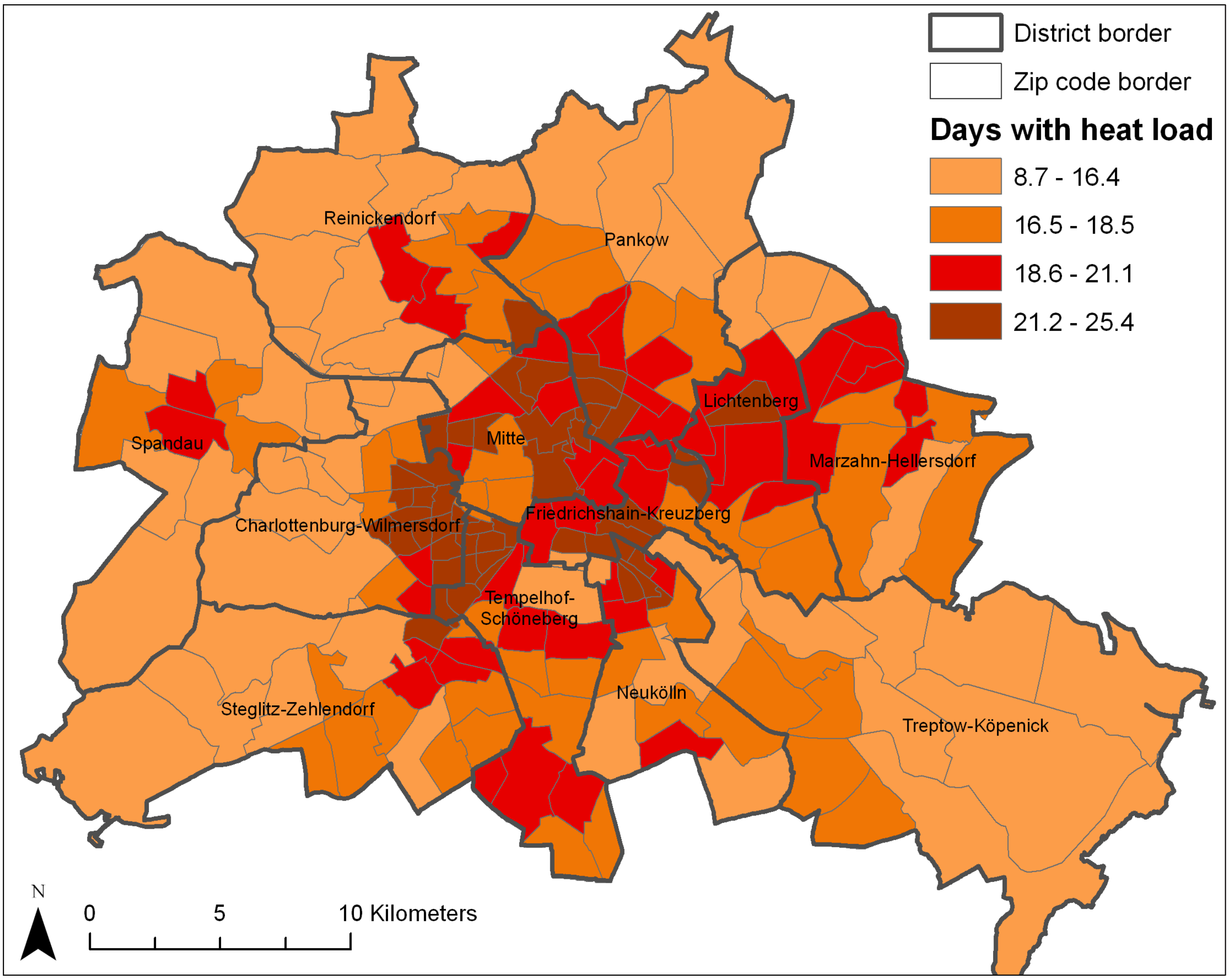

Fig. 2 Annual mean of days with heat load in quartiles on zip code level 2021-2050 in Berlin. Data basis: Information System City and Environment of the Senate Department for Urban Development and the Environment Berlin

admitted (see *Tab. 2*). On average, between 5 and 6 elderly people (> 64 years) with RD were admitted to a hospital per month and zip code area. At the maximum, 24 elderly people (> 64 years) with RD were admitted to a hospital per month and zip code area (see *Tab. 2*).

3.2.1 Spatial distribution of relative risks for hospital admissions among > 64-year-olds with respiratory diseases in Berlin on average from 2000 to 2009

The relative risks for hospital admissions among > 64-year-olds with RD were calculated for all zip code areas in Berlin (n = 189). To highlight significant clusters within the city area with elevated risks for hospital admissions among > 64-year-olds with RD, the resulting maps only show relative risks of zip code areas within significant clusters.

The relative risks for hospital admissions among > 64-year-olds with RD during the summer months in 2000-2009 resulted in five significant clusters in the northern and southern city centre and one cluster in the south-east overall (see *Fig. 6*). The cluster with the highest risk was located within the district Neukölln (RR = 2.07). Zip code areas with highest risks (upper quartile: RR 1.5-2.07) were detected in the following quarters (in alphabetical order with districts in brackets):

- Gesundbrunnen (Mitte)
- Mitte (Mitte)
- Moabit (Mitte)
- Neukölln (Neukölln)
- Wedding (Mitte).

These quarters show a high building density and therefore increased heat loads (see *Fig. 1*); they are also characterised by adverse socio-economic conditions (see *Fig. 7*).

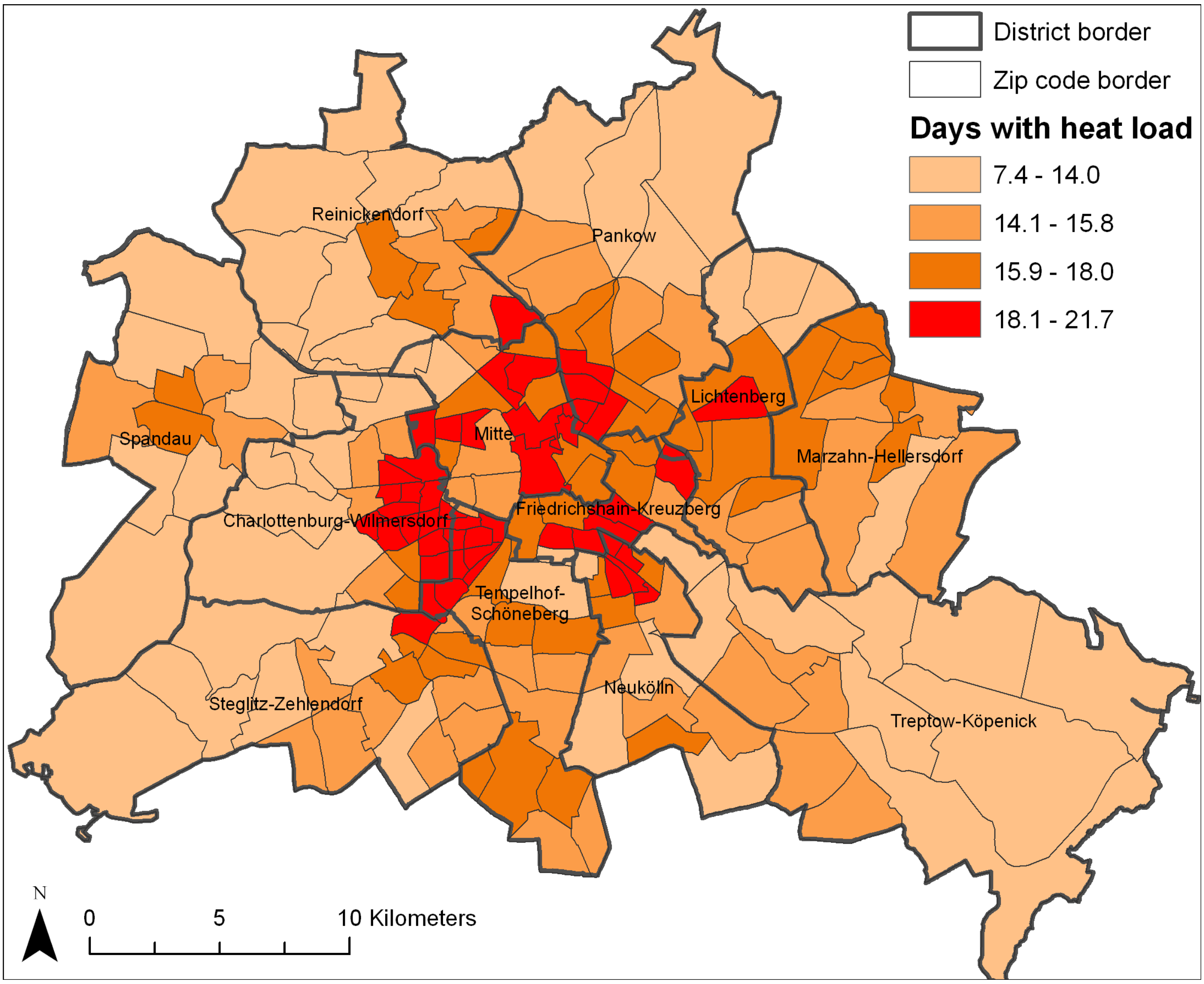

Fig. 3 Annual mean of days with heat load in quartiles on zip code level for the averaged period based on 1971-2000 and 2021-2050 in Berlin. Data basis: Information System City and Environment of the Senate Department for Urban Development and the Environment Berlin

Socio-economic status has a crucial impact on human health and disease occurrence. People with low socio-economic status are exposed to increased health risks because of adverse living conditions, health care and nutrition (*Klinenberg* 2002; SenGUV 2011). The social index 1 (SI1) measures socio-economic conditions related to health issues, ranging from level 1 (high social status) to level 7 (low social status). The north-western and east-southern areas of Berlin's city centre are especially affected by low socio-economic status (SI1 level 6

Tab. 1 Correlation coefficients for population density, percentage of > 64-year-olds, heat load and social index 1 on zip code level in Berlin (n = 189). Significance at the 0.01 level, 2-tailed (**). Data basis: Statistical Office Berlin, Senate Department for Health Berlin, Senate Department for Urban Development and the Environment Berlin

Correlation coefficients	Population density	Population 65+	Heat load 1971-2000	Heat load 1971-2050	Social index (SI1)
Population density	1	- 0.47 **	0.86 **	0.86 **	0.47 **
Population 65+		1	- 0.49 **	- 0.47 **	- 0.57 **
Heat load 1971-2000			1	1 **	0.4 **
Heat load 1971-2050				1	0.4 **
Social index (SI1)					1

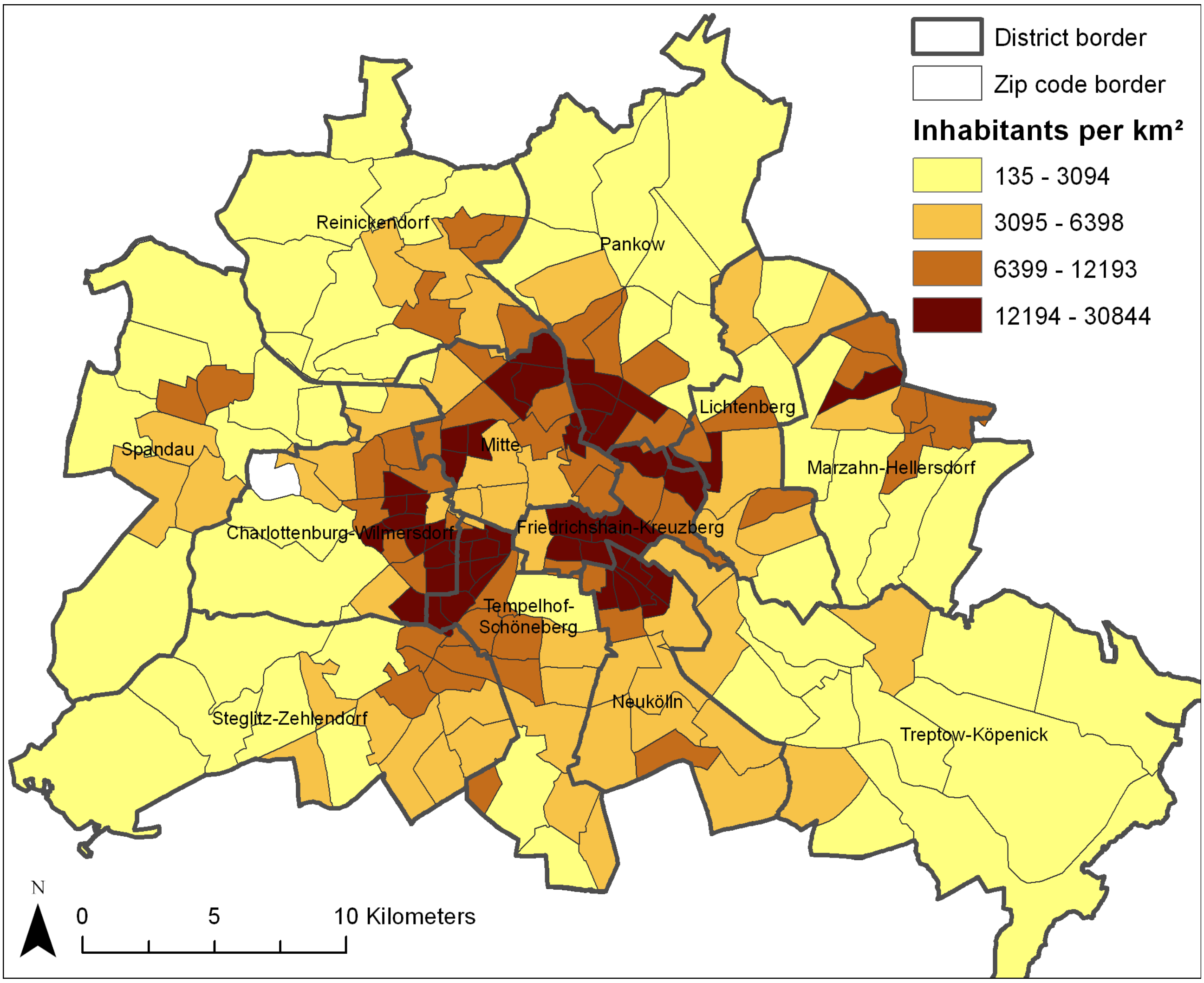

Fig. 4 Population density in quartiles on zip code level 2000-2010 in Berlin. Data basis: Statistical Office Berlin

and 7, see *Fig. 7*) and therefore by adverse health conditions. SI1 strongly correlates with chronic diseases such as COPD and acute upper respiratory tract infections. Morbidity rates increase with decreasing social status (SenGUV 2011). Four clusters with elevated relative risks for hospital admissions among > 64-year-olds with RD (see *Fig. 6*) were congruent with the northwestern and east-southern areas of Berlin's city centre, which are characterised by low socio-economic conditions. A significantly positive correlation between the risk for hospital admissions among > 64-year-olds with RD during the summer months and social index 1 (SI1) was investigated (r = 0.39, see *Tab. 3*). Thus, the relative risks were calculated again but with SI1 as a covariate. The covariate adjustment allowed for expressing health risks without the influence of social structures. After covariate adjustment, two significant clusters with elevated relative risks for hospital admissions among > 64-year-olds with RD were detected (see *Fig. 8*).

The biggest cluster was located in northeast Berlin, which partly corresponded with the northern cluster (district Mitte) in the city centre before covariate adjustment. The second cluster showed the highest risk (RR = 1.33) and was located in the southern city centre (district Neukölln), which also reflected the highest risk before covariate adjustment. Overall, the spatial distribution of relative risks differed for zip code areas and clusters before and after covariate adjustment for SI1. The zip code areas with the highest risk (upper quartile: RR 1.18-1.53) were now detected in the following quarters (in alphabetical order with districts in brackets):

- Lichtenberg (Lichtenberg)
- Märkisches Viertel (Reinickendorf)
- Mitte (Mitte)
- Neu-Hohenschönhausen (Lichtenberg)
- Neukölln (Neukölln)
- Prenzlauer Berg (Pankow)

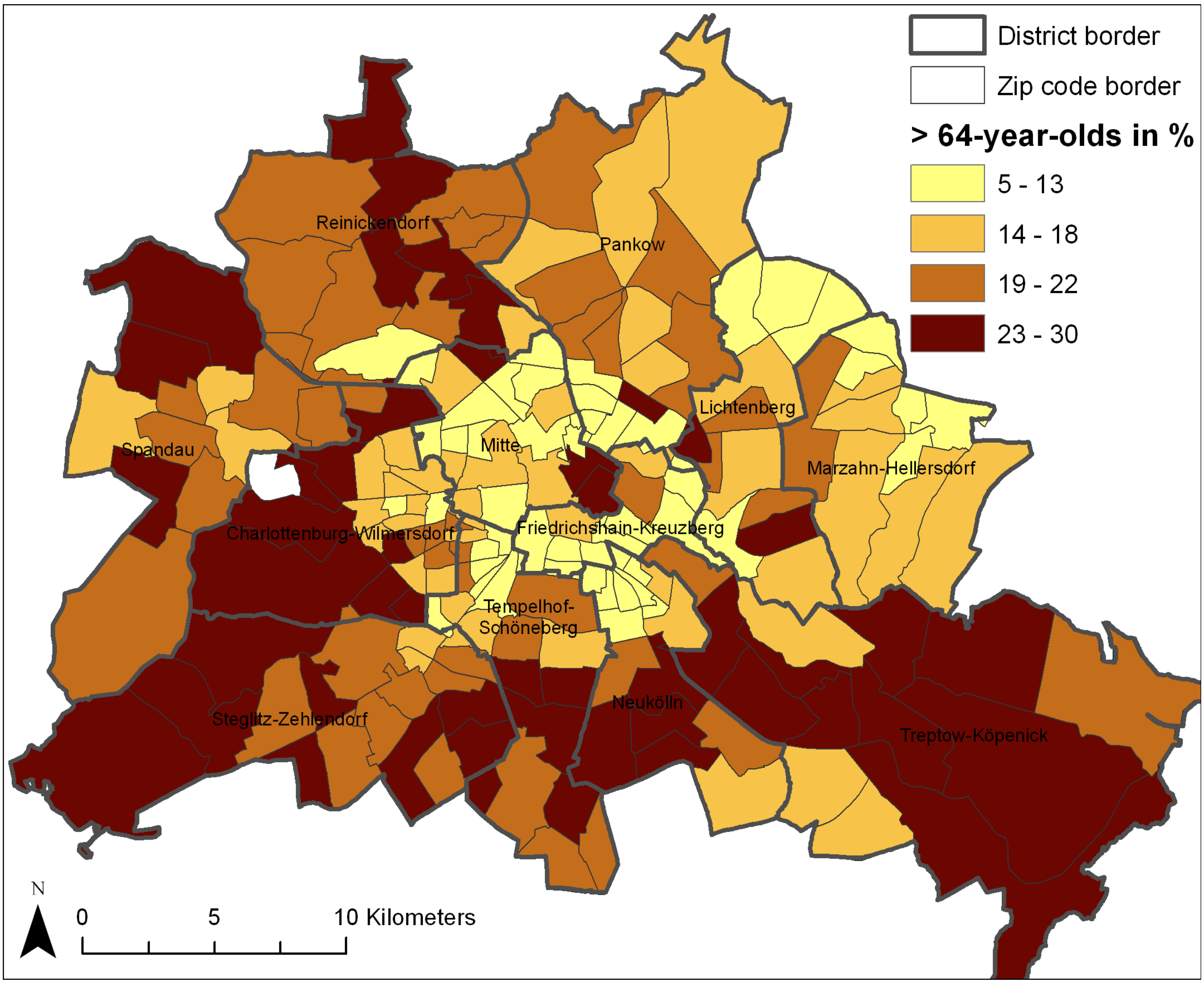

Fig. 5 Percentage of > 64-year-olds in quartiles on zip code level 2000-2010 in Berlin. Data basis: Statistical Office Berlin

- Reinickendorf (Reinickendorf)
- Wartenberg (Lichtenberg).

Except for the quarters Neu-Hohenschönhausen and Wartenberg (district Lichtenberg) in northeast Ber-

Tab. 2 Population, total number of cases and descriptive statistics for hospital admissions at > 64-year-olds (65+) with respiratory diseases (RD) in the study periods. Data basis: Research Data Centre of the Federal Statistical Office [hospital diagnosis statistics], Statistical Office Berlin

Study periods	**2000/06/01 – 2009/09/30**	**2003/07/01 – 2003/08/31**	**2006/7/1 – 2006/8/31**
Population 65+ in Berlin	570168	536539	603575
Total number of cases RD 65+ in Berlin	40575	1898	2146
Minimum *	0	0	0
Mean *	5.37	5.02	5.68
Maximum *	24	22	18

* of cases (RD 65+) per zip code area (n = 189) and summer month

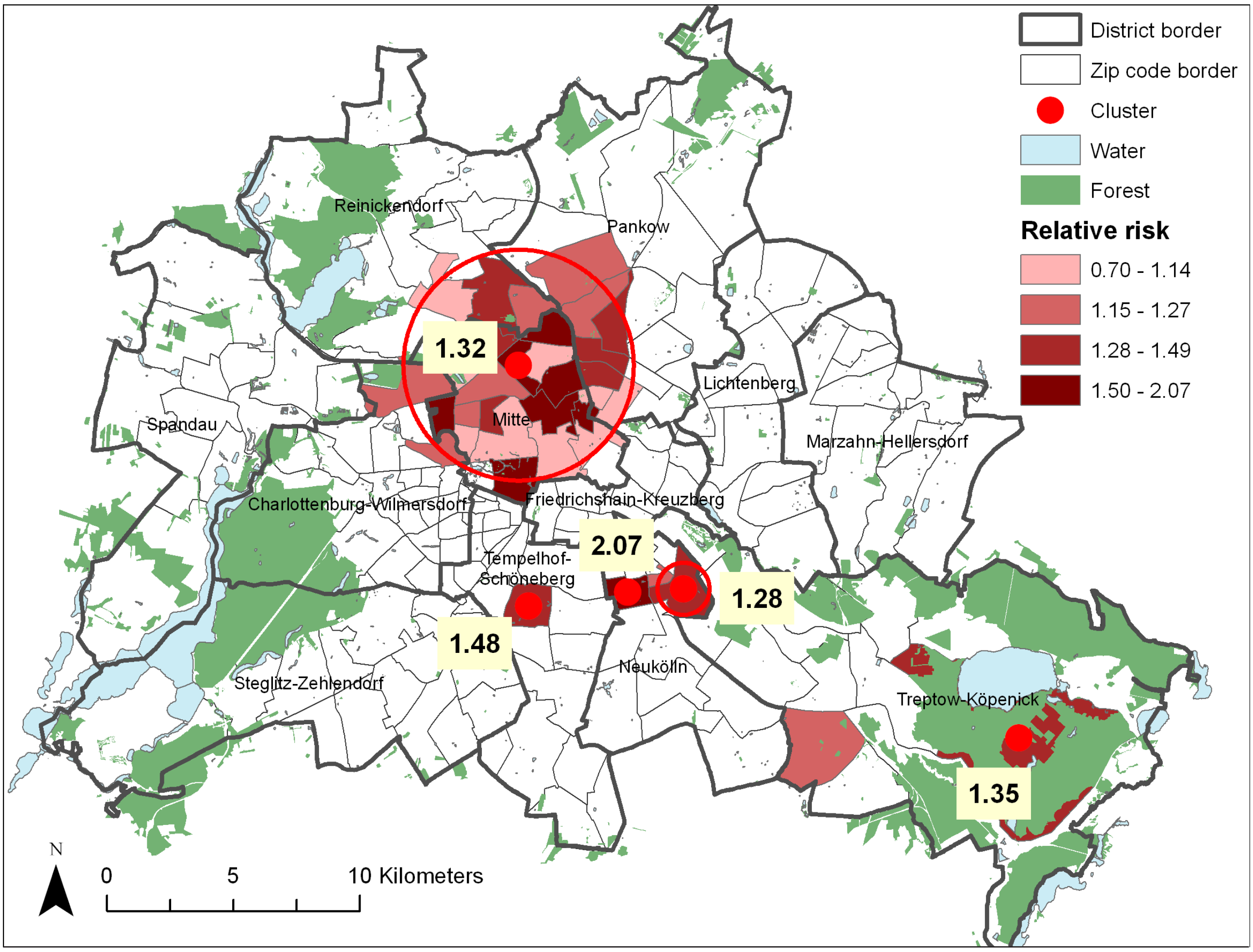

Fig. 6 Relative risk of zip code areas in quartiles within significant clusters of increased risk for hospital admissions at > 64-year-olds with respiratory diseases during summer months 2000-2009 in Berlin. Additionally, relative risks of clusters are displayed. Data basis: Research Data Centre of the Federal Statistical Office [hospital diagnosis statistics], Statistical Office Berlin

lin, the listed quarters covered areas with heat loads above the median (see *Fig. 1*).

3.2.2 Spatial distribution of relative risks for hospital admissions among > 64-year-olds with respiratory diseases in Berlin during the hot summers in 2003 and 2006

Within the study period 2000-2009, the summers of 2003 and 2006 showed the highest number of days with daily maximum air temperatures > 24 °C (*Scherber* et al. 2013) and the highest deviations of observed all-cause mortality rates from expected values on the basis of 1990-2006 in Berlin (*Gabriel* and *Endlicher* 2011). Therefore, the relative risks for hospital admissions among > 64-year-olds with RD were calculated only for the hot summers of 2003 and 2006 (July-August). The resulting significant clusters with elevated risks for hospital admissions among > 64-year-olds with RD are an example of spatial distributions of health risks according to actual heat stress.

The relative risks for hospital admissions among > 64-year-olds with RD were calculated before and after covariate adjustment for SI1 across all zip code areas in Berlin (n = 189). After adjustment, no significant clusters were found. The resulting maps only show the relative risks in zip code areas within significant clusters with elevated risks.

In July and August 2003, the highest risks (upper quartile: RR 1.85–2.3; see *Fig. 9*) for hospital admissions among > 64-year-olds with RD within significant clusters were detected in the (districts in brackets) Neukölln (Neukölln) and Mitte (Mitte) quarters. In July and August 2006, the highest risks (upper quartile: RR 1.73–2.57; see *Fig. 10*) for hospital admissions among > 64-year-olds with RD within significant clusters were

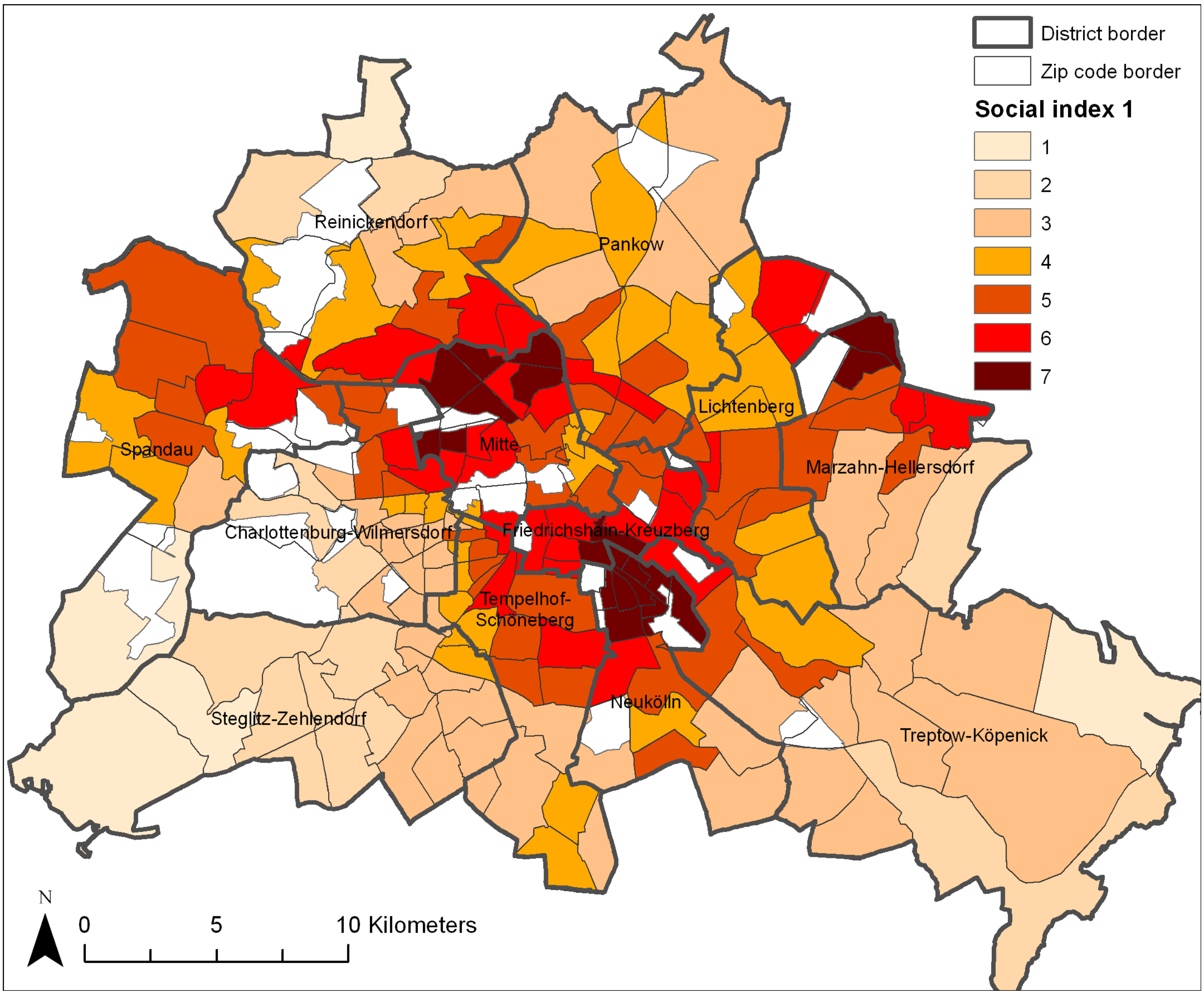

Fig. 7 Social Index 1 on zip code level in Berlin (1 = high social status; 7 = low social status). Data basis: Senate Department for Health Berlin

detected in the (districts in brackets) Mitte and Wedding (Mitte) and Prenzlauer Berg (Pankow) quarters.

The quarters with the highest risks for hospital admissions among > 64-year-olds with RD in the hot summers of 2003 and 2006 are characterised by high population densities (see *Fig. 4*), high numbers of days with heat loads (see *Figs. 1* and *2*) and adverse socio-economic conditions (see *Fig. 7*).

Tab. 3 Correlation coefficients for relative risk and relative risk adjusted for social index 1 (SI1) for hospital admissions of > 64-year-olds with respiratory diseases during summer months 2000-2009, population density, heat load and social index 1 on zip code level in Berlin (n = 189). Significance at the 0.01 level, 2-tailed (**). Data basis: Research Data Centre of the Federal Statistical Office [hospital diagnosis statistics], Statistical Office Berlin, Senate Department for Health Berlin, Senate Department for Urban Development and the Environment Berlin

Correlation coefficients	Population density	Heat load 1971-2000	Heat load 1971-2050	Social index (SI1)
Relative risk	0.25 **	0.22 **	0.22 **	0.39 **
Relative risk SI1 adjusted	0.01	0.02	0.02	- 0.03

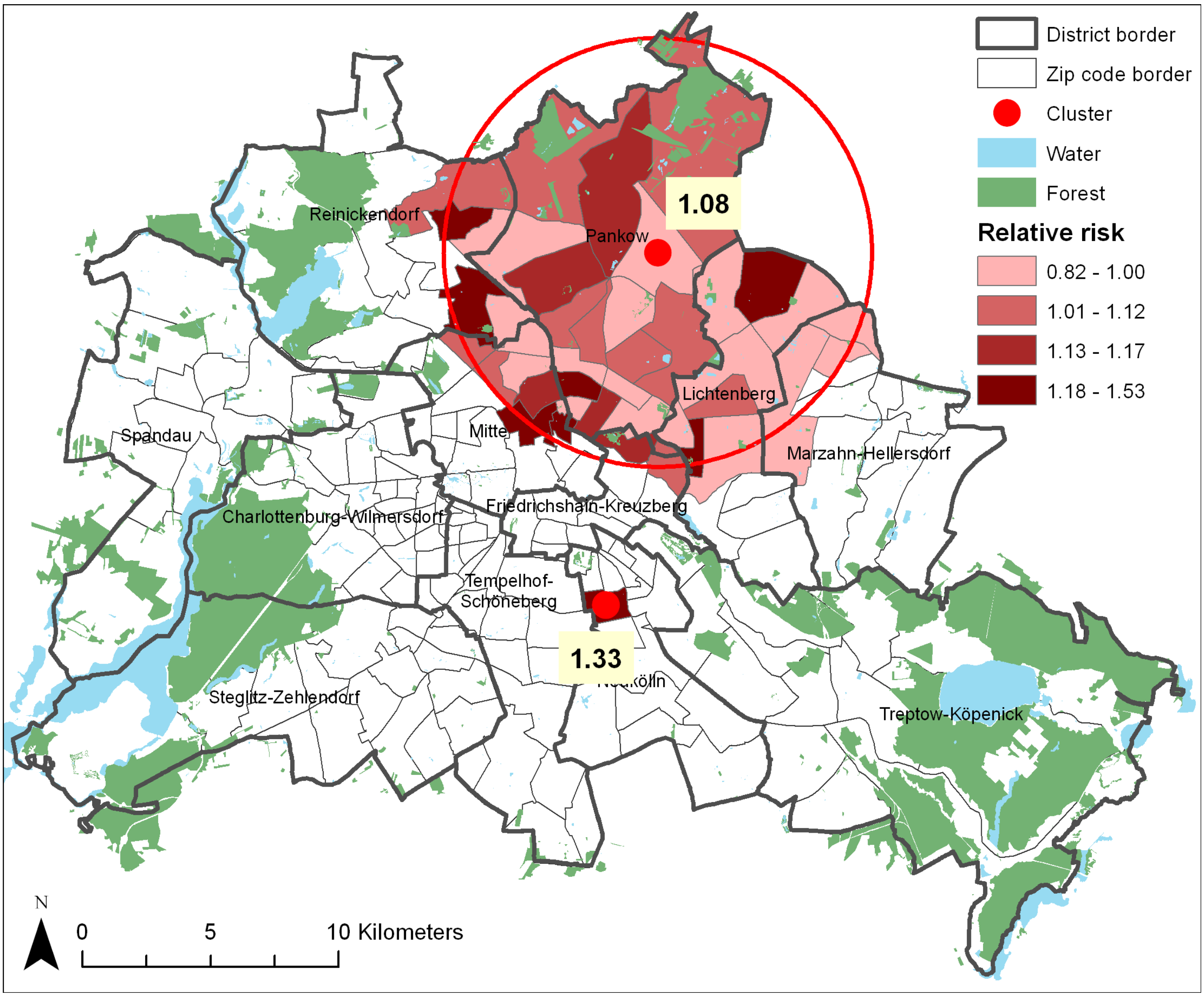

Fig. 8 Relative risk of zip code areas, taking the social index 1 into account, in quartiles within significant clusters of increased risk for hospital admissions of > 64-year-olds with respiratory diseases during summer months 2000-2009 in Berlin. Additionally, relative risks of clusters are displayed. Data basis: Research Data Centre of the Federal Statistical Office [hospital diagnosis statistics], Statistical Office Berlin

The districts Mitte and Neukölln were detected in all calculations of relative risk for hospital admissions among > 64-year-olds with RD within significant clusters with elevated risks.

3.3 Correlation between population and social factors, heat load and relative risk for hospital admissions among > 64-year-olds with respiratory diseases in Berlin

Urban areas with high population densities correlated strongly positively with the number of days with heat loads based on the period 1971-2000 and the average of the periods 1971-2000 and 2021-2050 (r = 0.86; see *Tab. 1*). The areas with high population density and heat loads are basically located in Berlin's city centre. Because of the inverse distribution of the elderly (> 64-year-olds), the majority of elderly people live in the periphery and the number of > 64-year-olds correlated moderately negatively with heat load (1971-2000: r=0.49; 1971-2050: r=-0,47) and population density (r = -0.47) at the zip code level in Berlin (see *Tab. 1*). Urban areas with adverse socio-economic conditions concerning health aspects are mainly located in the north-eastern and south-western parts of the city centre. Therefore, social index 1 (SI1) correlated moderately negatively with the number of > 64-year-olds (r = -0.57) and correlated moderately positively with population density (r = 0.47) and heat load (r = 0.4; see *Tab. 1*).

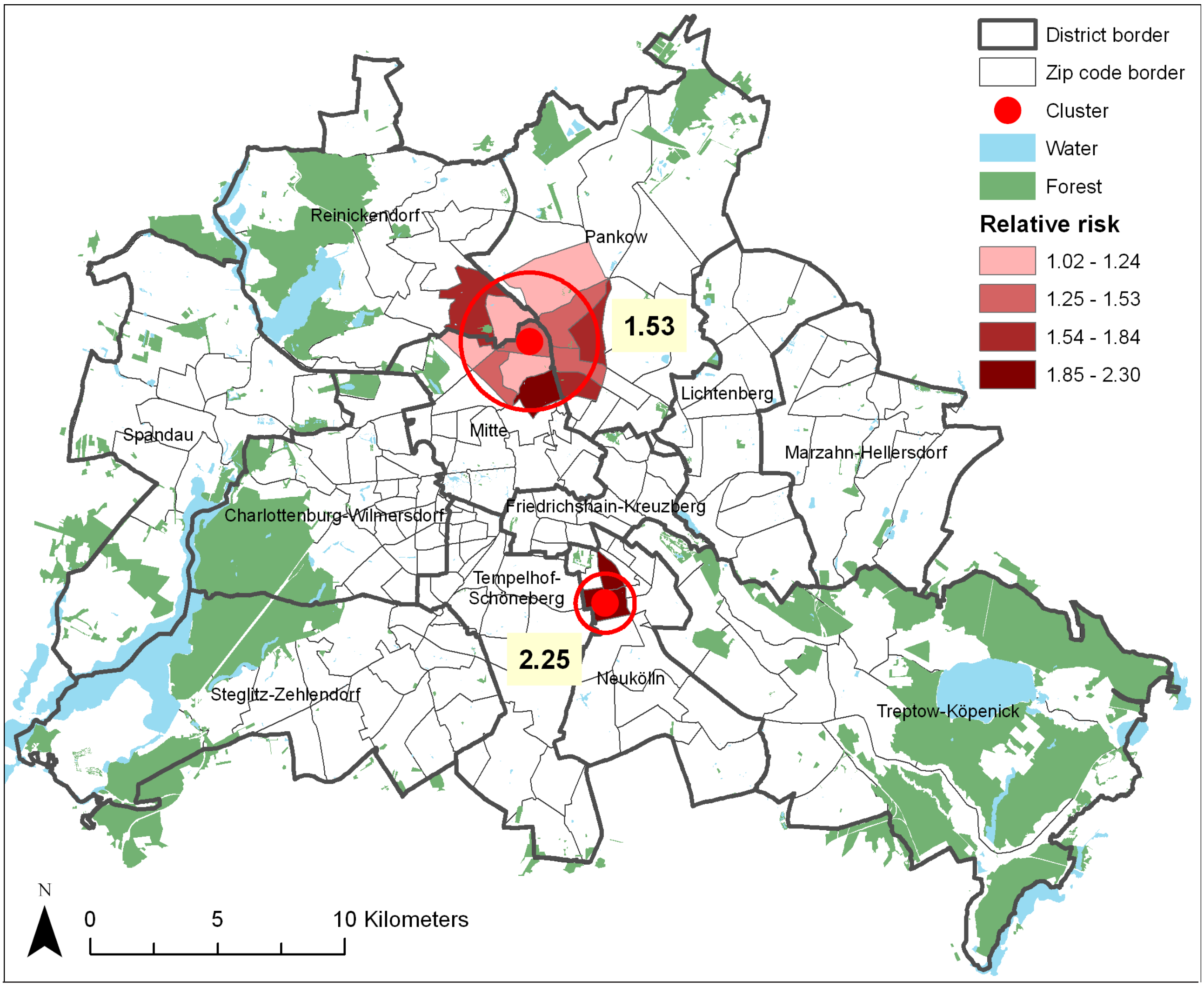

Fig. 9 Relative risk of zip code areas in quartiles within significant clusters of increased risk for hospital admissions of > 64-year-olds with respiratory diseases during July and August 2003 in Berlin. Additionally, relative risks of clusters are displayed. Data basis: Research Data Centre of the Federal Statistical Office [hospital diagnosis statistics], Statistical Office Berlin

The highest relative risks for hospital admissions among > 64-year-olds with RD within significant clusters without a covariate adjustment for SI1 were mostly detected in the city centre. Thus, the relative risks correlated slightly positively with population density (r = 0.25), heat load (r = 0.22) and SI1 (r = 0.39; see *Tab. 3*). The highest correlation coefficient was calculated for the relative risk for hospital admissions among > 64-year-olds with RD and SI1. The relationship between socio-economic conditions and health risks indicated a covariate adjustment for social status to isolate the impacts of heat load. After covariate adjustment for SI1, the correlation between relative risks for hospital admissions among > 64-year-olds with RD and heat load did not reach statistical significance (see *Tab. 3*).

4. Discussion

4.1 Limitations

The bioclimatic evaluation of patients' residences in Berlin was based on the spatial distribution of the annual mean number of days with heat load for the periods 1971-2000 and 2021-2050. The actual distribution of heat load for the study period was not available. The results of the analysis are discussed on the assumption that the spatial distribution of heat load based on the period 1971-2000 and the average of the periods 1971-2000 and 2021-2050 are representative of the study period 2000-2009 and based on a purely spatial study approach. An actual distribution of heat load within the study period in high spatial and temporal resolution would also enable a temporal study approach.

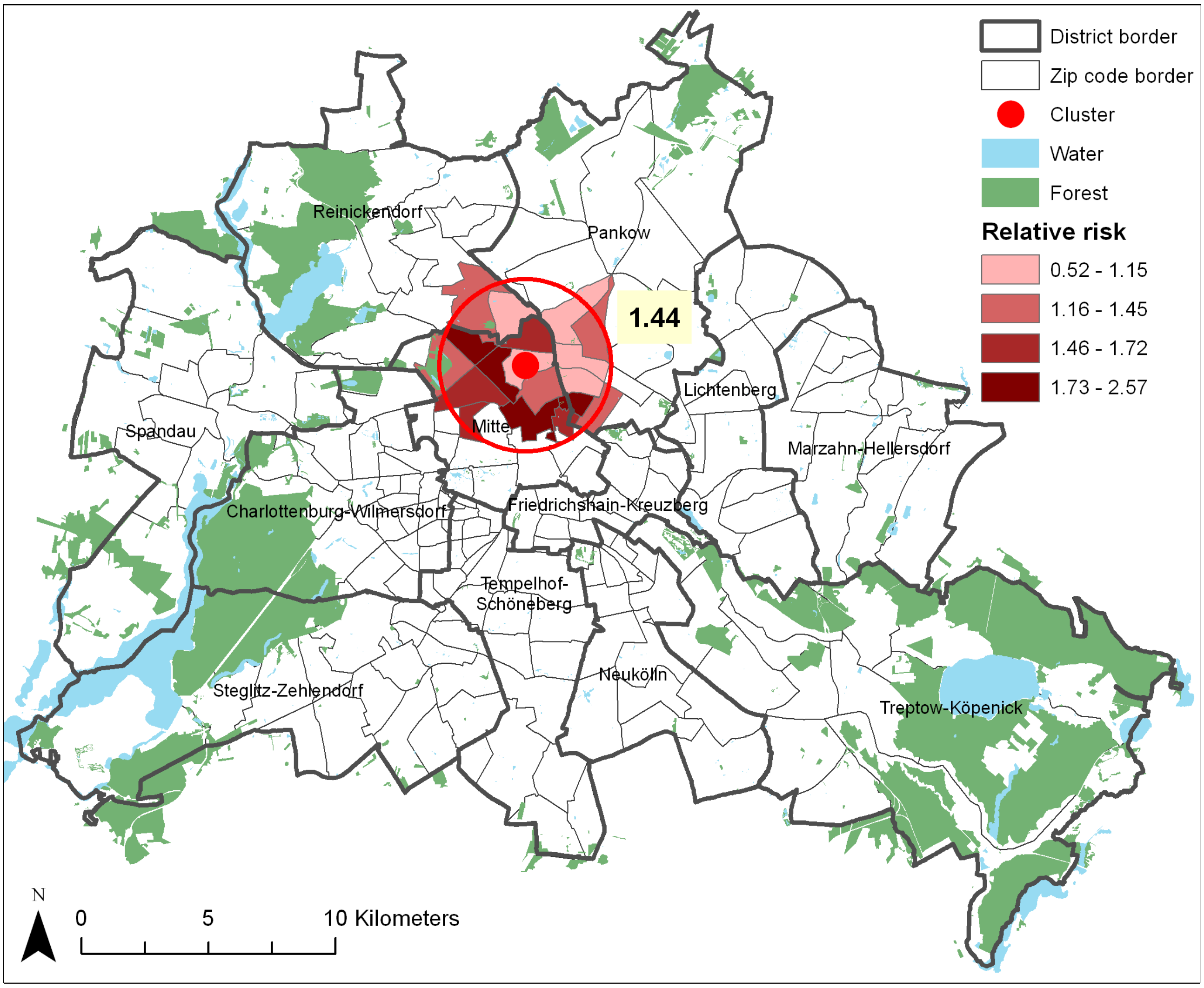

Fig. 10 Relative risk of zip code areas in quartiles within significant clusters of increased risk for hospital admissions of > 64-year-olds with respiratory diseases during July and August 2006 in Berlin. Additionally, relative risks of clusters are displayed. Data basis: Research Data Centre of the Federal Statistical Office [hospital diagnosis statistics], Statistical Office Berlin

The Social Structure Atlas Berlin, which provides socio-economic data, has been published since 1990. Because of different spatial units, varying indicators and new index calculations, a time series approach concerning social index 1 (SI1) was not portable. The analysis was based on the assumption that SI1 sufficiently represented the rating of socio-economic conditions in spatial resolution for the research period 2000-2009 in Berlin, although social indexes changed from 2003 to 2008 at the district and urban planning area levels (SenGUV 2009). A temporal adjustment concerning SI1 is recommended for further analyses.

In terms of methodology in spatial epidemiological modelling, the positive correlation between heat load and SI1 at the zip code level in Berlin needs to be considered. The interpretation of heat effects on respiratory diseases (RD) is aggravated by the significant correlation between SI1 and heat load in Berlin. The parameters of both heat load and socio-economic status determine impacts on health. After covariate adjustment for SI1, heat load effects did not reach statistical significance either by reason of multicollinearity between heat load and SI1 or due to the number of cases. Multicollinearity needs to be regarded in further spatial epidemiological analyses.

4.2 Study results in scientific context

The relative risks for hospital admissions among > 64-year-olds with respiratory diseases (RD) during the summer months in Berlin based on the number of cases from 2000 to 2009 indicated significant clusters of increased risk in the city centre. The significant clusters of increased risks for hospital admissions among > 64-year-olds with RD during the hot summers of 2003 and 2006 (July and August) pointed directly to the north-western and south-eastern areas of Berlin's city centre. These quarters are characterised by high population densities, densely built-up areas with a high annual mean number of days with heat loads and adverse socio-economic conditions. The relative risks for hospital admissions among > 64-year-olds with RD based on the number of cases from 2000 to 2009 correlated significantly with the annual mean number of days with heat loads based on the period 1971-2000 and the average of the periods 1971-2000 and 2021-2050 at the zip code level in Berlin. The relative risks increased with the number of days with heat load.

These findings correspond to the European study of high temperatures and hospitalisations in the PHEWE project ('Assessment and prevention of acute health effects of weather conditions in Europe') in 12 European cities. High temperatures have a specific impact on respiratory admissions, particularly with regard to the elderly, in whom the underlying mechanisms are poorly understood (*Michelozzi* et al, 2009). Exacerbations of COPD are one of the most common reasons for hospital admissions in RD categories among the elderly (*Viegi* et al. 2007). These acute episodes are associated with airways and systematic inflammation as well as with cardiovascular comorbidity and may be triggered by heat exposures (*Michelozzi* et al. 2009).

This analysis demonstrated that risks for hospital admissions among > 64-year-olds with RD show spatial variations across Berlin during the summer months. A study in California (USA) including emergency department visits exhibited statistically significant variations across different regions. Elevated risk rates were observed statewide for > 64-year-olds with RD during heat wave periods. The highest risks for emergency visits for heat-related illnesses, however, were registered in the Californian central coast region, where there are typically moderate summer temperatures. Residents of this region are less acclimatised, have less access to climate-controlled environments, or may not consider themselves vulnerable to heat waves. Therefore, they may not take measures to prevent heat stress (*Knowlton* et al. 2009). A study in Phoenix, Arizona, in the United States, showed the strongest correlation to heat-related emergency calls from 2002 to 2006 at the 24-h maximum air temperature or the 24-h average heat index (*Silva* et al. 2010). Furthermore, an analysis of vulnerability factors for heat-related morbidity and mortality noted that higher vulnerability was seen within downtown areas of US cities compared with suburban areas (*Reid* et al. 2009).

According to the Berlin public health report for 2010/2011, age-standardised morbidity rates are spatially distributed differently. Clusters with high rates for COPD are essentially found in the (districts in brackets) Kreuzberg (Friedrichshain-Kreuzberg), Neukölln (Neukölln), Wedding and Gesundbrunnen (Mitte) quarters and parts of the Spandau district. Morbidity index 1 in the Berlin public health report, which also includes acute and chronic RD, shows high values in the Moabit and Wedding (Mitte) and Kreuzberg (Friedrichshain-Kreuzberg) central quarters and in the centrally located quarters of the Spandau, Reinickendorf, Neukölln and Tempelhof-Schöneberg districts (SenGUV 2011). Apart from slight differences, these findings basically correspond to the results of the spatial analysis for hospital admissions among > 64-year-olds with RD. The significant clusters of elevated relative risks for hospital admissions among > 64-year-olds with RD within the Mitte and Neukölln districts were congruent on all resulting maps and are consistent with the descriptions in the public health report. The report relates elevated morbidity rates to socio-economic conditions in Berlin. Social index 1 (SI1) correlates with indicators for unemployment, need for financial help and various indicators of health care. Adverse social and health conditions are characterised by strong interactions. Rates of acute and chronic diseases, including COPD, increase with decreasing socio-economic conditions (SenGUV 2011). These findings are in accordance with the results of the correlation analysis. The Berlin public health report does not consider bioclimatic aspects. The findings of the spatial analysis complement the disease mapping with an exposure mapping and correlation analyses concerning heat load and relative risk for hospital admissions among > 64-year-olds with RD.

An investigation into neighbourhood microclimates and vulnerability to heat stress in Phoenix showed that lower socio-economic groups were more likely to live in warmer neighbourhoods with greater exposure to heat stress due to having fewer social and material resources to cope with extreme heat (*Harlan* et al. 2006). Therefore, it is necessary to consider socio-economic conditions in spatial epidemiological approaches to environmental impacts on health.

A socio-spatial distribution of environmental burdens can be observed in Berlin. Central areas in particular exhibit considerably enhanced multiple environmental burdens next to coexistent low development indexes, whereas border areas tend towards the opposite (*Lakes* and *Klimeczek* 2011). An analysis of the socio-spatial distribution of bioclimatic conditions in Berlin valued the urban bioclimate on the basis of the predicted mean vote (PMV). In particular, planning areas with low development indexes are concerned by negative bioclimatic conditions (*Kleinschmit* et al. 2011a). Significantly positive correlation coefficients between zip code areas with a high number of days with heat load and low socio-economic conditions comply with findings from the socio-spatial analysis of bioclimatic conditions in Berlin. Urban green and water spaces have a crucial impact on bioclimatic conditions. The impacts of green and water spaces on the urban bioclimate have been considered in the evaluation of heat stress with UBIKLIM. The socio-spatial distribution of green spaces in Berlin indicates an unbalanced arrangement. Planning areas with low development indexes are marked by poor access to open green spaces (*Kleinschmit* et al. 2011b). Concerning a health-related evaluation of the urban environment, green and water spaces should be respected in further analyses.

4.3 Outlook

The analysis showed that not only elderly people within the city centre are at a higher risk. Taking socio-economic spatial structures into account, the border areas of Berlin exhibited increased health risks for the elderly as well. Specifically, quarters with moderate socio-economic status but elevated population and building density pointed to adverse health effects. However, the significant correlation between population density, morbidity risk, heat load and socio-economic status aggravated a confident allocation of heat effects within Berlin. Further analyses should comprise building structures and features, e.g., cooling and insulation, to derive parameters for living conditions. The elderly and chronically ill are often immobile and spend most of their time at home. Indoor conditions such as air temperature, air movement, humidity and the radiation temperature of indoor surfaces affect indoor thermal comfort (*Koppe* et al. 2004).

Future challenges concerning vulnerability to heat are determined by climate change, demographic change, social disparities and an increase in chronic diseases. Because of climate change, heat waves will very likely increase in intensity and frequency in Europe (*Alcamo* et al. 2007; *Rahmstorf* and *Coumou* 2011; *Schär* and *Fischer* 2008). Mean daily temperatures in Berlin have increased, on the average, by 1 °C since the beginning of the last century, and they will further increase by 1 °C until the middle of the 21st century. The number of 'summer days', 'hot days' and warm days with high humidity will rise considerably (*Linke* and *Grimmert* 2010). Projections of an urban bioclimate model (UBIKLIM) demonstrate a slight but significant increase until the middle of the 21st century and a distinct increase in heat load until the end of the 21st century in Berlin. The highest rise will be expected in Berlin's inner city (*Behrens* and *Grätz* 2010). Demographic changes have caused an increase in the elderly population. Berlin's elderly population (> 64 years) increased by 33 % from 1991 to 2009, and one-third of all single-person households were 60 years old or older in 2009 (*Kuchta* and *Nauenburg* 2011). At present, per capita health care costs for the age group > 65 years are twice as high and those for the age group > 85 years are almost five times as high as the average (*Nöthen* 2011). Growing social disparities, rising chronic diseases and an aging population intensify issues in public health care (WHO 2004). Heat impacts on health harm on a personal level burden public health care and cause impacts on economies. Vulnerability to heat and health risks are expected to increase in the future (*Confalonieri* et al. 2007; *Koppe* et al. 2004).

The urban population is especially exposed to increased air pollutants (*D'Amato* et al. 2010), such as ozone and pollen, caused by traffic emissions, prolonged vegetation periods and established neophytes in urban areas. Ozone and pollen concentrations trigger the respiratory tract and may exacerbate existing respiratory symptoms (*Bell* et al. 2004; *Brunekreef* et al. 2000; *Darrow* et al. 2012). Exacerbations of chronic obstructive pulmonary diseases (COPD) are the most common reason for hospital admissions in respiratory disease categories among the elderly (*Viegi* et al. 2007). Further analyses should also consider aspects of air quality and pollen concentrations concerning environmental impacts on respiratory diseases in urban areas.

Finally, high building density and a lack of urban green and water spaces determine the adverse bioclimatic evaluation of urban environments. The resulting heat stress causes impacts on health, especially on respiratory illness. According to the Berlin Environment Senate Department, a climate-change induced increase in health-related heat stress is very likely. Therefore, there is an urgent need for action in terms of short- and long-term adaptation in urban areas (*Endlicher* et al. 2008; *Endlicher* and *Kress* 2008).

5. Conclusions

Spatial differences in the relative risks for hospital admissions among > 64-year-olds with respiratory diseases (RD) can be related to spatially varying population structures and socio-economic and bioclimatic conditions in Berlin. Findings from the spatial analysis show significant intra-urban disparities in the relative risks for hospital admissions among > 64-year-olds with RD. The relative risks for hospital admissions among > 64-year-olds with RD during the summer months in Berlin based on the number of cases from 2000 to 2009 indicated significant clusters of increased risk in the north-western and south-eastern city centre. These areas are characterised by high population densities, densely built-up areas with a high annual mean number of days with heat load based on the period 1971-2000 and the average of the periods 1971-2000 and 2021-2050 and adverse socio-economic conditions.

Most of the elderly population lives in the border areas of the city, which feature lower heat loads. However, disease mapping for hospital admissions among > 64-year-olds with RD during the summer months from 2000 to 2009 and the hot summers of 2003 and 2006 shows significant clusters of highest risks in essentially the city centre (the Mitte and Neukölln districts). Correlation analyses indicate a slightly positive significant relationship between heat load and relative risk for hospital admissions among > 64-year-olds with RD at the zip code level without controlling for socio-economic conditions. Relative risks for hospital admissions among > 64-year-olds with RD increase significantly with increasing heat load at the zip code level in Berlin. Because of the significantly positive correlation between social index 1 (SI1) and the annual mean number of days with heat loads in Berlin, the interpretation of the findings is not definite. Further considerations of multicollinearity in the analysis are necessary.

To develop adaptation strategies for adequate health care and prevention concerning heat stress, knowledge about the spatial distribution of morbidity risks within Berlin is imperative. Vulnerable city quarters have to be identified to arrange and implement specific health care and prevention strategies. Urban areas with a high number of elderly people, as well as urban areas with lower elderly populations but elevated heat loads and adverse socio-economic conditions, should be noticed. Identifying areas with increased respiratory morbidity risks helps to apply the directed practice of telemedicine to improve health care for patients with chronic obstructive pulmonary disease (COPD) and to specifically implement health care intervention and prevention strategies into urban planning.

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Notes

[1] The ICD-10 is a medical classification list by the World Health Organization (WHO) using codes classified into chapters and blocks. The 10th revision of the International Statistical Classification of Diseases and Related Health Problems (ICD) was released in 2000.

[2] Berlin is structured into 12 districts as administrative units, and – at a lower level – 96 quarters. The quarters are used as statistical units and official locations. The quarters can comprise different zip code areas such that borders of zip code areas and quarters can differ.

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