GI_Forum 2017, Issue 1
Page: 315 - 326
Full Paper
Corresponding Author:
christian1.mueller@hs-bochum.de
DOI: 10.1553/giscience2017_01_s315

# Locating Urban Heat Stress Vulnerability: A GIS-based Spatial Cluster Analysis of Urban Heat Load, the Elderly and Accessibility of Urban Green Spaces

Christian Mueller[1], Ulrike Klein[1] and Angela Hof[2]
[1]Hochschule Bochum, Germany
[2]University of Salzburg, Austria

**Abstract**

Urban parks provide important ecosystem services, for instance curbing urban heating by the cooling effect of evapotranspiration and shading. As elderly people constitute a group of citizens who are particularly vulnerable to urban heating, the accessibility of urban parks is of special interest for this target group. For Salzburg City, we aggregated to census tracts (Zählsprengel) (1) the near-future average annual sum of summer days, as modelled by the Austrian national weather service, (2) the walking distances to urban parks as calculated by GIS-based network analysis, and (3) the proportion of citizens who are more than 65 years old. Using geostatistical cluster analysis, areas were identified which comprised a combination of high urban heating risk, a high proportion of elderly people, and low accessibility to urban parks. The case study showed that the methodology is suitable for identifying contiguous and homogeneous areas of interest to which targeted planning strategies for climate adaptation can be applied, especially if the spatial resolution is increased by microscale demographic data.

**Keywords:**

cluster analysis, urban heat, accessibility, urban green space, urban parks

## 1 Introduction and problem statement

Urban parks are not only the major locality for recreation of city dwellers. They also have a 'Cool Island' effect on surrounding built-up areas. The spatial range of the result of evaporative cooling, shading and thermal admittance is related to park size as well as to the density, direction and vertical extent of built-up areas (Žuvela-Aloise et al., 2016). Parks therefore provide regulating ecosystem services by cooling the surrounding built-up areas. In the literature, there is a general consensus that climate change adaptation in urban areas calls for the protection of existing green spaces and, ideally, the creation of more green spaces (Gill et al., 2007). Yet, it is unanimously accepted that space is limited and contested, so that competing land uses curb the implementation of planning recommendations, and compact cities tend to have smaller and more disconnected green spaces.

A very recent review article has highlighted a research gap by pointing out that most studies on urban green spaces do not represent the diversity of modern urban societies (Botzat et al., 2016) and that survey-based research on park visitors and residents omits social groups with more limited physical access to urban green spaces. Especially for city dwellers with impaired physical mobility and limited access to public transportation, including on grounds of travel costs, park accessibility is an important spatial constraint. The frequency of walking for pleasure or fitness is a typical close-to-home activity that is affected by both the amount of green space and the distance to it (Neuvonen et al., 2007). A study in Vienna (Arnberger & Eder, 2011) found no differences between park visitor age groups for gender, ethnic origin, group size or access mode, but visitors over the age of 60 visited the green space more often for walking than for other activities. Since elderly people are among the most vulnerable groups for urban heat stress, more research is needed to adequately consider this group in urban planning. In particular, the relationship between access to parks and exposure to urban heat island effects might be of interest for sustainable planning with respect to this group. Targeting this specific age group also reflects the policy and planning paradigm that urban green spaces are important age-friendly features of livable cities (WHO, 2007) and that elderly city dwellers especially need good access to urban green spaces because factors such as old age and poor health can reduce their mobility and hence the frequency of use of the nearest green spaces (Schipperijn et al., 2010). Last but not least, attractive public green spaces are important from a public health perspective, as recreation and physical activities in parks have demonstrated positive effects on health for an increasingly ageing and urbanized society (Arnberger & Eder, 2011).

Analyses utilizing Geographic Information Systems (GIS) have shown that equity in accessibility of urban green space is limited. Accessibility can be evaluated by per capita values, radius (buffer) methods that employ Euclidean or city block distance algorithms, or network analyses. It has been shown that the last of these outperforms both spatially implicit per capita and buffer methods (Barbosa et al., 2007; Comber et al., 2008; Kabisch & Haase 2014; Nicholls 2001). In the light of these findings, the present paper has the following objectives:

- to use network analysis in GIS coupled to Python applications to calculate walking distances to parks as an indicator of accessibility of public green spaces for residential buildings and urban census tracts
- to integrate the derived walking distances with demographic data and climate scenarios in one analysis
- to pursue a systemic view by combining these data sets, pertaining to different aspects of urban systems
- to identify homogeneous and contiguous areas to which high proportions of senior citizens, high urban heat stress risk, and low accessibility to urban parks apply
- to frame automated GIS workflows and tools which allow urban planners and decision-makers to deduce these areas of special interest from data which is readily available to them.

# 2 Data and methods

## Study area and urban climate change

Global warming is expected to increase the number of days with heat stress in urban areas. This will add to the urban heat island effect (Früh et al., 2011; Kuttler, 2011). The increase of densely built-up areas in Austria's main cities over the period 2011–2030 necessitates additional future green spaces to keep thermal comfort at the current level (Loibl et al., 2015). In this study, Salzburg City (47° 48' N, 13° 00' E) was used as a case study. It is the fourth largest city in Austria and ranks among the Austrian cities that face the most pronounced need to mitigate future increases of thermal load (Loibl et al., 2015), a challenge that many other European cities are facing.

## Analysing walking distances to parks for residential buildings

An indicator for the accessibility of green spaces supports urban planners in retrofitting urban areas by enlarging green spaces or establishing new parks. A meaningful indicator should measure walking distances from residential buildings or areas over the existing road and path network, which is a very persistent infrastructure in urban settings, as are the residential buildings themselves. The latter could thus be used for this indicator. The metric is applicable in a flexible manner, e.g. by combining the walking distances with walking speeds adjusted to specific target groups.

A tool was created which calculates this accessibility indicator as walking distances from buildings to parks through a pedestrian network. The accessibility tool takes advantage of the complementary functionalities of ArcGIS and Python. The advantage of ArcGIS as a geographical information system is that it can be used for visualization in layers and triggering scripts. Python, which allows access to the ArcPy library, was applied for object-oriented programming and automated processing.

A pedestrian network dataset was created by using the Network Analyst Extension for ArcGIS. For topology reasons, segments had to connect to end points of each other. The length of feature segments in metres was established as the cost attribute. By referring to the set of urban green spaces as destinations, the accessibility tool finds the closest green area for each building. Parks, in this case, are defined as public urban green spaces within the administrative city boundaries. Parks are landscaped and planted with trees, shrubs, lawns and occasionally flowerbeds, and offer recreational infrastructure for different activities and user groups. As network analyses are only able to handle point data, the polygon midpoints were created for each building. For parks, all vertices were converted to points. These points were snapped to the edges of the network, using a search tolerance of 100 metres.

The walking distances to the nearest park were stored as attributes in the building feature layer and could be analysed further. For the purposes of this paper, all buildings within residential zones or zones of mixed use in the land-use plan were selected. The land-use plan (scale 1:5,000) regulates the land use of the entire municipal area with regard to built-up, traffic and agricultural areas. Finally, calculated walking distances for each residential building were aggregated as mean values to census tracts.

## Demographic data: percentage of elderly at census-tract level

In Austria, the most detailed demographic and census data available is at the scale of census tracts (Zählsprengel), which correspond with administrative units. In the Salzburg City case study area, there are 192 census tracts (Stadtgemeinde Salzburg, 2016). Demographic data from the 2013 census was analysed for the percentage of city dwellers aged 65 years and over.

## Geodata on future urban climate and exposure to thermal load in the study area

Following the modelling approach of Früh et al. (2011) to estimate climate change impacts on urban environments, a research project by the Austrian national weather service (ZAMG) evaluated possible future changes in urban heat stress in five large cities in Austria (Žuvela-Aloise et al., 2012). The research took into account regional climate projections and urban morphology, thus creating a microscale urban climate model. Modelling results are based on regional climate projections for various International Panel for Climate Change (IPCC) scenarios, A1B, B1, A2, which were down-scaled using a set of regional climate models (Žuvela-Aloise et al., 2012). ZAMG (2016) provides spatial data as two-dimensional grid fields in text format, with a spatial resolution of 100 × 100 m, for all five cities. The number of summer days (defined as days when the maximum temperature reaches 25°C or more) is a suitable parameter for the estimation of the development of the thermal load, either in a future climate or in comparison between different locations within a city. It is not only the daytime heat, but also the lack of night-time cooling that determines the magnitude of a heat episode and its impacts on human health, especially for vulnerable groups such as small children and the elderly (Kuttler, 2011; Žuvela-Aloise et al., 2016). The data for the scenario A1B (2021–2050) were downloaded and imported into ArcGIS as grids. Scenarios in the A1 group are based on assumptions of further global economic growth, and in the A1B scenario, all possibilities for energy generation are used equally. Converted to maps, the data presents the average number of summer days in 100 × 100m grid cells and provides detailed information on future urban climate at the residential scale for use in the planning of adaptation strategies.

## Spatial analysis

In agreement with the rule that the coarsest spatial resolution determines the scale of spatial analysis, the census tracts were used for a cluster analysis. First, the mean walking distances to the nearest park were aggregated to individual census tracts. For this step, the results of the network analysis (see section 2.2) were used. Second, the results of calculating the percentage of elderly people (65 years and over) in the data tables were joined to the attribute table of the census tract polygons. Third, the mean number of summer days, as projected in the climate scenario for 2021–2050, was calculated for each census tract by using the Zonal Statistics tool in ArcGIS. The 'Grouping analysis' cluster-analysis tool from the Spatial Statistics toolbox and the mapping clusters toolset in ArcGIS were then used to identify clusters of census tracts where unique combinations of ageing population, exposure to thermal load in the near future and walking accessibility to urban parks occur. Using a multidimensional data space, this method allows the identification of preferably homogeneous and spatially contiguous clusters. For spatial constraints, the k-Means algorithm was applied. For this purpose, eight neighbouring census tracts were considered, and the Euclidean distance was used for the distance measure. These parameters were set according to the most concise outcomes in terms of high variability between clusters and low variability within clusters.

## 3 Results and discussion

### Residential accessibility to parks in Salzburg City

According to Barbosa et al. (2007) and Schipperijn et al. (2010), residential buildings which are within a walking distance to parks of 300m or less are considered to have appropriate access to green space. The map in Figure 1 shows that these buildings are located around the city centre of Salzburg. Residential buildings with walking distances to parks of 500m or more are predominantly located in the outskirts of the city, where green space other than urban parks might be available. These edge effects might be considerable, and the city surroundings should be taken into account in future studies. However, it can also be seen in Figure 1 that there are exceptions to this overall impression, as there are areas with high accessibility to parks in the eastern and northern outskirts as well as in the western part of the centre of Salzburg.


**Figure 1:** Walking distances to parks for all residential building in Salzburg City

## Clusters of unique combinations of ageing population, exposure to thermal load in the near future, and walking accessibility to urban parks

As can be seen in Figure 2, aggregated values of the walking distance to parks, proportion of senior citizens (65 years or older), and the sum of summer days per year were considered in a cluster analysis for each census tract. In addition, the geographical location of each census tract was considered. In total, 15 unique clusters were identified.

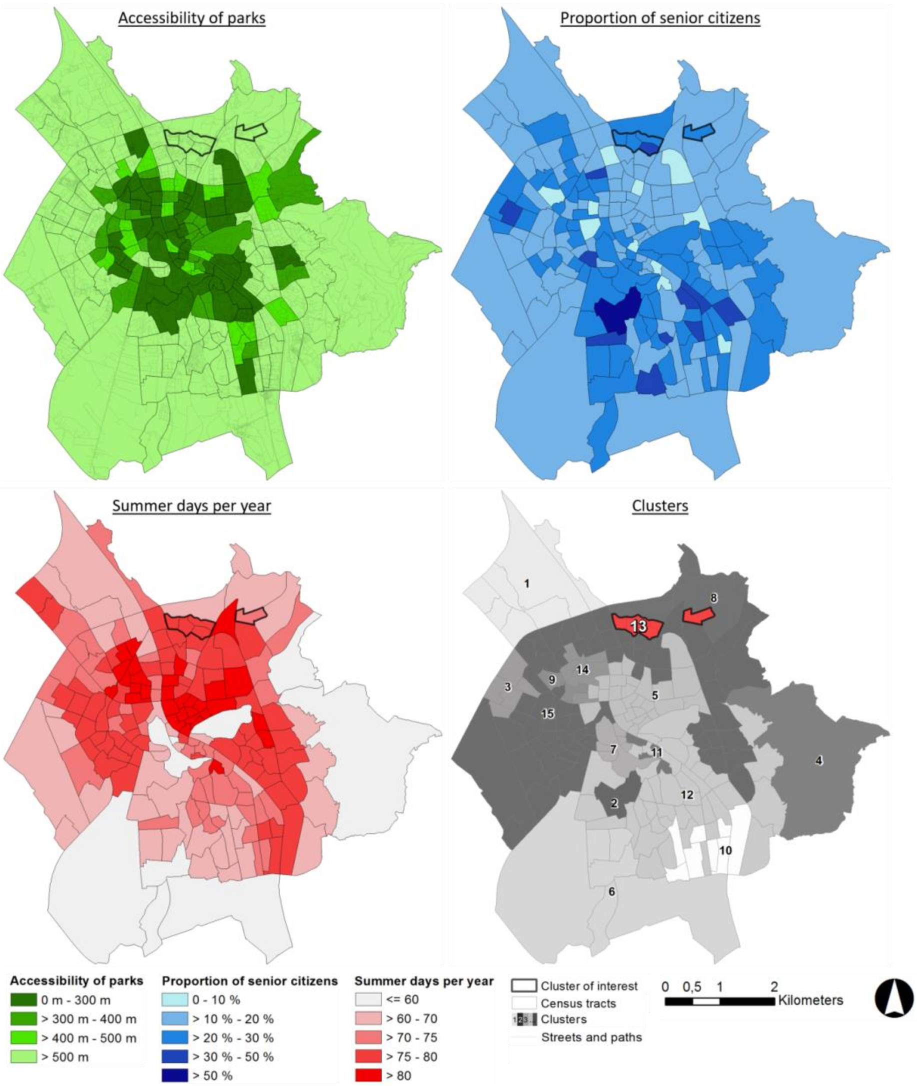


**Figure 2:** Results of grouping census tracts with a cluster analysis (bottom right: the cluster numbers correspond with Table 1) to identify unique combinations of walking accessibility to urban parks (top left), ageing population (top right) and exposure to thermal load in the near future (bottom left).

The explanatory power of these clusters was $R^2 \approx 0.74$ for walking distances to parks, $R^2 \approx 0.67$ for the sum of summer days per year, and $R^2 \approx 0.59$ for the percentage of elderly people (explaining approximately 74%, 67% and 59% of the variation in the data, respectively).

It is worth noting that the parameters considered comprise values for different time periods (2013 demographic data; latest street and path network; climate scenarios for 2021–2050). As the street and path network is considered a largely persistent urban infrastructure, the distortion by a comparison with demographic data from 2013 is regarded to be tolerable in this study. Thermal load is essentially caused by the type of building structure, the surface sealing and the vegetation deficit, which are all relatively persistent characteristics of urban morphology. Therefore, the spatial pattern of summer days in the scenario for 2021–2050 is very similar to the spatial pattern of the reference with measurement data for 1971–2000. What the future scenario highlights is the increasing number of summer days per 100 x 100m grid cell. Taking modelling results for future climate scenarios into account is justified because the methodology presented here itself provides future scenarios based on the present situation. This might be compared to alternative scenarios and contribute to an informed evidence base for urban planners and decision makers.

**Table 1:** Median walking distances to parks, proportions of senior citizens, and summer days per year for each of the identified clusters (cluster numbers correspond with Figure 2). Values which are less/greater than the median over all census tracts are printed in italics/bold respectively.

| Cluster number | Walking distance to parks (m) | Proportion of senior citizens (%) | Summer days per year |
|---|---|---|---|
| 1 | **2743** | *15.7* | *70* |
| 2 | *183* | **63.7** | *62* |
| 3 | **1739** | **29.3** | *73* |
| 4 | **789** | *17.1* | *27* |
| 5 | *281* | *14.1* | **82** |
| 6 | **1536** | **23.6** | *58* |
| 7 | *345* | **20.6** | *61* |
| 8 | **1662** | *15.5* | *66* |
| 9 | *379* | *11.1* | **78** |
| 10 | **829** | *16.1* | *73* |
| 11 | *230* | *17.8* | **76** |
| 12 | *511* | **24.6** | *71* |
| 13 | **1164** | **25.3** | **78** |
| 14 | *212* | **24.4** | **81** |
| 15 | **599** | *17.3* | **77** |
| Median over all census tracts | 548 | 19 | 75 |

As can be seen in Table 1, spatial cluster 13 best fits the combination of parameters of interest, i.e. long walking distances to parks, high proportions of senior citizens, and high susceptibility to urban heat. The median values of all parameters in this cluster are: ($\overline{\text{Walking distance to parks}}_{\text{Cluster13}} \approx$ 1164m; $\overline{\text{Proportion of senior citizens}}_{\text{Cluster13}} \approx$ 25.3%; $\overline{\text{Summer day per year}}_{\text{Cluster13}} \approx$ 78). These values are above the median values over all census tracts: ($\overline{\text{Walking distance to parks}}_{\text{Cluster13}} \approx$ 548m; $\overline{\text{Proportion of senior citizens}}_{\text{Cluster13}} \approx$ 19%; $\overline{\text{Summer day per year}}_{\text{Cluster13}} \approx$ 75). This cluster is the only one with higher values in all three parameters than the median values over all census tracts (printed in bold in Table 1). For instance, in comparison to cluster 3, values for walking distance to parks and proportion of senior citizens are higher than the median values over all census tracts. However, the number of summer days per year in cluster 3 is lower than in cluster 13 and lower than the median value over all census tracts.

Figure 3 provides a more detailed comparison of the distributions of these parameters over all census tracts and within cluster 13. It shows that the median values of all three parameters are higher in this cluster compared to all census tracts. Additionally, the median walking distances to parks and the proportion of senior citizens are greater in cluster 13 than the 50% quantile range over all census tracts. This difference in the distribution of values is even more pronounced for the proportion of senior citizens. For this parameter, the 50% quantiles of cluster 13 (red box in Fig. 3) do not overlap with those over all census tracts (black box in Fig. 3). This strongly indicates a higher proportion of senior citizens in the cluster in question compared to all census tracts.

Accordingly, cluster 13 is highlighted in Table 1 and Figure 2. The map in Figure 2 shows that the spatial cluster of interest is located in the north-eastern outskirts of the city of Salzburg. Suitable climate adaptation in this particular area could comprise planning measures for more urban green space. This could satisfy the ecosystem service demands of senior citizens in particular as a target group which is especially vulnerable to urban heat loads.

Nevertheless, as the identified cluster is located close to the city's administrative border, the effects of being near the city's periphery might be considerable. For this cluster, green space other than urban parks, outside the city boundaries, might be accessible. Accordingly, the city surroundings and urban–rural interconnections should be taken into consideration if applying the method presented here for regional or urban planning.

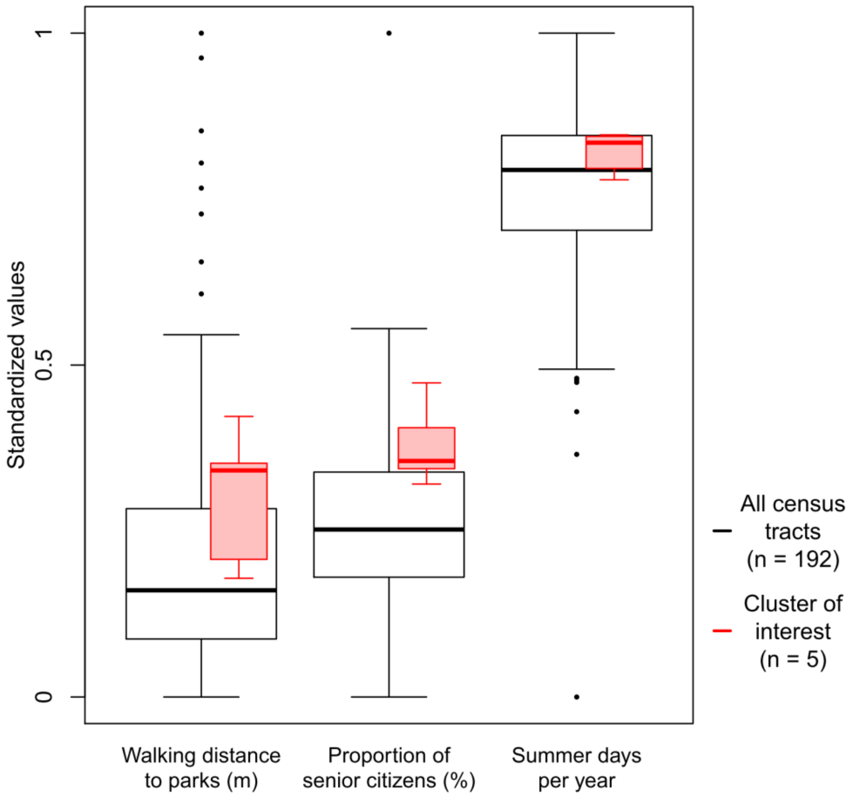


**Figure 3:** Distribution of the walking distances to parks, proportions of senior citizens, and mean number of summer days over all census tracts in comparison to the distribution of these parameters in the cluster of interest (number 13). Median values are represented as bold horizontal lines, the 50% quantile is represented as boxes, the 95% quantile is represented as 'whiskers', and outliers are shown as dots.

## 4 Conclusion and outlook

By applying the spatial functionality of GIS and using Grouping Analysis on the accessibility, demographic and climatic characteristics of census tracts, (preferably) spatially contiguous and homogeneous areas were identified. This could help planners to be more effective in applying strategies for climate change adaptation to areas with similarities in the need for action. Simply selecting census tracts that imply a pre-defined combination of attributes above particular threshold values would constitute an alternative and straightforward method. However, this would result in potentially isolated features of interest rather than in contiguous and homogeneous spatial clusters to which targeted urban planning measures with large scale effects can be applied (such as the creation of a park). This methodical advantage becomes more obvious as the analysis resolution is increased to city blocks or even individual buildings. The limitation of the analysis presented here lies in the demographic data being aggregated to census tracts based on population distributions. However, this spatial aggregation scheme is related to the analytical basis of both the urban climate maps and the accessibility metrics. First, the climate modelling applied to derive the data models the interactions between the buildings and the atmosphere in a sophisticated manner, in a microscale urban climate model that uses parameters of land-use data, building structure and variations in elevation in great detail (Žuvela-Aloise et al., 2012). Second, network analyses for the calculation of walking distances to parks can be applied to any scale that is relevant for urban planning, i.e. city districts, census tracts, city blocks, or even individual buildings. For this study, network analyses were conducted for residential buildings and aggregated to census tracts. Given that climate, accessibility and demographic data are generally available to municipalities on a much finer scale than the data used in this study, the methodology presented here might be applied by city administrations to generate much more precise and better-informed outcomes. This could provide decision makers with new insights for better-informed, targeted and therefore more sustainable planning of urban green spaces.

## References

Arnberger, A., Eder, R. (2011): The influence of age on recreational trail preferences of urban green-space visitors: a discrete choice experiment with digitally calibrated images. In Journal of Environmental Planning and Management 54 (7), pp. 891–908. DOI: 10.1080/09640568.2010.539875.

Barbosa, O., Tratalos, J.A., Armsworth, P.R., Davies, R.G., Fuller, R.A., Johnson, P., & Gaston, K.J. (2007): Who benefits from access to green space? A case study from Sheffield, UK. In Landscape and Urban Planning 83 (2–3), pp. 187–195. DOI: 10.1016/j.landurbplan.2007.04.004.

Botzat, A., Fischer, L.K., & Kowarik, I. (2016): Unexploited opportunities in understanding liveable and biodiverse cities. A review on urban biodiversity perception and valuation. In Global Environmental Change 39, pp. 220–233. DOI: 10.1016/j.gloenvcha.2016.04.008.

Comber, A., Brunsdon, C., & Green, E., (2008): Using a GIS-based network analysis to determine urban greenspace accessibility for different ethnic and religious groups. In Landscape and Urban Planning 86 (1), pp. 103–114. DOI: 10.1016/j.landurbplan.2008.01.002.

Früh, B., Becker, P., Deutschländer, T., Hessel, J.D., Kossmann, M., & Mieskes, I.(2011): Estimation of Climate-Change Impacts on the Urban Heat Load Using an Urban Climate Model and Regional Climate Projections. In J. Appl. Meteor. Climatol. 50 (1), pp. 167–184. DOI: 10.1175/2010JAMC2377.1.

Gill, S.E., Handley, J.F., Ennos, A.R., Pauleit, S. (2007): Adapting Cities for Climate Change. The Role of the Green Infrastructure. In Built Environment 33 (1), pp. 115–133. DOI: 10.2148/benv.33.1.115.

Kabisch, N., & Haase, D. (2014): Green justice or just green? Provision of urban green spaces in Berlin, Germany. In Landscape and Urban Planning 122, pp. 129–139. DOI: 10.1016/j.landurbplan.2013.11.016.

Kuttler, W. (2011): Climate change in urban areas, Part 1, Effects. In Environmental Sciences Europe 23 (1). DOI: 10.1186/2190-4715-23-11.

Loibl, W., Tötzer, T., Köstl, M., Nabernegg, S., & Steininger, K.W. (2015): Cities and Urban Green. In Steininger, K.W., König,M., Bednar-Friedl,B., Kranzl, L., Loibl, W., Prettenthaler, F. (Eds.): Economic Evaluation of Climate Change Impacts: Development of a Cross-Sectoral Framework and Results for Austria. Cham: Springer International Publishing, pp. 323–347. DOI: http://dx.doi.org/10.1007/978-3-319-12457-5_17.

Neuvonen, M., Sievänen, T., Tönnes, S., & Koskela, T. (2007): Access to green areas and the frequency of visits – A case study in Helsinki. In Urban Forestry & Urban Greening 6 (4), pp. 235–247. DOI: 10.1016/j.ufug.2007.05.003.

Nicholls, S. (2001): Measuring the accessibility and equity of public parks. A case study using GIS. In Managing Leisure 6 (4), pp. 201–219. DOI: 10.1080/13606710110084651.

Schipperijn, J., Ekholm, O., Stigsdotter, U.K., Toftager, M., Bentsen, P., Kamper-Jørgensen, F., & Randrup, T.B. (2010): Factors influencing the use of green space: Results from a Danish national representative survey. In Landscape and Urban Planning 95 (3), pp. 130–137. DOI: 10.1016/j.landurbplan.2009.12.010.

Stadtgemeinde Salzburg (2016): Bevölkerung am 31.10.2013 in der Stadt Salzburg nach Geschlecht, Alter, Staatsangehörigkeit und Geburtsland. Quelle: STATcube – Statistische Datenbank von STATISTIK AUSTRIA.

WHO (World Health Organization) (2007): Global Age-Friendly Cities: A guide. Retrieved from http://www.who.int/ageing/publications/Global_age_friendly_cities_Guide_English.pdf (13.01.2017)

ZAMG (Zentralanstalt für Meteorologie und Geodynamik, Austrian National Weather Service) (Ed.) (2016): Stadtklima Zukunft. Retrieved from https://www.zamg.ac.at/cms/de/klima/informationsportal-klimawandel/daten-download/stadtklima-zukunft

Žuvela-Aloise, M., Koch, R., Buchholz, S., & Früh, B. (2016): Modelling the potential of green and blue infrastructure to reduce urban heat load in the city of Vienna. In Climatic Change 135 (3-4), pp. 425–438. DOI: 10.1007/s10584-016-1596-2.

Žuvela-Aloise M., Nemec J., Oberzaucher J., & A. Neureiter (2012): BMWFW Projekt SISSI-2: Simulationen von Städtischen Klimaszenarien 2. ZAMG Endbericht, 63 pp. Edited by Zentralanstalt für Meteorologie und Geodynamik (ZAMG).