



Heat vulnerability and adaptive capacities: findings of a household survey in Ludwigsburg, BW, Germany

Kevin Laranjeira¹ · Franziska Götttsche¹ · Joern Birkmann¹ · Matthias Garschagen²

Received: 1 December 2020 / Accepted: 19 April 2021 / Published online: 10 May 2021
© The Author(s) 2021

Abstract

In 2019, record-setting temperatures in Europe adversely affected human health and wellbeing (WMO 2020) and cities—thus, people in urban areas suffered particularly under heat stress. However, not only heat stress but also the differential vulnerability of people exposed is key when defining adaptation priorities. Up to now, local data on vulnerability and particularly adaptive capacities is rather rare. Various aspects of human vulnerability to heat and capacities to adapt to heat stress in urban areas still have to be explored and assessed, for example in terms of the adaptation at home, during work or while commuting to work. The paper presents new findings of a household survey on how and where different groups experience heat stress and how they assess their susceptibility and capacities to cope and adapt. The findings are based on a survey conducted in the medium-sized city of Ludwigsburg, Germany. Findings show significant linkages and correlations between socio-economic factors and heat vulnerability and capacities to respond. The analysis gives special emphasis to relationships between willingness to implement adaptive measures to reduce heat stress risks and risk perception and adaptive capacities. Particularly, the analysis of future adaptation options and the ability and willingness of different households to implement these provides new insights on the differential capacities to adapt and the need for tailor-made transformation programs.

Keywords Adaptive capacities · Heat stress · Household survey · Exposure · Vulnerability

This article is part of a topical collection on *Risk & amp; Vulnerability to Extreme Events: Dynamics and Future Scenarios*, edited by Joern Birkmann and Matthias Garschagen

✉ Kevin Laranjeira
kevin.laranjeira@ireus.uni-stuttgart.de

¹ Institute of Spatial and Regional Planning, University of Stuttgart, 70569 Stuttgart, Germany

² Department of Geography, Ludwig-Maximilians-University Munich (LMU), 80333 Munich, Germany

1 Introduction

The WMO¹ report on the state of the global climate in 2019 identifies the past 5 years as the warmest on record. In 2019, record-setting temperatures in Europe and all around the world adversely affected human health and wellbeing, illustrated by an increased mortality during heat waves in several countries (WMO 2020). Regarding the scientific evidence available, it is likely that extreme heat events will increase in the future (IPCC 2019; IPCC 2014). A study by Forzieri et al. (2017) based on data analysis to forecast future risks from weather-related extreme events assumes that by the year 2100, two thirds of the European population could be affected by annually occurring weather-related extremes (Forzieri et al. 2017). Urban areas are particularly affected by heat events due to the high degree of sealing, building structure, relatively low proportion of green spaces, and an altered water balance (Chmielewski et al. 2005). However, the extent to which such extreme heat events pose a risk for different areas and population groups depends not only on their intensity and frequency of occurrence, but is also largely determined by the susceptibility as well as the adaptability and coping capacity of the society and individuals living there (Birkmann et al. 2020; Birkmann et al. 2018; Birkmann 2008). The degree of susceptibility to heat as well as the lack of adaptive capacities and the lack of coping capacities are considered particularly relevant when assessing vulnerability to heat stress (Welle and Birkmann 2015). According to Wolf and McGregor, local spatial information on heat vulnerability, below regional or city level, is particularly valuable for decision makers (Wolf and McGregor 2013). Hamstead et al. note that vulnerability assessment at a fine spatial scale enables to more precisely identify vulnerable residential populations at risk of extreme heat-related impacts (Hamstead et al. 2018). Wilhelmi and Hayden state that the analysis of specific conditions at the local level could add a great value for decision-making processes in urban planning when dealing with heat vulnerability and adaptation capacities (Wilhelmi and Hayden 2010). The analysis of socio-demographic, socio-economic, and environmental factors that influence and determine heat vulnerability at district and neighbourhood level was a central research task within the project “Future-oriented vulnerability and risk assessment as an instrument for promoting resilience of cities and urban infrastructures” that is the basis of this paper (ZURES 2020). Besides the analysis of urban climatic conditions, this project investigated vulnerability characteristics, including aspects of coping and adaptation to heat stress in two medium-sized cities in Germany, namely the city of Bonn and the city of Ludwigsburg. Next to the analysis of officially available statistical and spatial data, two household surveys were conducted to gain more insight into how different population groups assess their capacities and different potential measures to cope and adapt to heat stress in the future. Thus, the survey provides new insights in terms of data and facts, as well as new methodological advances on how to capture these aspects. In conjunction with available statistical and spatial data, this information can be used to identify proxy indicators for potential individual adaptive behaviour at a later stage.

The analysis at household level within the ZURES project aimed to explore and validate indicators for vulnerability and adaptation to climate change and heat stress in particular. Secondly, the survey examined correlations between specific socio-economic characteristics and individual adaptive behaviour and capacities. Identifying such correlations is an important first step to better understand adaptive capacities and their determinants. Quantitative field research in form of household surveys is considered particularly helpful for generating

¹ World Meteorological Organization

information for a comprehensive analysis of existing adaptive capacities (see e.g. Wilhelmi and Hayden 2010; Hamstead et al. 2018). Such an analysis examines socially induced vulnerability and adaptive capacities in connection with socio-economic and socio-demographic differences (Hayden et al. 2017). In this context, Wilhelmi and Morss emphasize that there is a large deficit of available data with regard to *local* adaptive capacities (Wilhelmi and Morss 2013). Against this background, the paper can provide new insights and findings about the linkages between adaptive capacities and risk perception, health conditions, and access to green spaces and individual housing situations. In this regard, particular emphasis is given to the following questions:

1. How can survey-based analysis on household level help to better understand individual vulnerability and adaptive capacities to heat stress?
2. Which health problems do households experience during heat stress events?
3. Where are hotspots of perceived heat stress in cities?
4. What relationships do exist between the willingness and capacity to adapt?
5. Which factors influence the willingness to adapt and capacities to adapt?
6. What factors constrain adaptive behaviour?

2 Conceptual-theoretical background

2.1 Vulnerability

The term vulnerability describes—in a general context—the susceptibility of individuals or social systems to natural hazards. However, this general definition has been enhanced in the scientific discourse with additional characteristics that describe vulnerability more precisely. The United Nations Office for Disaster Risk Reduction (UNDRR) defines vulnerability as “the conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards.” (UNISDR 2020: n.p). The IPCC² special report on the impacts of global warming of 1.5 °C defines vulnerability as “the propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or susceptibility to harm and lack of capacity to cope and adapt.” (IPCC 2019: 560). An important difference between the two definitions lies in the question of the role of abilities to cope with and adapt to adverse effects of natural hazards. In this regard, Wisner et al. underscore that the ability to anticipate, adapt, and cope with impacts of extreme events and natural hazards is also a component of vulnerability (cf. Wisner et al. 2004: 11). The concept within the WorldRiskReport operationalizes vulnerability by means of three dimensions: susceptibility, described as the probability of suffering damage from a hazardous event, the lack of coping capacities, and the lack of adaptive capacities (Bündnis Entwicklung Hilft 2015; Welle and Birkmann 2015). With reference to the theoretical considerations in literature, susceptibility of individuals and social systems as well as their ability to cope and adapt are perceived as key components of vulnerability. Following this understanding of vulnerability, the paper explores the relationships between socio-demographic vulnerability indicators and heat-susceptibility and different determinants of household-related adaptive capacities.

² Intergovernmental Panel on Climate Change (IPCC)

2.2 Adaptation and adaptive capacity

Adaptation to climate change refers to the process of the adjustment of natural and social systems to actual or expected climate changes and their consequences in order to reduce negative impacts and exploit potential benefits (IPCC 2007; IPCC 2012; IPCC 2014; IPCC 2019). In this context, specific adaptation measures are to be understood as the manifestation of adaptive capacities (Smit and Wandel 2006). Adaptive capacities are the entire potential of individuals or social systems, such as municipalities, to adapt to climate change, its associated events, and resulting consequences (IPCC 2019; Birkmann et al. 2013). The term adaptive capacity often refers to long-term strategies and approaches that can also take resources into account which are not yet available (Vogel and O'Brien 2004; Birkmann et al. 2013). In contrast to coping capacities, which rather refer to direct short-term measures during, before or after an extreme event, aiming at a rapid restoration of an original state, adaptive capacities are rather strategic measures that also include the anticipation of potential future risks (Vogel and O'Brien 2004; Birkmann 2008; Birkmann et al. 2013). Willingness to adapt has not yet been a fixed term in the terminology of vulnerability and risk research. While the specific term or concepts regarding the willingness to change individual behaviour in the context of climate change are considered in some studies within the research field of environmental psychology (see e.g. Hayles and Dean 2015; Whitmarsch 2009; Nilsson et al. 2004), there is no extensive research on it in the context of vulnerability and risk research. Willingness to adapt might also be associated with Grothmann and Patt's concept of Adaptation Intention within their Model of Private Proactive Adaptation to Climate Change (MPPACC) (see in detail Grothmann and Patt 2003). Differing to the concept of *Adaptation Intention* within the MPPACC, we define willingness to adapt as a constitutive component of adaptive capacity—as a cognitive state, which sets the basis for the development of long-term adaptation strategies and thus enables the existence of adaptive capacity itself, which in turn, in its manifestation, represents the actual act of adaptation in form of strategic adaptation measures. In this regard, the new data from the household survey provides new insights and more evidence about the linkages between general socio-economic vulnerability, adaptive capacities and the willingness to adapt in the context of heat stress in urban areas. In the following, we introduce the survey method prior to presenting key findings of the household survey.

3 Survey methodology

3.1 The area of inquiry

The household survey was conducted within the ministerial-funded project ZURES (Future-oriented vulnerability and risk assessment as an instrument for promoting resilience of cities and urban infrastructures) in the city of Ludwigsburg in Baden-Wuerttemberg, Germany. With 93,482 (as of 2018)³ inhabitants, the city of Ludwigsburg is classified as a medium-sized city in the state of Baden-Wuerttemberg, which functions as an important service centre for the surrounding municipalities. The survey was conducted in the city centre and the District East within Ludwigsburg. The selection of districts was based on the results of a climatic analysis

³ All statistics of the city of Ludwigsburg and its districts listed here are taken from the official data of the city of Ludwigsburg (see City of Ludwigsburg 2020)

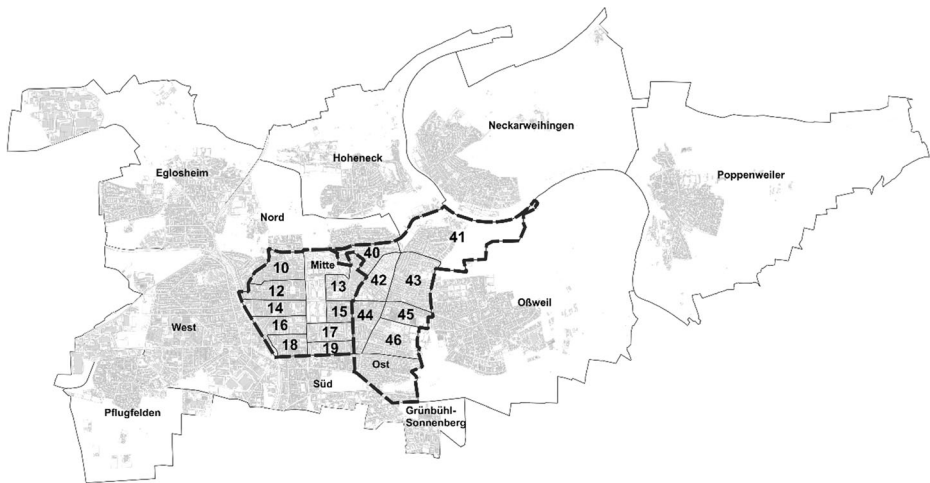


Fig. 1 Area of inquiry

for the entire urban area,⁴ as well as on socio-ecological vulnerability issues.⁵ Both areas are characterized by a high bioclimatic load on hot days (see in detail Birkmann et al. 2018; GEO-NET 2018), a high degree of sealed surfaces, and a relatively high population density (>93.00 inhabitants/ha), compared to population density of the surrounding districts and especially the outskirts of the city (with a maximum of 22.62 inhabitants/ha). Additional both districts show comparable distributions of subpopulations, which are considered more vulnerable towards extreme heat, like people over 65 years of age or poor populations, measured by the proportion of households receiving social assistance (see in detail City of Ludwigsburg 2020). The objective was to find areas with high exposure to heat and a comparable population density and structure. Thus, comparing the inner city with the periphery would have been less appropriate. On the one hand, this should prevent the survey results from being biased by significant differences of the districts, regarding heat exposure or substantial differences of the district-specific population structure. On the other hand, the general research interest was focused on the analysis of highly exposed areas and differential vulnerabilities and adaptive capacities at the household level. With 15,612 inhabitants, Ludwigsburg-East is the most populous district of Ludwigsburg. Ludwigsburg-Central is characterized by high influx rates from outside the city and currently has 11,601 inhabitants. Figure 1 shows the area of inquiry and its location within the city of Ludwigsburg.

3.2 Sampling

The household survey was conducted in Ludwigsburg from end of July until end of August 2018 and was completed in August 2018. The survey was deliberately conducted in midsummer in order to be able to assess perceived heat stress as realistically as possible. An influence on the response behaviour due to the chosen survey period and the associated climatic conditions, e.g.

⁴ Conducted by GEO-NET Umweltconsulting GMBH (see GEO-NET 2018).

⁵ The socio-ecological vulnerability characteristics used here include the proportion of the population over 65 years of age and under 6 years of age, as well as the proportion of poor population. A literature analysis carried out within the ZURES project shows that these indicators can be used for the operationalization of heat vulnerability (see Sandholz et al. 2018).

with regard to questions on willingness to adapt, cannot be excluded. However, such an influence was accepted in order to facilitate answering the survey and to get more reliable results, for example in terms of health issues during heat events. It is assumed that a survey addressing the topic of perceived heat stress in summer, if carried out during winter months, would have led to less reliable results. Furthermore, occurring biases, such as the measurement of an excessive willingness to adapt to heat, if this is the case at all, would only show a positive correlation between experiences with heat events and willingness to adapt. This, in turn, would lead to the thesis that empirically generated knowledge of potential risks, gained through experience, could increase the willingness of individuals to adapt. Consequently, the choice of the survey period is not seen as an essential disadvantage with regard to the quality of the data collected.

The household survey conducted encompassed a paper questionnaire that was sent to randomly selected households within the two districts. The questionnaire could be answered both in writing and online. A total of 666 households took part in the survey and the overall response rate was 22%. The questionnaire consisted of 101 questions divided into 19 subsections. Only closed-ended questions were used. Participants of the survey could answer using either four-point rating scales or nominal scales with a differing number of choices (two choices at minimum 15 at maximum). Socioeconomic data like income level or age where surveyed in aggregated groups using fixed answer categories (e.g. 64–74 years of age; over 74 years etc.). In addition to socio-demographic information, six main topics were surveyed. Figure 2 illustrates the seven topics surveyed and provides information about the number of

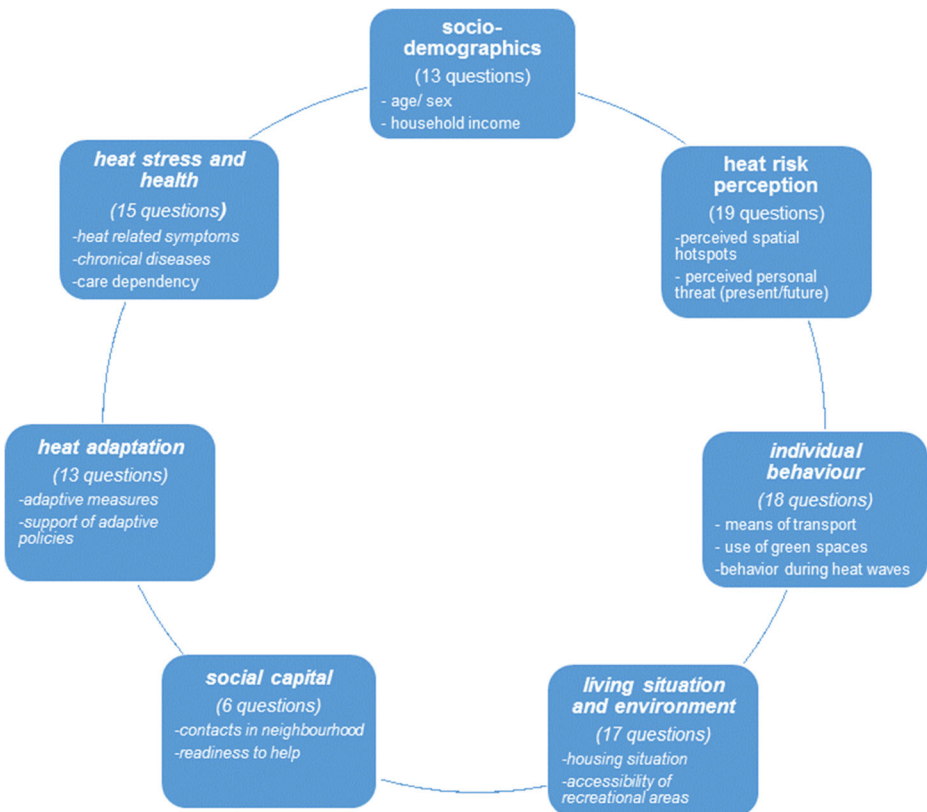


Fig. 2 Main topics of household survey

corresponding questions for each topic (see Fig. 2). The questionnaire was pre-tested and then partially revised. The evaluation was carried out by machine (scan).

3.3 Data analysis

The analysis of the data was carried out using SPSS. Besides the analysis of specific distributions within the surveyed sample, cross tables were used to identify starting points for explorative analysis of correlations between specific socioeconomic factors and data or factors that were considered to potentially provide information about individual adaptive behaviour, adaptive capacities, and vulnerability. Specific relationships were investigated based on assumptions derived from literature review. Tested correlations aimed either at confirming the relevance of commonly used vulnerability indicators or at gaining new insights in terms of adaptive capacities on household level and their determinants.

4 Results of the household survey and discussion

4.1 Socio-demographic structures

The majority of respondents (56%) are female, 43.7% are male, and 0.3% stated “other/divers”. The age of respondents was surveyed in four age groups. The age group from 18 to 34 years accounts for 26.2% of respondents. The majority of respondents are persons between 35 and 64 years of age (48.9% of respondents). Eleven percent of the respondents are between 65 and 74 years old and 13.8% are older than 74 years (see Fig. 3). Overall, households with at least one person having a university degree are clearly overrepresented with 55.6%. Asked about the highest educational level of a person living in household, 9.8% stated an apprenticeship, 12.2% an A-level or general qualification for university entrance, 11.8% a secondary school leaving certificate (Realschule), and 3.6% a lower secondary school leaving certificate (Hauptschule). Not having an educational background was reported by 0.6% of the respondents. Regarding the monthly disposable household income, 21.1% of households belong to the lowest income bracket up to €2000 per month. More detailed, 2.9% of the respondents within the lowest income bracket up to €2000 have a household income of less than €900 and therefore can be considered as relatively poor. 25.4% of the households surveyed have a monthly net income of €2000 to less than €3200 at their disposal. A total of 22.1% of households have a monthly income between €3200 and €4500. 19.5% of the households have a monthly income of €4500 to €6000. 11.9% of the households have more than €6000 at their disposal (see Fig. 3). Thus, 31.4% of households belong to the two highest income groups recorded, with a monthly disposable income of at least €4500. One fourth of all households surveyed are single-person households (25.8%). However, the vast majority of the households surveyed are two-person households (41.7%). In 26.6% of the surveyed households, three or four persons belong to a household. Only 5% of the households reported more than four persons living together. The duration of living in Ludwigsburg might also influence the risk perception within the city. In this regard, the overwhelming majority of the interviewees (61.1%) have been living in Ludwigsburg for more than 10 years. 11.7% of the interviewees stated to live there for 6 to 10 years and 22.3% have been living in Ludwigsburg for 1 to 5 years. Only 5% stated that they have been living in Ludwigsburg for less than 1 year.

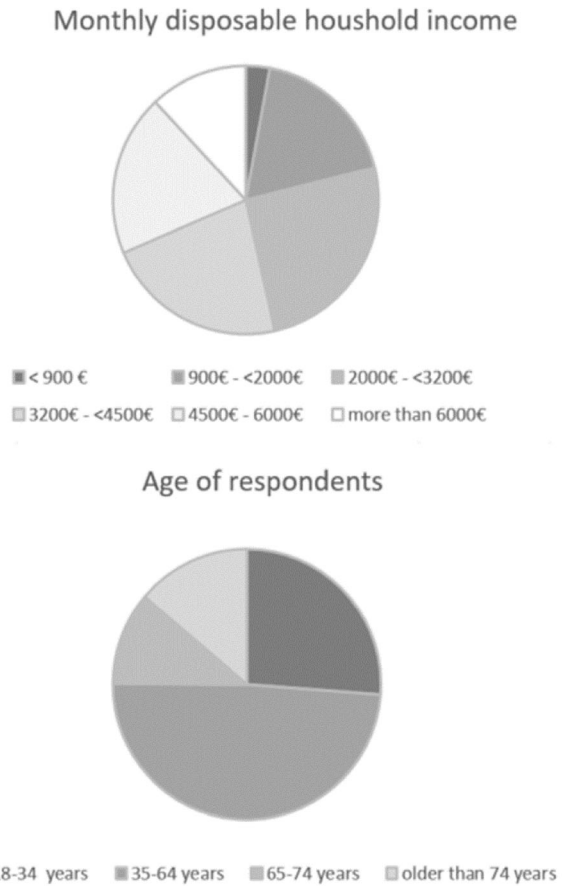


Fig. 3 Socio-demographic structures

4.2 Risk perception

Individual risk perception to climate change and heat stress also influences adaptation decisions and the willingness to adapt. Whether adaptation to experienced or future events takes place depends on the extent to which a personal risk is perceived at present or in terms of future climate change (Adger et al. 2008; Grothmann and Patt 2003). Thus, the identification of environment-related hazards and extreme events that are classified as a direct or potential threat by individual persons or larger societal groups is a reasonable first step when analyzing individual adaptation to climatic events (see also Howe et al. 2019; Smit and Wandel 2006).

The household survey in Ludwigsburg captured attitudes towards climate change and different natural hazards. About 91% of the respondents believe that climate change exists. Around 86% of the respondents believe that climate change is a problem and 68% think that it is also noticeable in Ludwigsburg. Furthermore, 68% think that climate change affects them personally. Asked for a statement which natural hazards already pose a personal risk to the household, about 70% stated that they already see a personal risk in heat waves. Even more households perceive storms as a current risk (74%). Heavy rainfall events are also mentioned as a present risk just as frequently as heat waves. Fewer households state floods (41.3%) and

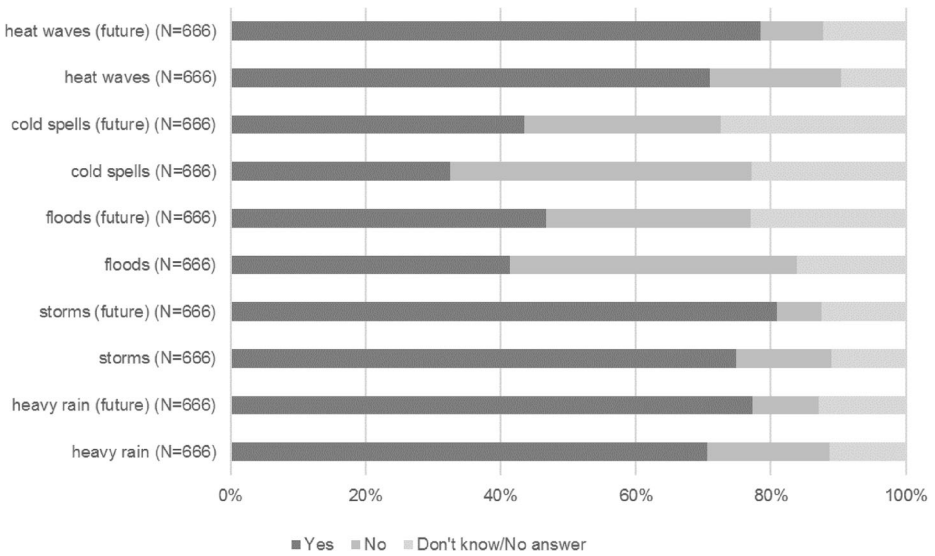


Fig. 4 Perception of natural hazards that pose a personal risk (present/future)

cold spells (32.4%) to be an already existing personal risk. In addition, a vast majority of households are convinced that storms (80.9%) and heavy rain (77.2%) will pose a personal risk also in the future (up to 2030). Cold spells (43.4%) and floods (46.7%) are mentioned less often. Heat waves were ranked to be second among the future personal risks (78%) (see Fig. 4). Interestingly, the respondents see a higher personal risk of these events (climate influenced natural hazards) in the future than at present. This leads to the conclusion that the respondents perceive future climatic changes as a source of potential personal risk. Furthermore, 87% assume that heat waves will be a growing problem in the future. The results suggest that especially experiences with intense heat in one’s own living space contribute to an increased risk perception. A highly significant and positive correlation between the perception of heat waves as a problem in one’s own apartment or house and the perception of heat waves as a personal risk was found ($V = 0.344***$).⁶ The lack of a private heat-protected retreat seems to be crucial with regard to the individual identification of heat as a problem.

4.3 Heat-health-risk-nexus

Another factor that can contribute to an increased risk perception is the identification and conscious perception of heat-related health problems (see also CDC 2012). Heat-related health problems most frequently mentioned in the household survey are lethargy/exhaustion, sleeping problems, and concentration problems. Approximately 11% of the respondents state that they often suffer from dizziness, headaches, or cardiovascular problems when exposed to intense heat. Nausea was mentioned by only 3% as a symptom frequently occurring during heat events (see Fig. 5).

The data show that specific symptoms occur with varying frequency within different age groups. According to the survey conducted in Ludwigsburg, persons under 65 years of age seem to suffer more frequently from sleeping and concentration problems than older persons. Persons over 65 years of age suffer more frequently from serious health problems such as

⁶ ***The correlation is significant at the level of 0.001

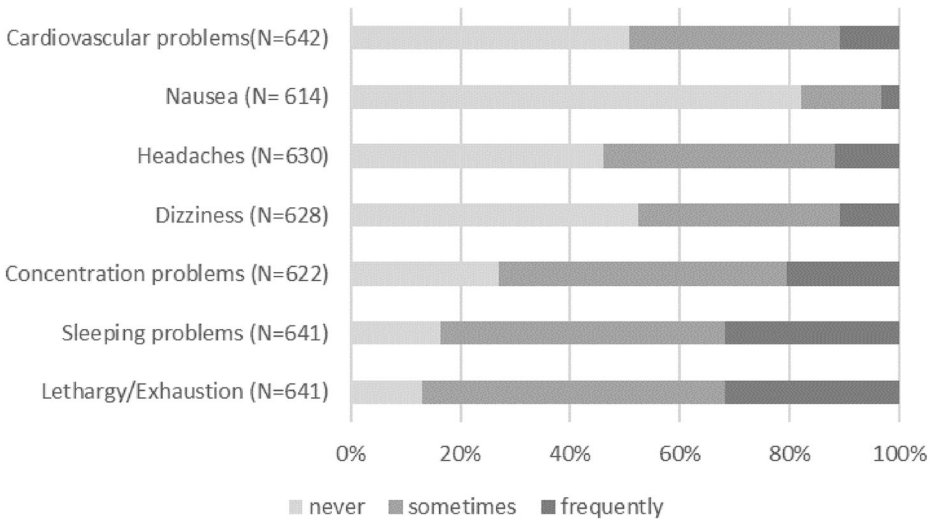


Fig. 5 Heat-related health problems

cardiovascular disorders. When asked if they already suffered from health problems associated with extreme heat and which problems they suffered from in particular, 19% of the respondents over 65 years of age indicated that they often suffer from cardiovascular problems associated with heat. Figure 6 shows the frequency distributions of cardiovascular problems as a function of age. The expected link and correlation between age and the occurrence of cardiovascular problems can also be statistically confirmed (Spearman’s $\rho = 0.234^{***}$ / Kendall’s tau-b = 0.212^{***}). These age-related differences show the relevance of the indicator “over 65 years”, which was used in the ZURES project to measure vulnerability to heat stress. Overall, the findings underscore that elderly can be considered more vulnerable to heat stress compared to other age groups.

Besides age, susceptibility to heat is also influenced by pre-existing health problems like diabetes or other chronic diseases (IPCC 2012; Balbus and Malina 2009). People suffering

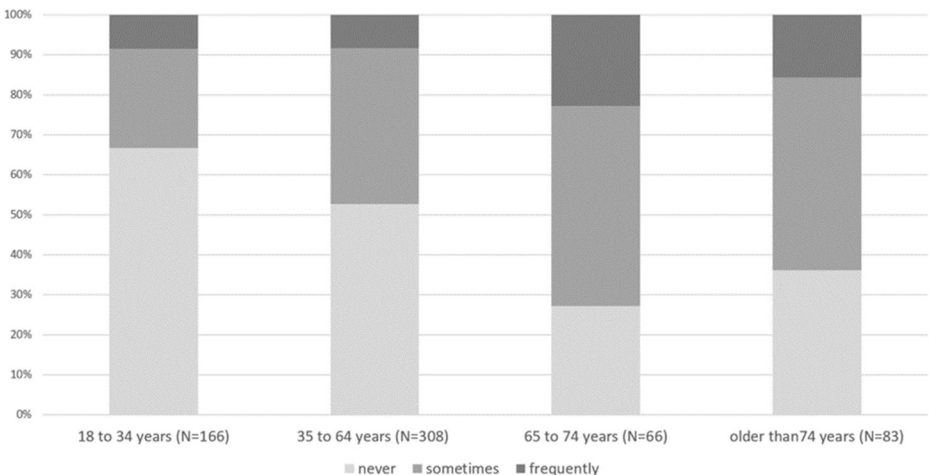


Fig. 6 Cardiovascular problems with heat as a function of age

from such pre-existing health problems are more likely to be harmed in case of extreme heat events (IPCC 2012). In this context, the household survey revealed that households in low-income groups encompass a significantly higher percentage of household members with pre-existing health problems compared to households of middle- and high-income groups. According to the data, 19% of households within the low income group up to €2000 state that at least one person living there is considered to be sick or in need of medical care. In contrast, 9% of households in middle-income groups (3200–4500€) and only 1.7% of households in high-income groups (6000€ and above) are reported to be sick persons or persons in need of medical care. Asked more specifically about existing health issues of persons in the household, 44% of concerned households with a low income (up to 2000€) mentioned that at least one person in the household suffers from a chronic disease like cardiovascular problems or diabetes. The same category accounts for only 25.3% of concerned households in middle income groups and 14.3% in high income groups (see Fig. 7). Consequently, the household survey confirms that people with pre-existing health problems, that are more likely to be adversely affected during times of heat stress, can be proportionally found more frequently in low income households compared to households in middle- and high income classes. Thus, household income has an indicative and proxy function for susceptibility in this context.

Moreover, the results of the household survey reveal that the perception of heat stress varies greatly in different locations of the city. According to the data, the vast majority of respondents perceive heat stress particularly in public transport (83%) and the city centre (76%). More than half of the respondents perceive heat stress at work as intense or very intense. The lowest level of heat stress is perceived in parks and gardens (see Fig. 8).

The results are also consistent with other studies. In a similar survey conducted within the same project in Bonn, as well as in other studies in the German cities of Magdeburg and Karlsruhe (Landeshauptstadt Magdeburg and ThINK 2017; Kunz-Plapp et al. 2016), public transport and the inner city area were identified as hotspots of perceived heat stress. Equally, these studies identified green, recreational areas as heat-relief zones. The results of the household survey in Ludwigsburg also indicate that these areas are perceived as heat-hotspots, regardless of the age of the respondents.

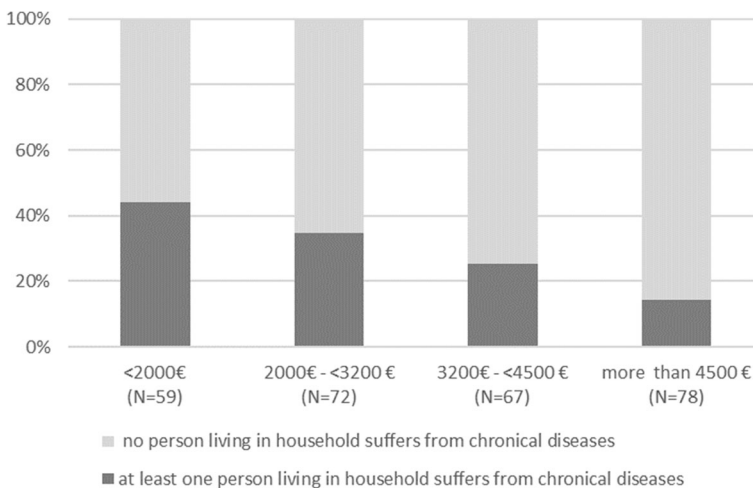


Fig. 7 Disposable household income and presence of chronic diseases

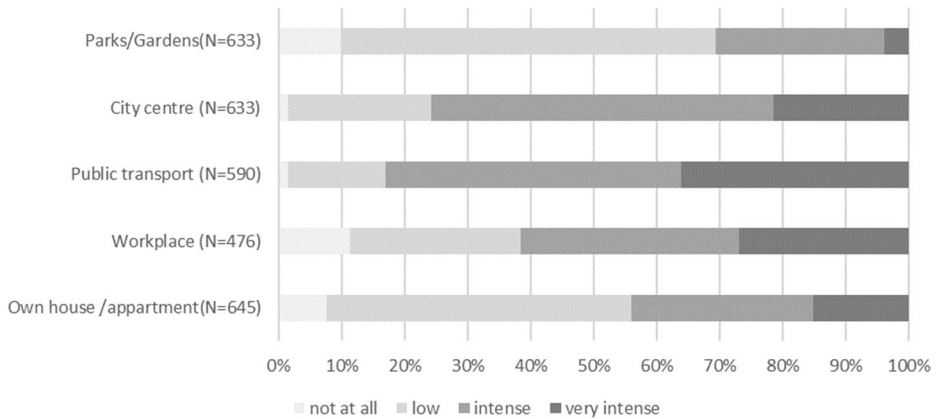


Fig. 8 Hotspots of perceived heat stress

4.4 Use of green spaces and housing situation

The results of the household survey show that parks and gardens can serve as important retreat areas during extreme heat events in medium-sized cities (see Fig. 8). Especially in case of households not having a private garden or balcony, publicly accessible green and recreational areas are an alternative for households. About 25% of the households surveyed indicated that their house or apartment does not have access to a garden, “green” balcony or patio. This applies especially to residents of apartment buildings. The data from the household survey show that 73% of the respondents live in apartment buildings. About 30% of them state that they do not have access to a private garden, a “green” balcony or patio. The extent to which public green and recreational areas are frequented seems to be related to their geographical proximity and the personal effort it takes to get there. In Ludwigsburg, about 82% of the respondents indicated that they visit green areas that are located within walking distance. Moreover, less than half of the respondents stated that they would also visit green spaces within a distance that requires the use of a bicycle, public transport, or car.

4.5 Adaptation to heat stress

With regard to adaptation strategies and adaptive capacities, the survey asked about measures the respondents have already implemented or plan to implement to protect themselves against heatwaves. In addition, the survey also explored what people would do in the future if the occurrence and intensity of heat stress stayed the same or intensified. Figure 9 shows the results regarding the willingness to implement measures to prevent heat stress. It shows that measures that are associated with only a slight or minor change in lifestyle or linked to rather low monetary expenditure have been implemented or are planned to be implemented. These measures include the creation of additional shading, for example by means of awnings or blinds, climate-adapted design of one’s own garden, balcony, or courtyard with plants or water elements and the adaptation of personal habits such as the choice of working hours, meeting points, or means of transport as well as the change of the sleeping area (Fig. 9). On the contrary, measures which are associated with major changes in everyday life or increased monetary expenditure have rarely been implemented or planned to be implemented by the respondents. In this context, only 8% of the interviewees stated that they had already installed an air conditioning system or were planning to do so. About 36%

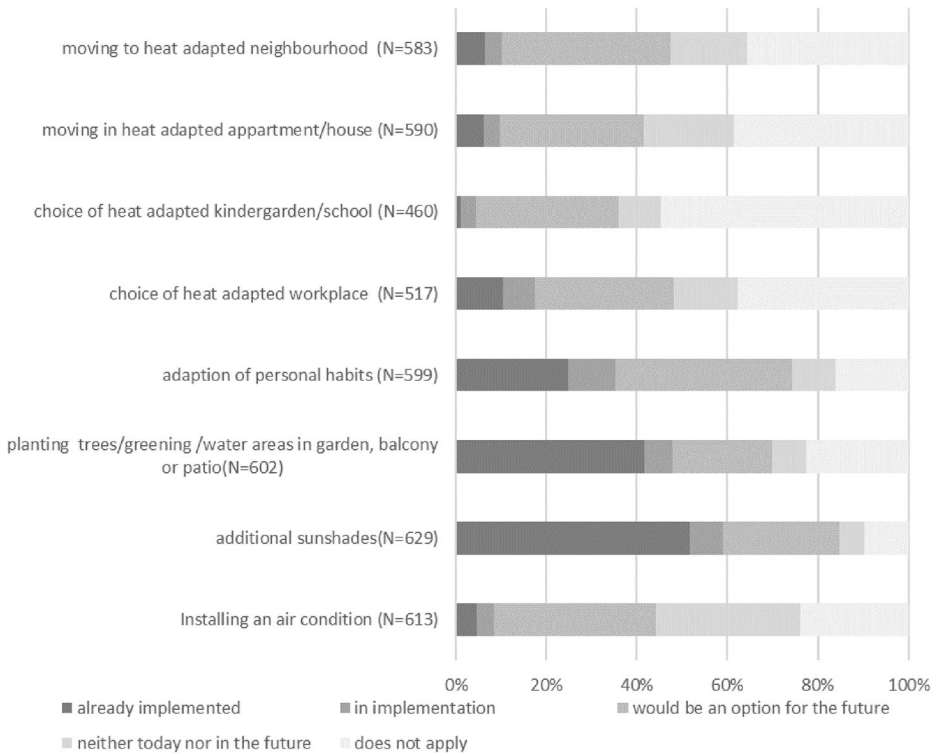


Fig. 9 Potential measures for protection against heat waves

indicated the installation of an air conditioning system as a possible option for the future. About 56% of those surveyed stated that the installation of an air conditioning system is not an option. However, the use of air conditioning needs to be critically revisited. On the one hand, scientific findings show that the mortality rate due to cardiovascular disorders during heat events can be reduced by the use of air conditioning (cf. Barnett 2007). On the other hand, other research results indicate that the use of air conditioning systems by many citizens results in high additional energy consumption and thus higher emissions of greenhouse gas, especially in urban areas (Lundgren and Kjellstrom 2013). In addition, the direct heat output of air conditioning systems leads to a rise in temperature in the immediate surroundings and thus to an intensification of urban heat (Lundgren and Kjellstrom 2013). One reason for the broad rejection of the installation of air conditioning among the respondents could be the discussed educational-bias within the sample. This refers to the assumption that the environmental awareness rises with the level of education (see also Kuckartz and Rheingans-Heintze 2006). Despite the possibility that the rejection of using air conditioning systems is due to environmental reasons, it is assumed that the high costs associated with the purchase of an air conditioning system are factors that reduce the installation of air conditioning in cities in Germany as an adaptation measure. This assumption is also statistically confirmed by the household survey. The willingness to implement adaptation measures that involve high monetary expenditure, such as the installation of an air conditioning system, seems to increase with rising household income. Even though this correlation is rather weak, the results point to the connection of available financial resources and adaptive capacities. In contrast, the implementation of measures that are associated with a fundamental change in living conditions seems to depend less on financial

resources than on e.g. the age of the respondents. The results indicate that people are less willing to implement adaptation measures, such as moving to a heat-adapted living environment, as they get older (see Fig. 10). The data show a highly significant correlation between the age of the respondents and their willingness to move to a heat-adapted living environment (Spearman's $\rho = 0.239^{***}$ /Kendall's tau-b = 0.217^{***}). This result is also consistent with other studies regarding the willingness to move among different age groups (Friedrich 2008; Scheiner et al. 2011). In this respect, the adaptive capacity of the older population appears to be lower than the adaptive capacity of younger people. In combination with increased physical heat susceptibility of persons over 65 years of age, this population group can be classified as particularly vulnerable.

The results of the household survey show that individual risk perception and the existence of social capital can be seen as dimensions of adaptive capacity or at least as factors influencing it. In particular, social contacts among neighbours seem to be a factor increasing adaptive capacities and coping capacities. The analysis of the data shows a highly significant positive correlation between people with intensive and regular contact to people in their neighbourhood and the willingness to offer help in their neighbourhood (Spearman's $\rho = 0.551^{***}$ /Kendall's tau-b = 0.512^{***}). At the same time, the data suggest that people having regular contact to their neighbours are more likely to believe that they can generally rely on help from their neighbours (Spearman's $\rho = 0.741^{***}$ /Kendall's tau-b = 0.685^{***}). This suggests that people who are well integrated in their neighbourhood are more likely to expect rapid help in an immediate emergency situation within their living environment.

With regard to risk perception, our findings indicate that the perception of heat as a problem at home seems to be related to individual attitudes towards adaptation measures. Thus, significant positive correlations between risk perception in one's own home and the willingness to move to a heat-adapted apartment/house or living environment were found (Cramer's $V = 0.301^{***}$ /Cramer's $V = 0.257^{***}$). With regard to the adaptation of personal habits such as the choice of working hours, meeting points or means of transport and the change of the sleeping area, a significant, albeit weak, positive correlation with the perception of heat as a problem in one's private living space could be found (Cramer's $V = 0.157^{**}$). In addition to attitudes towards private adaptation measures, correlations between risk perception and endorsement of policies related to climate adaptation were found. Thus, there are significant links between risk perception of heat (in one's own home) and advocacy of spending public funds on heat adaptation, even at the expense of other sectors of public interest (Cramer's $V = 0.175^{**}$).

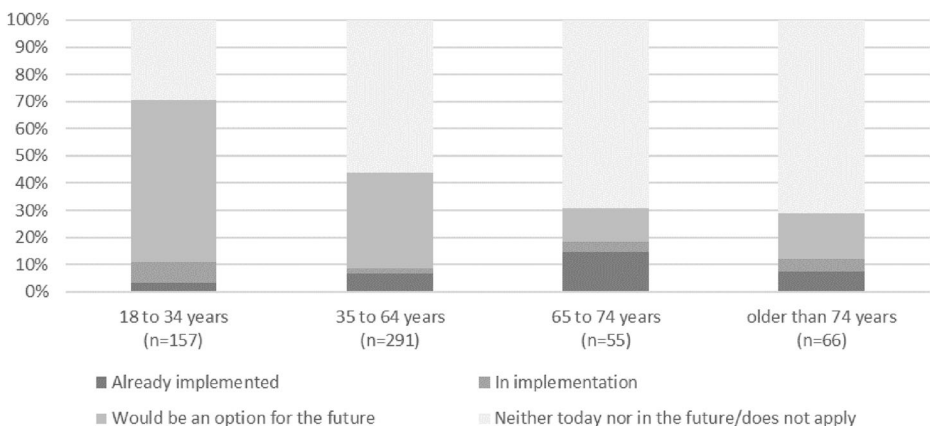


Fig. 10 Moving to a heat-adapted living environment as a function of age

The results indicate that risk perception seems to play a key role regarding the willingness to adapt and consequently also influences adaptive capacities.

Analyzing the willingness to adapt, surveyed by questions on the implementation of adaptation measures, offers the opportunity to find out more about adaptive capacities of people or groups of people who support, implement or reject these measures and thus to better understand the interrelationship between socio-economic factors and individual adaptive capacities at the household level. Since the survey aimed at generating data which is easy to replicate by asking closed-ended question and using mainly standardized answer scales, the proposed methodology to analyze individual adaptive capacities by surveying the willingness to implement specific adaptation measures, can also easily be transferred and replicated in other cities, locations and contexts. In this regard, it would be interesting to see which individual adaptive measures are likely to be implemented in dependency of different political, economic, and cultural backgrounds and conditions in different countries within and outside the European Union.

5 Discussion and conclusion

The results of the household survey on heat stress conducted in Ludwigsburg confirmed the relevance of vulnerability indicators such as age, socio-economic situation (e.g. income), or access to green and recreational areas in terms of the vulnerability and adaptive capacity to heat stress. In addition, new insights were gained in terms of the influence of risk perception, willingness to adapt and adaptive capacities, also linked to age, income, and social capital. Furthermore, the analysis of the data reveals spatial hotspots of perceived heat stress within the city. We found that it is not just the living location where heat stress is particularly seen as a threat. Next to the city centre, it is the public transport where many respondents suffer heat stress. These results are also consistent with other studies regarding spatial hot spots of perceived heat stress (Landeshauptstadt Magdeburg and ThINK 2017; Kunz-Plapp et al. 2016). This also applies for the findings on the relationship between the age of the respondents and their willingness to implement adaptive measures which are associated with a fundamental change of habits and lifestyle, such as moving to a heat-adapted living environment (cf. inter alia Friedrich 2008; Scheiner et al. 2011). However, this is not the case regarding the results on which green spaces and recreational areas are visited regularly. In contrast to the findings in Ludwigsburg, a comparable household survey conducted in Bonn showed that the visit of such areas does not depend on the means of transport it takes to get there (Sandholz and Sett 2019). It is assumed that this is due to different topographic conditions of the site. However, the differences of the results also illustrate the relevance of small-scale, local analyses in order to be able to optimally capture the special characteristics and needs of a city.

Regarding the methodology, the survey-based assessment of adaptive capacities at household level is not new to the field of vulnerability research. There are several studies that attempt to assess adaptive capacities via household surveys as part of vulnerability analyses (cf. inter alia Sorg et al. 2018; Jamshed et al. 2018). Few survey-based studies address the interrelationships between socio-demographic characteristics, adaptive capacities, and specific adaptation measures. However, these relationships are not commonly studied, hence why this paper is filling in a significant research gap. Recent studies by Hayden et al. 2017 or Voelkel et al. 2018 focus on analyzing the interrelationships of socio-demographic characteristics, perceived heat stress, and individual adaptive behaviour and adaptive capacities. Voelkel et al.

point out that heat exposure and adaptive capacity are clearly associated with socio-demographic differences. Their findings indicate that certain social groups within a population—such as low-income groups—have rather low adaptive capacities due to socio-demographic factors and experience disproportionately high temperatures and limited access to refuge from extreme heat (Voelkel et al. 2018). Results from Hayden et al. indicate that sociodemographic factors, such as income, have an influence on the individual adaptive capacities of a population. It shows that though there was widespread air conditioning availability throughout the area of inquiry, the majority experienced heat-related symptoms, because they could not afford to use air conditioning due to the high cost of electricity (Hayden et al. 2017). Taking up and expanding this approach, our research particularly explored the interrelations between socio-demographic characteristics of a household and the differential forms of adaptive behaviour and specific adaptation measures. This refers to the distinction of measures that are associated with specific personal costs like the level of monetary expenditure or changes of habits and lifestyle. Such analyses allow identifying starting points to develop incentive measures or policies, which correspond to the needs and interests of specific vulnerable target groups. Consequently, analyzing adaptive capacities at household level can enable decision makers to better understand issues that are limiting adaptive capacities of households and to find solutions and measures that promote adaptive capacities and adaptation of households towards changing climatic conditions—thus directing individual adaptive behaviour and promoting a more resilient population.

The results highlight that survey-based small scale analysis can contribute to better understand adaptive capacity and vulnerability at the household level. Since planned adaptive measures have to also be accepted and carried by the population of a city, such analyses can improve future development strategies in growing medium-sized cities in terms of the consideration of existing adaptive capacities and human vulnerability or also help to establish new development strategies for adaptation issues at household level.

Author contribution K. Laranjeira: conceptualization, methodology, formal data analysis, investigation, data curation, project administration, writing—original draft, figures, visualization of data.

J. Birkmann: writing—review and editing, supervision, project administration, funding, acquisition.

F. Göttsche: writing—review and editing, project administration

M. Garschagen: questionnaire design, writing—original wordings of survey questions, funding acquisition

Funding Open Access funding enabled and organized by Projekt DEAL. This paper is based on data and work of the research-project “Future-oriented vulnerability and risk assessment as an instrument for promoting resilience of cities and urban infrastructures” (ZURES). ZURES was funded by the German Federal Ministry of Education and Research (BMBF) within the funding program of social-ecological research-Focus: Sustainable transformation of urban spaces.

Data availability Original data of the household-survey conducted in Ludwigsburg within the ZURES project is not publically available. To get further information about data accessibility, please contact the Institute of Spatial and Regional Planning, University of Stuttgart, Stuttgart 70569, Germany.

Code availability N/A

Declarations

Conflict of interest The authors declare no competing interests.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

References

- Adger W, Dessai S, Goulden M, Hulme M, Lorenzoni I, Nelson D, Naess L, Wolf J, Wreford A (2008) Are there social limits to adaptation to climate change? *Clim Chang* 93:335–354. <https://doi.org/10.1007/s10584-008-9520-z>
- Balbus J, Malina C (2009) Identifying vulnerable subpopulations for climate change health effects in the United States. *J Occup Environ Med* 93:33–37. <https://doi.org/10.1097/JOM.0b013e318193e12e>
- Barnett AG (2007) Temperature and cardiovascular deaths in the US elderly: changes over time. *Epidemiology* 18:369–372. <https://doi.org/10.1097/01.ede.0000257515.34445.a0>
- Birkmann J (2008) Global environmental change, natural hazards, vulnerability and disaster resilience. Necessity of a widening of perspectives in spatial planning. In: *Raumforschung und Raumordnung* 66(1):5–22
- Birkmann J, Böhm HR, Buchholz F, Büscher D, Daschkeit A, Ebert S, Fleischhauer M, Frommer B, Köhler S, Kufeld W, Lenz S, Overbeck G, Schanze J, Schlipf S, Sommerfeldt P, Stock M, Vollmer M, Walkenhorst O (2013): *Glossar Klimawandel und Raumentwicklung*. 2. Überarbeitete Fassung
- Birkmann J, Sorg L, Fleischhauer M (2018) Klimawandel: Szenarien zur zukünftigen Vulnerabilität. Expositions- und Vulnerabilitätsszenarien für wachsende Mittelstädte – Fallbeispiel Ludwigsburg. In: *Raumplanung* 199(6–2018):29–35
- Birkmann J, Sauter H, Garschagen M, Fleischhauer M, Puntub W, Klose C, Burkhardt A, Göttsche F, Laranjeira K, Müller J, Bueter B (2020): New methods for local vulnerability scenarios to heat stress to inform urban planning - case study City of Ludwigsburg / Germany - (paper draft for climatic change SI)
- Bündnis Entwicklung Hilft (2015): *World Risk Report 2015: Focus: food security*. Berlin/Bonn: Bündnis Entwicklung Hilft and United Nations University – Institute for Environment and Human Security (EHS)
- CDC (Centers for Disease and Control Prevention) (2012): Recognizing, preventing, and treating heat-related illness: WB 2333. In: http://www.cdc.gov/nceh/hsb/extreme/heat_illness_training.htm, accessed 02. October 2020
- City of Ludwigsburg (2020): Statistik - Daten und Fakten über Ludwigsburg. In: https://www.ludwigsburg.de/start/stadt_buerger/statistik.html, accessed 02. October 2020
- Chmielewski FM, Heyer E, Hupfer P, Kuttler W, Pethe H (2005) *Witterung und Klima*. Teubner, Eine Einführung in die Meteorologie und Klimatologie. Stuttgart
- Forzieri G, Cescatti A, Batista e Silva F, Feyen L (2017): Increasing risk over time of weather-related hazards to the European population: a data-driven prognostic study. In: *Lancet Planet Health* 2017; 1: e200–e208
- Friedrich K (2008) Binnenwanderungen älterer Menschen – Chancen für Regionen im demographischen Wandel? In: *Informationen zur Raumentwicklung*. H. 3-4:185–192
- GEO-NET Umweltconsulting GmbH (GEO-NET) (2018): *Climatic analysis for the city of Ludwigsburg, ZURES Project*. Hannover
- Grothmann T, Patt A (2003): Adaptive capacity and human cognition. Presentation at the Open Meeting of the Global Environmental Change Research Community, 16–18 October 2003, Montreal, Canada, 1–19
- Hamstead Z, Farmer C, McPhearson T (2018) Landscape-based extreme heat vulnerability assessment. *J Extreme Events* 05(04):1850018. <https://doi.org/10.1142/S2345737618500185>
- Hayden MH, Wilhelmi OV, Banerjee D, Greasby T, Cavanaugh JL, Nepal V, Boenert J, Sain S, Burghardt C, Gower S (2017) Adaptive capacity to extreme heat: results from a household survey in Houston, Texas. In: *weather*. *Clim Soc* 9:787–799
- Hayles C, Dean M (2015) Social housing tenants, climate change and sustainable living: a study of awareness, behaviours and willingness to adapt. *Sustain Cities Soc* 17:35–45
- Howe P, Marlon J, Wang X, Leiserowitz A (2019): Public perceptions of the health risks of extreme heat across US states, counties, and neighborhoods. *Proc Natl Acad Sci USA* 2019, 116 (14) 6743–6748; <https://doi.org/10.1073/pnas.1813145116>

- IPCC, (2007): Climate change 2007: synthesis report. Contribution of working groups I, II and III to the fourth assessment report of the intergovernmental panel on climate change [Core Writing Team, Pachauri, R.K and Reisinger, A.(eds.)]. IPCC, Geneva, Switzerland
- IPCC (2012) Managing the risk of extreme events and disasters to advance climate change adaptation, special report of the IPCC. Cambridge University Press, Cambridge
- IPCC (2014): Climate change 2014: synthesis report. Contribution of working groups I,II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Genf: IPCC
- IPCC (2019): Global warming of 1.5°C. An IPCC special report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. Genf: IPCC
- Jamshed A, Rana I, Birkmann J, Nadeem O (2018) Changes in vulnerability and response capacities of rural communities after extreme events: case of major floods of 2010 and 2014 in Pakistan. *J Extreme Events* 04: 1750013. <https://doi.org/10.1142/S2345737617500130>
- Kuckartz U, Rheingans-Heintze A (2006) Trends im Umweltbewusstsein. Umweltgerechtigkeit, Lebensqualität und persönliches Engagement. Wiesbaden. VS Verlag
- Kunz-Plapp T, Hackenbruch J, Schipper H (2016). Factors of subjective heat stress of urban citizens in contexts of everyday life. *Natural Hazards and Earth System Sciences*. 16. 977–994. <https://doi.org/10.5194/nhess-16-977-2016>
- Landeshauptstadt Magdeburg, Think (Thüringer Institut für Nachhaltigkeit und Klimaschutz) (2017) Klimaangepasstungskonzept für die Landeshauptstadt Magdeburg. Stadt Magdeburg
- Lundgren K, Kjellstrom T (2013) Sustainability challenges from climate change and air conditioning use in urban areas. *Sustainability* 5:3116–3128. <https://doi.org/10.3390/su5073116>
- Nilsson A, von Borgstede C, Biel A (2004) Willingness to accept climate change strategies: the effect of values and norms. *J Environ Psychol* 24:267–277
- Sandholz S, Wannewitz M, Garschagen M (2018) Urban heat and social vulnerabilities: a literature review on criteria and scenarios of vulnerability in the context of climate change. Bonn
- Sandholz S, Sett D (2019) Erfahrungen und Bedarfe von Akteuren der Stadtplanung im Hinblick auf Vulnerabilität gegenüber Hitzestress Ergebnisse einer Haushalts-Umfrage zum Hitzeempfinden in Bonn, Bonn
- Scheiner J, Reuschke D, Friese M (2011): Umzugsverhalten älterer Menschen: Vorsorgend, Nachsorgend oder gar nicht? Raum und Mobilität. Arbeitspapiere des Fachgebiets Verkehrswesen und Verkehrsplanung 26. Dortmund
- Smit B, Wandel J (2006) Adaptation, adaptive capacity and vulnerability. *Glob Environ Chang* 16:282–292. <https://doi.org/10.1016/j.gloenvcha.2006.03.008>
- Sorg L, Medina N, Feldmeyer D, Sanchez A, Vojinovic Z, Birkmann J, Marchese A (2018) Capturing the multifaceted phenomena of socioeconomic vulnerability. In: *Natural Hazards* 92(1):257–282
- UNISDR (2020): Terminology on disaster risk reduction. In: <https://www.unisdr.org/we/inform/terminology#letter-v>, accessed 02.August 2020
- Voelkel J, Hellman D, Sakuma R, Shandas V (2018) Assessing vulnerability to urban heat: a study of disproportionate heat exposure and access to refuge by socio-demographic status in Portland. *Oregon Int J Environ Res Public Health* 2018(15):640
- Vogel C, O'Brien K (2004) Vulnerability and global environmental change: rhetoric and reality. In: *AVISO – Information Bulletin on Global Environmental Change and Human Security*, (13), 1–8
- Welle T, Birkmann J (2015) The world risk index – an approach to assess risk and vulnerability on a global scale. *J Extreme Events* 2. <https://doi.org/10.1142/S2345737615500025>
- Whitmarsh L (2009) Behavioural responses to climate change: asymmetry of intentions and impacts. *J Environ Psychol* 29(1):13–12
- Wilhelmi OV, Hayden MH (2010): Connecting people and place. A new framework for reducing urban vulnerability to extreme heat. *Environ Res Lett* 5(1):14021
- Wilhelmi OV, Morss RE (2013) Integrated analysis of societal vulnerability in an extreme precipitation event. A Fort Collins case study. *Environ Sci Pol* 26:49–62. <https://doi.org/10.1016/j.envsci.2012.07.005>
- Wisner B, Blaikie P, Cannon T, Davis I (2004) *At risk: natural hazards, people's vulnerability and disasters*, 2nd edn. Routledge, London

- Wolf T, McGregor G (2013) The development of a heat wave vulnerability index for London, UK. *Weather Clim Extreme* 1:59–68. <https://doi.org/10.1016/j.wace.2013.07.004>
- World Meteorological Organization (WMO) (2020): WMO Statement on the State of the Global Climate in 2019. WMO-No. 1233., Geneva/Switzerland: World Meteorological Organisation
- ZURES-website (2020): Future Oriented Vulnerability and Risks-Assessment as a tool to strengthen the resilience of cities and urban infrastructures (zukunftsorientierte Vulnerabilitäts- und Risikoanalyse als Instrument zur Förderung der Resilienz von Städten und urbanen Infrastrukturen). <https://www.zures.de/>

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.