2. Urban vulnerability analysis towards heat based on the example of the city Hanover

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Abstract

The exposure to heat is currently seen as the most important direct impact of climate change on human health (Menne 2011: 6f). In areas with high levels of sealing and low aeration, the overheating in cities leads to urban heat islands. This results in an acute need for action for urban and environmental planning to optimally exploit the potential of local measures to mitigate this stress situation for urban residents and to be able to localize the adaptation measures to the changing climate. Against this background, planning action is crucial to the reduction of vulnerability as well as the targeted establishment of adaptation capacities against the effects of climate change (BMVBS 2010: 10).

This master-thesis aim to use a GIS-based analysis to accurately identify the vulnerabilities of the city of Hanover against heat (depending on the different adaptive capacities of the room). The work shows that against the background of increasing climate change, the determination of the vulnerability of urban areas plays a central role in maintaining healthy living quality. Furthermore, this work has shown that vulnerability analysis is a central starting point when it comes to identifying vulnerable uses of space against the effects of climate change and making them more adaptable through planning measures.

Introduction

Climate change and fluctuations have already been recorded in the past. However, human activity has never before had such a rapid and significant impact on the climate as it has in recent decades (UBA 2012: www, IPCC 2014: 6f).

According to the Intergovernmental Panel on Climate Change (IPCC) (2007), climate projections assume that the average annual temperature in Germany will warm increase by 1.8 to 4,0 degrees between 2081 and 2100 compared to the reference period 1980-1999 (Federal Government 2008: 8f). Climate change will vary significantly from region to region and season to season.

The frequency and intensity of extreme weather events will increase overall. In the future, there will be fewer cold days, but the number of summer days (daily maximum above 25°C), hot days (daily maximum above 30°C) and tropical nights (daily minimum not below 20°C) will probably increase significantly (SMUL 2005: 9f; Witting & Schuchardt 2013: 43; UBA 2017: www). Due to the rise in temperature and the higher number of heat days, there will also be more frequent heat periods, which may last longer (Witting & Schuchardt 2013: 43).

This range of possible climatic changes influences in particular future-oriented planning projects, so that climate change is becoming increasingly crucial for planning (BMVBS 2009: 5; Rössler et al. 2014: 1). Compared to rural areas, large cities, urban regions and their inhabitants are particularly affected by extreme weather events and face challenges of adequate adaptation to climate change (BMZ o. J.: www; Witting & Schuchardt 2013: 43). Due to large surfaces of sealing, the concentration of the population, the durability of built infrastructure or the excessive input of air pollutant emissions, cities heat up much more than the surrounding countryside, a fact which can be summarised under the terms “urban heat”-problem or “heat island effect” (Steinrücke et al. 2010: 1, Stadt Karlsruhe 2013: 78). Additionally, there are high settlement pressure and still-rising demand for housing, which tends to exacerbate the problem even further (GEWOS 2013: 4; Stadt Karlsruhe 2013: 78).

Consequently, there is an increased need for action in urban areas - in comparison to the surrounding countryside. When developing adaptation measures for the consequences of climate change, it should be noted that each city has its own urban climate as a result of its respective urban structures (so-called urban climate). So that cities, individual districts and even apartment blocks can exhibit different sensitivities and vulnerabilities (LHS Stuttgart 2017: www). The significant impact of climate change, particularly in the case of heat pollution, does not only affect human health in the sense of a healthy life, work and environment. Human health (in terms of healthy living and working conditions) is most affected by the consequences of climate change (Campe et al. 2015: 343f). Especially in inner-city quarters, due to the heat islands, is associated with the heat-induced health burdens for the residents and an impairment of the residence quality (IPCC 2014: 16; Holst & Mayer 2010: 13, Bongardt 2013: 13).

To improve the performance, well-being and health of people, the cities and conurbations will inevitably have to focus more on the future of the adaptation to the consequences of climate change (Steinrücke et al. 2010: 1). In the future, urban development will have a unique role. It should develop solutions, which are optimized for urban climates in order to reduce the thermal stress within the settlement area even under extreme heat conditions (Stadt Karlsruhe 2013: 78).

However, it is not only the warmer urban climate that increases health and physical stress. The sensitivity of human beings to heat also determines the level of stress. Not all people are affected equally: Especially the elderly, sick people or Infants are more sensitive or more susceptible (so-called vulnerable children population groups). However, even healthy people, heat can lead to exhaustion and lead to reduced productivity (BMVBS 2009: 22, Stadt Hannover 2009: 2; IPCC 2014: 16; Rössler et al. 2014: 1, UBA 2015: 606ff). To adapt to the heat islands in urban areas, it is, therefore, necessary to identify the likely effects, to assess them as best as possible and to represent them spatially. Only on this basis, climate-change-adapted structures can be developed in order to reduce the risks for human health and the environment or delete them.

Thus, the urban climate and its effect on humans acts as a decisive factor in urban planning and, against this backdrop, they are also a key factor for the establishment of legal principles (e. g. §1 para. 3 no. 4 BNatSchG or the Federal Immission Control Act) (Reiss-Schmidt & Beckröge 1993: 58f; Matzarakis 2001: 9).

According to recent developments in urban and landscape planning principles (see Federal Nature Conservation Act §1 Para. 3 No. 4 BNatSchG or BauGB 2011 (§1 Para. 3 No. 4 BNatSchG or BauGB 2011). 1 para. 5 BauGB), it becomes clear, that urban climatic issues and their effects are already relevant to planning and will be among the most important tasks of spatial development in the future due to the increasing number of extreme weather events (Spieckermann & Franck 2014: 159). Although climate change and extreme weather events cannot be excluded from planning processes, the vulnerability of the population and cities can be reduced through foresighted action (adaptation).

Therefore, of essential importance are the identification of heat-sensitive as well as affected areas and the derivation of local spatial vulnerabilities within the urban periphery. An urban vulnerability analysis against heat stress using the example of the City of Hanover can record and evaluate affected urban areas, as well as their vulnerability, as determined by compensating adaptation capacities.

Concept and aim

Vulnerability to heat stress results from social aspects demographic sensitivity as well as from use-related sensitivity (degree of sealing) including compensatory reduction and alternative capacities. The work aims to identify vulnerability precisely (depending on the different adaptation capacities of the space) and to determine where adaptation measures are necessary and which areas should be given priority. The results are presented in maps and are intended as a decision-making aid for the implementation of adaptation measures.

Methods

There are hardly any standardized methods in the literature for investigating existing vulnerability (Weis et al. 2011: 12). The methodological steps of vulnerability analysis were mainly oriented to sections of the vulnerability analysis in the Region of West Saxony in May 2011 (Schmidt et al. 2011).

First, the first component of vulnerability, the exposure to heat, is described. In addition to exposure, sensitivity is also considered. Shown are two different sensitivities. The third result is the intersection of the sensitivities and the exposure, this results in **an area that is affected.**

The Exposure describes the heat islands in the city (status 2006). These areas are characterised by dense building development and high degrees of sealing. Due to their greater distance from greened areas, they are no longer sufficiently ventilated during higher temperatures at night (Department of Environment and City Green 2015: 2).

The exhibition shows current heat islands, but also future rooms burdened by heat, in which the summer heat load will increase until 2050. The gradation is carried out in the categories moderate, high and very high Increase of days with heat load during the period 2001-2010 to 2046-2055 (Department of Environment and City Green 2015: 3). In addition to exposure, **sensitivity** is also considered. This reflects the sensitivity of the population (BMVBS 2011: 5) towards the phenomenon.

To determine the sensitivity of the people to heat stress, two aspects should be considered.

A. Sensitivity to use describes exposure to heating effects due to sealing.

B. Demographic sensitivity describes the sensitivity of people to heat stress, depending on their age or condition of health. Another factor of demographic sensitivity is population density per hectare (Schmidt et al. 2011: 48).

The intersection of the sensitivities and the exposure results in **an area that is affected.** This mainly depends on the geographical distribution and the possible overlapping of the sensitive areas in the climate-charged urban space. In addition to the determination of the areas currently affected, the analysis will also be carried out in future identified affected areas. After determining and evaluating the local impact, **the adaptation capacities** are determined. To maintain well-being and quality of life as well as the reduction of climatic stress in urban areas, there are several different adaptation concepts. In the result, there is an **adaptation by reduction** or also an **adaptation by evasion.**

A reduction capacity exists, for example, through the presence of areas producing cold air such as forests, water bodies or agricultural land. Such entities cause a reduction of heat stress of the areas affected within urban space by radiating effects.

In contrast, the avoidance capacity describes the presence of climatically favourable areas that can be visited in the event of increasing heat loads. Due to their small size, these areas have no mitigating effect on the surrounding buildings (Schmidt et al. 2011: 53). In the context of two different adaptive capacities, two different vulnerabilities of space arise accordingly (BBSR 2016: 21).

The assessment of the vulnerability of urban spaces to heat within the framework of their **reduction capacity** results from the combination of demographic sensitivity and exposure as well as the use-related sensitivity (this component based on the degree of sealing, includes compensating reduction capacities). Vulnerability within the framework **of the alternative spaces** results from the combination of the affected areas with the alternative capabilities (alternative spaces within walking distance).

Results

The results of the individual steps of the vulnerability analysis are described below. The data on exposure were given and are, therefore, not described in the results chapter. The first partial result was the spatial determination of the sensitivities. The next step was to determine the affected areas in relation to heat. This result, in combination with the adaptive capacities, finally resulted in the vulnerability of urban spaces.

Sensitivity - The sensitivity is based on two indicators: firstly, the demographic sensitivity, which relies on the proportion of senior citizens in the total population, the population density and the density of socially sensitive facilities, and secondly, on the usage-related sensitivity. The second indicator is the degree of sealing, which, according to Mosimann (et al. 1999) is derived from the land-use mapping (ATKIS Basis DLM).

Results on demographic sensitivity

The map (see Figure 1) depicts the urban areas in which demographic sensitivities overlap and spaces are to be assessed by different sensitivities. The population density, the proportion of senior citizens and the density of sensitive social facilities overlap. The demographically sensitive areas were assigned to a 5-step sensitivity scale. Areas with a very low demographic sensitivity are located outside the city, where the population density is very low, the proportion of senior citizens is deficient, and the density of social facilities is very low. These are, for example, the characteristics of the districts Misburg-Süd, Lahe or Isernhagen-Süd. Due to the concentration of high individual sensitivities, the districts Oststadt, Vahrenwald, List, Südstadt or Linden-Nord and Linden-Mitte are highly demographically sensitive. One striking feature is the concentration of high to very high demographic sensitivities surrounding the medium-sensitive districts of city-centre, Nordstadt and Calenberger-Nordstadt.

Results on use-related sensitivity

The higher the degree of sealing of a surface, the higher is the degree of sensitivity of the surface to heat. Highly sensitive areas include mainly industrial and commercial areas, traffic areas but also areas with restricted development methods. The housing estates with an open construction method and individual buildings as well as railway facilities are less sensitive. Green areas and open spaces that are not sealed, such as forests, water bodies and agricultural areas, are not sensitive to heat loads. These areas are shown in white on the map.

Legend Degree of sealing
Sensitivity due to use shown in five categories

(white)	No sealing (green and open spaces)
(grey)	Hardly any sealing (< 25% sealing)
(yellow)	Low degree of sealing (25-50% sealing)
(pink)	Average degree of sealing (50-70% sealing)
(red)	High degree of sealing (> 70% sealing)

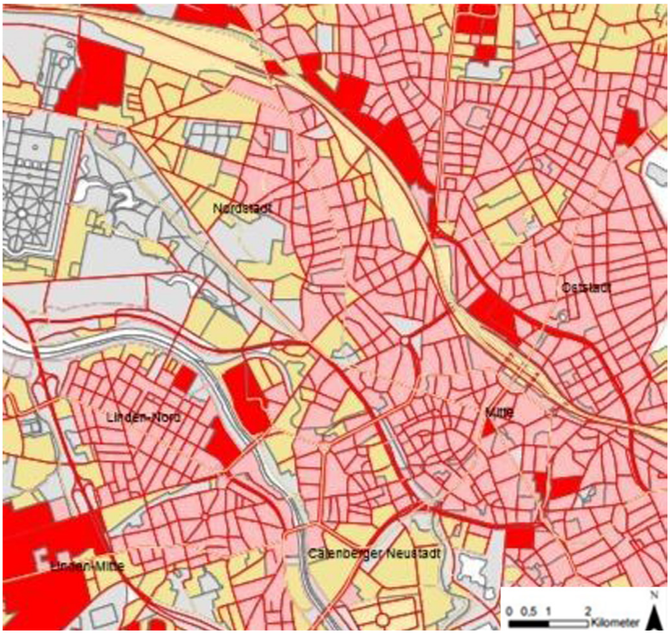


Fig. 1. Degree of sealing – Sensitivity due to use shown in five categories. (Michalczyk 2017)

Results of the affectedness

<u>The Current</u> affectedness is composed of the aggregation of demographically sensitive areas with highly bioclimatic settlement areas. Three levels of concern in the urban area were identified: medium, high and very high. Larger areas with medium levels of exposure to heat are primarily commercial and industrial zones outside the city, in the districts of Stöcken, Brink-Hafen and Mittelfeld. In comparison, very severely affected areas can only be found in smaller parts of the urban area. These areas are located in the districts of Vahrenwald, List, Südstadt and Oststadt.

<u>The Future</u> affectedness is composed of the aggregation of demographically sensitive areas with areas where heat stress will increase by 2050. It is generally noticed that in 2050 significantly more residential areas within the urban area will be affected by heat stress. It is also noticeable that the degree of involvement only increases in small areas (e. g. Linden-Mitte, Vahrenheide). In a few settlements, the degree of concern even decreases (e. g. in Misburg-Süd).

It is expected, that many urban areas will be at least severely affected by heat, unless protective- or adaptation measures are taken.

It should be noted that, especially in the currently highly and very highly affected areas, the degree of affectedness will expand significantly in the future (see Figure 2). A significant spatial expansion of the affected areas can be expected in the districts of the city centre, Vahrenwald, List, Oststadt, Südstadt, Linden-Nord and Calenberger Neustadt. On the other hand, the outskirts of the city are less affected due to a low increase in heat and a low demographic sensitivity.

Fig. 2. Excerpt from the district maps Vahrenwald/List. Top: Areas currently affected by heat, bottom: areas with an increase in heat load (scenario 2050) (Michalczyk 2017)

Results on adaptation capacity

From a climate-ecological perspective, the green and open spaces in the city of Hanover provide a dual ecosystem service. On the one hand, heat-stressed city dwellers can use the areas during the day as a recreation area (alternative space including pedestrian accessibility). On the other hand, the areas are above all cold air production and transport areas with radiating effects on surrounding areas, which normalise the urban climate and enable the inhabitants to have a restful sleep. Both maps (see Figure 2) represent almost the same green and open spaces. The map of alternative areas shows large areas such as forests, parks, water bodies and garden colonies, as well as smaller climate comfort islands. The agricultural areas in the urban area are unsuitable as an alternative space and are therefore not shown. It can also be seen that green and open spaces can be reached within a maximum radius of 300 meters (corresponding to 5-10 minutes on foot) in the city area, and that it is ensured that the population can seek recreation in nearby bioclimatic favoured areas on hot days. In addition to the green and open spaces, the map also shows the agricultural spaces, including the radiating effects (up to 100 meters) as areas of climate-ecological importance with heat reduction capacities.

Vulnerability results

Both vulnerable areas identified are made up of
- the walking accessibility of the alternative areas
- vulnerable areas resulting from adaptation capacity.

The results on the vulnerabilities are explained separately below.

Vulnerability resulting from the consideration of alternative spaces

The following figures 3-6 show the current impacts with a focus on demographic sensitivities, the alternative areas suitable for recreation and their pedestrian accessibility (up to a 300 meter radius). Consequently, the areas affected by the heat that is outside the walking distance of the evacuation areas are vulnerable residential areas. The inhabitants of the affected areas lack the possibility to visit recreational areas and climatic comfort islands within walking distance in case of high heat loads.

Fig. 3. Section of the current results map; Linden-Mitte district. Vulnerability under consideration of the alternative spaces (current scenario). (Michalczyk 2017)

Fig. 4. Section of the results map 2050; Linden-Mitte district. Vulnerability under consideration of the alternative spaces (scenario 2050). (Michalczyk 2017)

Fig. 5. Section of the current results map; City Center of Hanover. Vulnerability under consideration of the alternative spaces. (Michalczyk 2017)

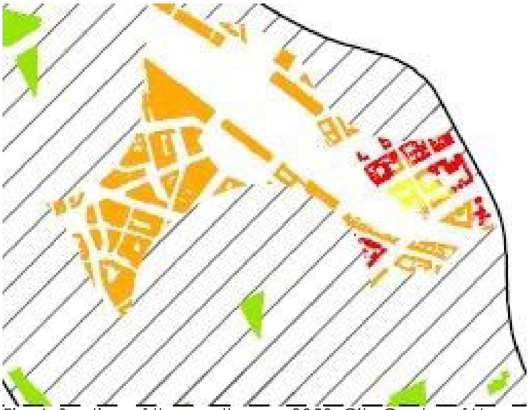


Fig. 6. Section of the results map 2050; City Center of Hanover. Vulnerability under consideration of the alternative spaces (scenario 2050). (Michalczyk 2017)

Legend

Current affectedness

- Medium affectedness
- High affectedness
- Very high affectedness

Within walking distance (up to 300 meters)

- Accessibility

Alternative spaces

- Parks
- cemetery
- Water bodies
- Garden plot

Dense vegetation

- Near-natural surface
- forest

Low-growing and loose vegetation

- Loose vegetation

Climate-comfort islands (< 2 ha)

- Climate comfort-islands

All in all, however, there is almost area-wide accessibility of alternative spaces within the city on foot. Only small residential areas are situated beyond a walking distance.

In comparison to future vulnerability, which results from taking the alternative spaces into account, it becomes clear that generally, only a small spatial expansion of the vulnerable areas takes place. The areas that will be vulnerable in the future are more likely to be affected by heat (see Figure 3, Figure 4, Figure 5, Figure 6). This result supports the need for future action.

Vulnerability arising from the reduction capacity

Four factors can explain the spatial pattern shown in the following Figures 7 and 8: Firstly, the areas are climatically highly contaminated settlement areas (as of 2006), which are also sensitive to heat due to their demographic composition. This is the reason why they are affected. This affectedness is the second factor. Thirdly, the sensitivity to use (degree of sealing) contributes to the identification of vulnerable areas, which in turn is reduced by the fourth factor “radiative effects”. The interaction and possible superposition of all factors result in low, medium and highly vulnerable settlement areas to heat.

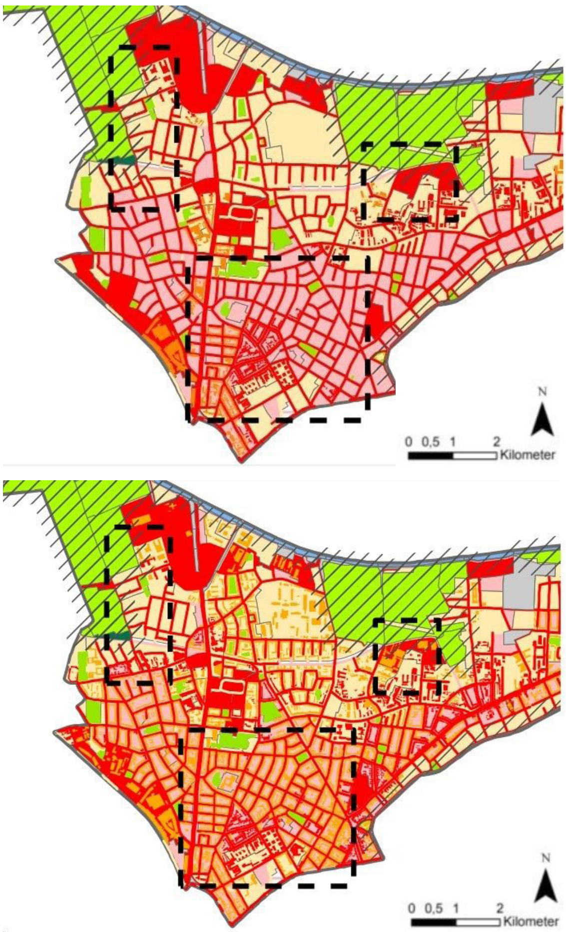


*Fig. 7. and 8. Upper figure shows the section Vahrenwald district; Vulnerability under consideration of the reduction capacity (current scenario). Lower figure shows the same vulnerability in the future scenario. (*Michalczyk *2017)*

Legend

Built-Up Areas

Degree of sealing (area without reduction capacity)

- Hardly any sealing (< 25% sealing)
- Low degree of sealing (25-50% sealing)
- Average degree of sealing (50-70% sealing)
- High degree of sealing (> 70% sealing)

Current affectedness

- Medium affectedness
- High affectedness
- Very high affectedness

Radiative effects (up to 100 meters)

- Fresh air effect, up to 100 meter

Areas/uses with reduction capacity (> 2ha)

Green and open spaces

- Parks
- cemetery
- Water bodies
- Garden plot

Dense vegetation

- Near-natural surface
- Forest

Low-growing and loose vegetation

- Loose vegetation

Agricultural area

- Field
- meadow

Climate-comfort islands (< 2 ha)

- Climate comfort-islands

Currently, vulnerability to heat is most evident in the densely populated area and on the highly sealed industrial and commercial sites. Where high degrees of sealing outside the radiation effects overlap with high levels of contamination, there is the highest degree of vulnerability. This shows the greatest need for action to reduce heat exposure.

The comparison (following Figures 9 and 10) shows that the selected areas will increase only less their level of vulnerability by 2050. It becomes clear that the spatial extent of the vulnerabilities will increase and that in 2050 almost the entire inner city area will be vulnerable to heat.

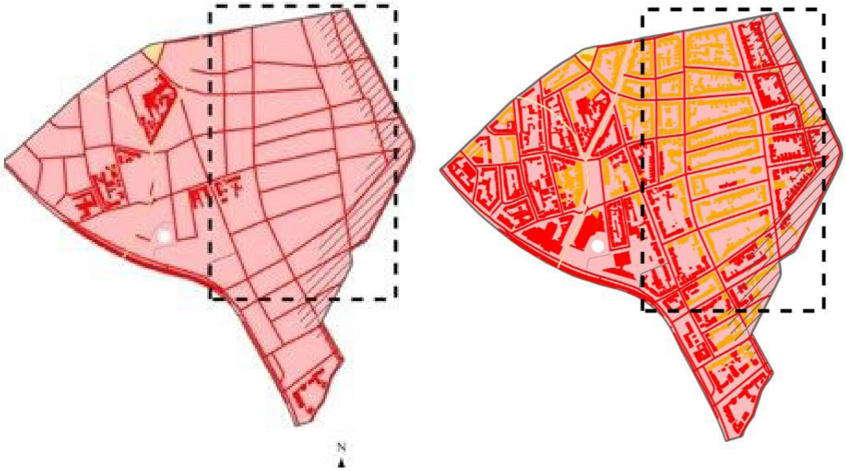
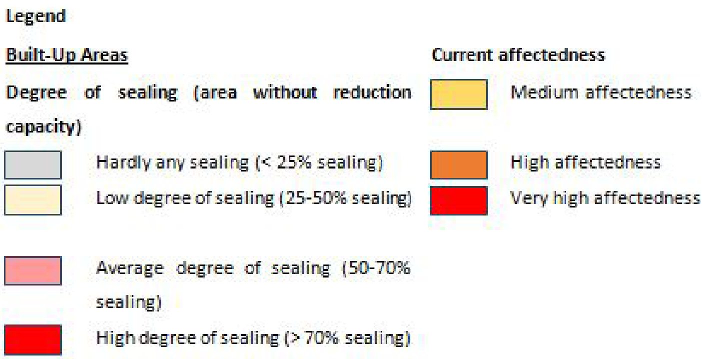


Fig. 9. and 10. Left figure shows the Vulnerability under consideration of reduction capacity (CURRENT scenario) and right: Vulnerability under consideration of reduction capacity (scenario 2050) (MICHALCZYK 2017)



Where there is currently no overlapping of sensitivities, the settlement areas are only sensitive to heat due to their use or the degree of sealing. In the future, a significant increase of vulnerable settlement areas can be expected. Because of the increasing demographic ageing, the expected migration and the associated growth in development, an increase in the degree of vulnerability is to be expected.

Summary of the results to vulnerabilities

The result is only a small increase in vulnerability over a large area. This means that the settlement areas that are currently vulnerable will also be vulnerable to heat in the future. The future vulnerable areas will tend to be more affected by heat.

Vulnerability in the light of alternative spaces The result is only a small increase in vulnerability over a large area. This means that the settlement areas that are currently vulnerable will also be vulnerable to heat in the future. The future vulnerable areas will tend to be more affected by heat.

Vulnerability in the light of mitigation capacity Currently, vulnerable areas will increase less in the degree of their vulnerability. Because of the increasing demographic ageing and the expected migration and the associated increase in development, an increase in the degree of vulnerability can be expected. It is also becoming clear that the spatial extent of the vulnerabilities will increase and that in 2050 almost the entire inner city area will be vulnerable to heat.

Guideline for Urban Development for Maintaining and Improving the Climate Situation in Hanover

Between 1950 and 2005, the proportion of the population living in cities increased globally from 29 per cent to 50 per cent. It can be assumed that this trend will continue so that in 2030, the urban population could account for around 60 per cent of the population (Kropp et al. 2009: 243). The city of Hanover is also expected to grow noticeably, from 524.450 in 2014 to 543.600 inhabitants by 2030 (3,7% growth) (Region Hannover & Landeshauptstadt Hannover 2014: 20f). Against this background, Hanover is one of the growing cities with pressure to move to and settle.

Urban development should be carried out with the aim of maintain or even improve the quality of life in the city despite climate change“ (Landeshauptstadt Hannover 2017: 14). This leads to the underlying idea of inner development, which - if all adaptive capacities are exhausted - is best suited to ensuring a liveable environment in the city even under the conditions of climate change (Brandl et al. 2011: 26). Due to higher energy efficiency, good connections to public transport and a comprehensive local supply network, fewer greenhouse gases are released in the densely populated city than in less densely-populated cities. Interior space development also offers the advantages of free space and soil protection. Against this background, there is the increasing demand for green and open spaces, which significantly improve urban climate and take on numerous climate-relevant functions (e. g. reduction of heat islands, pleasant living environment) (Brandl et al. 2011: 26).The combination and interlocking of open spaces and built-up areas, which can reduce the negative effects of climate change, is therefore essential for urban development in the City of Hanover (Knieling & Müller 2015: 19f; Schmidt et al. 2017: 25).

The aim of urban and environmental planning is, therefore, a sustainable, climate-change-adapted urban development, with a focus on re-compaction on unused, fallow or misused areas in the inner city (Schmidt 2017; Luft 2017). Within this framework, an internal development strategy should be sought which takes into account the city boundaries, preserves diversity in urban space and provides sufficient climate-effective green and open spaces (Luft 2017; Brandl et al. 2011: 67). When adapting to climate change, and especially to heat loads, it is sometimes overlooked that the need for action arises not only from the vulnerability of the urban structure but also from human vulnerability (Schmidt et al. 2017: 25). As a result, future adaptations to climate change should also take into account changes in society. In addition to planning adjustments that can reduce the consequences for the population, independent health care for each citizen is also important.

The two strategies with the concept of “inner development before outer development“ and “compact city“ are to be regarded as trend-setting for successful climate protection. The adaptation to climate change, however, is aimed at keeping areas free, especially in the highly densely populated inner-city areas, and would therefore instead be associated with the model of the “relaxed city“. As has already been shown, adaptation is to be seen as a cross-sectional task for planners, while the success of adaptation depends on integrative processes. To achieve this, the formal planning instruments must be exhausted (Steinrücke et al. 2010: 214f).

Conclusion

This paper explains that in view of increasing climate change, determining the vulnerability of urban areas plays a central role in maintaining a healthy quality of life. Furthermore, this work has shown that vulnerability analysis is a central starting point when it comes to identifying vulnerable land uses and structures to the effects of climate change and making them more adaptable through planning measures.

The analysis has shown that there is almost complete pedestrian accessibility to alternative spaces within the urban area. Only small settlement areas, such as in the city center, the district Vahrenwald, List or Linden-Mitte are beyond walking distance and can be considered vulnerable. In comparison to future vulnerability, only a small spatial expansion of the vulnerable areas takes place. The areas, that will be vulnerable in the future, are more likely to be affected by heat.

Vulnerability, taking into account reduction capacity, is currently most evident in areas where highly sealed surfaces overlap with a lack of radiative effects and high demographic impact. These are mostly in the densely populated part of the city Vahrenwald, List or Oststadt and the City center.

Because of the projected climate change, these problematic areas are likely to worsen and widen, which is why the identified areas should be considered primarily for the development and implementation of measures.

Against this background, climate adaptation measures should be implemented and applied above all in the highly sealed residential areas, which show also demographic sensitivities (e. g. high population densities, a high proportion of older people and low density of social infrastructure such as hospitals) e.g. in Mitte, Vahrenwald, Linden-Nord or Linden-Mitte.
In general and also in comparison with other large cities like Stuttgart, the city of Hanover has relatively only minor climatic problems due to its spatial location and is characterised by a quite good urban climate (Luft 2017; Schmidt 2017). However, the results of the vulnerability analysis also make it clear that the climatic situation will deteriorate by 2050.

Due to the desired re-densification (infill development) and the associated conflicts with the adaptation measures, solutions have to be found, allowing for a flexible adjustment. It is therefore essential for the success of climate-relevant actions that they are communicated and coordinated with the other concerns of urban development in order to create as many synergies as possible in planning and implementation. In the future, it will be increasingly important to test the compatibility of structural post-compaction measures particularly. In the event of priority given to post-compaction in the course of consideration, the following with the introduction of specific requirements for mitigation and compensation.

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