High Resolution Thermal Stress Mapping In Africa: Decision Maps for Urban Planning in Johannesburg

Floris C. Boogaard[1], Jeroen Kluck[2], Marieke de Groen[3]

Abstract

Urban planning will benefit from tools that can assess the vulnerability to thermal stress in urban dense cities. Detailed quick-scan heat stress maps, as made in this study for Johannesburg, have proven valuable in the decision-making process on this topic. It raised awareness on the urgent need to implement measures to tackle the effects of climate change and urbanization. Awareness on heat stress has led to the implementation of measures to mitigate the effects of climate change. As in other countries, nature-based solutions (e.g. green roofs and walls, swales, rain gardens, planting trees etc) are considered in urban areas in South Africa for various reasons. The awareness of the effect of nature based solutions on heat stress is still low, which can be improved by the use of heat stress maps. Some of these measures are already mapped on the open source web tool, Climate-scan (www.climatescan.nl) for international knowledge exchange around the globe.

Keywords: heatstress, modelling, climate adaptation, Urban Planning, thermal stress

Introduction

Thermal stress has become a key issue for many cities around the world. Densely-populated urban landscapes with concomitant infrastructure (asphalt, concrete, brick, metal) soak up heat from sunlight. This energy absorption leads to "*urban heat islands*", where cities experience higher-than-normal heat temperatures, as compared to surrounding areas. Urban areas throughout the world are exposed to heat stress and the resultant effects on infrastructure, livelihood, health etc. (see **Figure 1**). With the continuing impacts of climate change, thermal stress - already experienced in dense urban areas - will become more acute and will lead to serious problems such as indicated in (figure 1) the mindmap, which is used in the Netherlands to discuss on urban heat issues (figure 1). Therefore, urban planning departments are in need of tools that can assess the vulnerability to thermal stress so that they can

[1] Hanze University of Applied Science, Groningen, The Netherlands
Email: floris@noorderruimte.nl
[2] University of Applied Science Amsterdam, The Netherlands
[3] AquaLinks Research and Implementation, Johannesburg, South Africa

plan the implementation of measures to reduce heat stress, such as nature based-solutions (green roofs and walls, planting trees, swales, raingardens etc). Also, the maps will assist in making stakeholders and role players such as property developers aware of heat stress effects. Quick scan climate models can visualize priority areas to address several challenges in the urban dense areas, such as flooding, drought etc. (Boogaard et al., 2017). Quick scan detailed heat stress models are relatively new and are under development to provide urban planners detailed insights into the heat stress effect in cities, at a street, or even object level.

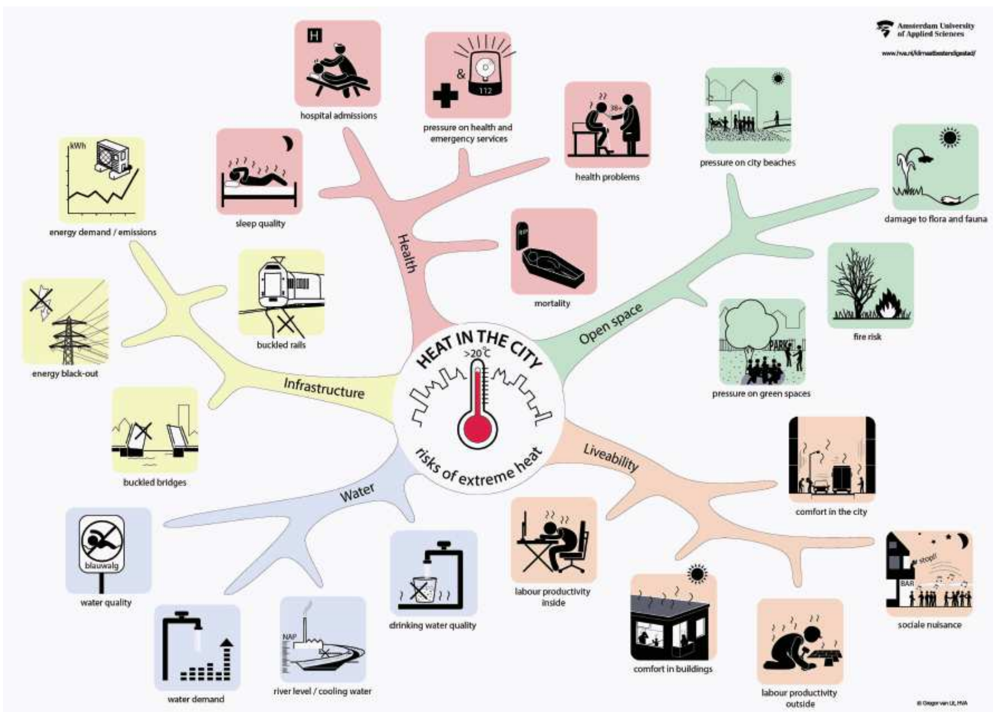

Figure 1 *Heat stress effecs in the city (Source : Klok and Kluck, 2016)*

In Johannesburg and other towns in South Africa, there are tree planting programmes by municipalities or sponsored by corporates or implemented by the towns (figure 2), not just for heat stress but for air quality and for liveability. This is also necessary to compensate for the town planning in the apartheid-area (Newspaper article King, 2016). Heat stress maps are currently not applied in South Africa.

Figure 2 (left) Mist machines as a common way in affluent areas in restaurants in South Africa to subdue heat stress. (Source : http://magiquemist.co.za/ (right) Tree planting day on school in Soweto, South Africa (Source : http://www.lifegreengroup.co.za)

Objectives

The objective of this research is the development of a detailed geographic information system (GIS)-based thermal stress map for cities like Johannesburg. While maps on flooding, drought, land subsidence (resulting in damage to infrastructure)are widely used (**Figure 3**), maps indicating heat stress in cities are relatively new for target user groups, such as urban planners, to assess the resilience and well-being of cities with these high resolution decision maps for urban planning.

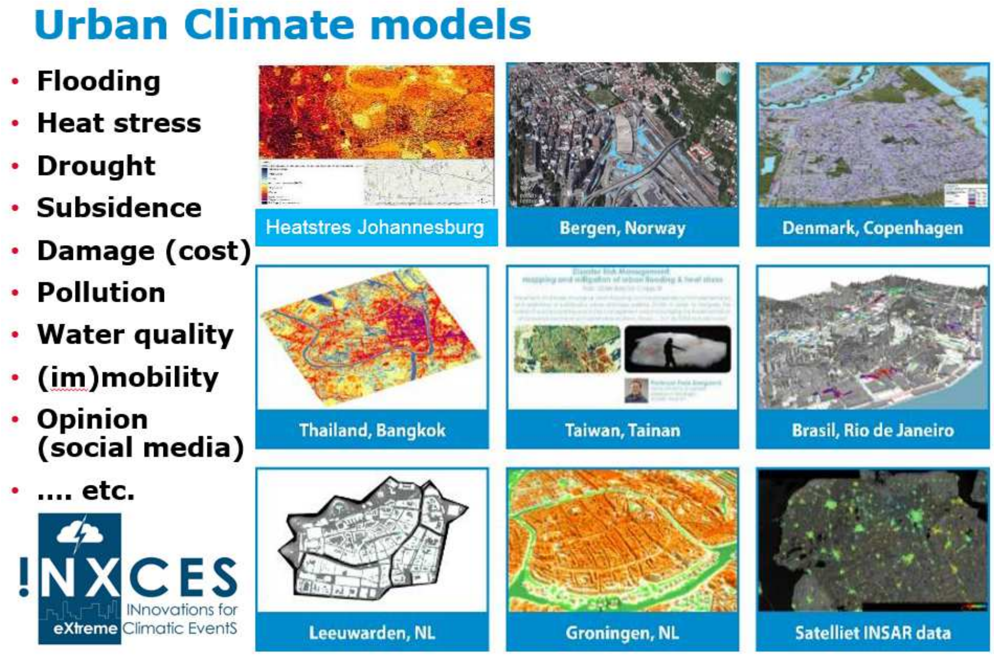

Figure 3 *Visualisation of outcomes of several quickscan climate models for urban planning (Source: www.inxces.eu, Boogaard et al 2017)*

Method

The quick-scan GIS-based thermal stress map of Johannesburg was developed in order to give a quick insight into the possible thermal stress locations in a part of the city. It is based on an accurate Digital Elevation Model in which physical processes are modelled in detail for a limited area. For a quick insight into thermal stress on a larger scale, to limit computation times, some rough simplifications (of the actual physical processes can be made (Boogaard et al., 2016). Those simplifications imply that the (relative) increase in air temperature is a summation of local effects like presence of buildings, trees, greenery and water) (Kluck et al., 2015). The maps present the PET (Physiological Equivalent Temperature) at the hottest hour of an almost windless day and are presented relative to the rural temperature of a meadow. The PET is calculated from the local estimation for air temperature, wind, and humidity. The choice for the hottest time of at a windless day makes that the direct radiation has a major influence on the PET (much more than air temperature, wind (because windless), and humidity).

To make a detailed map the following data is needed: Topographical maps with detailed information on materials, roads, waterways and dataset inclusive of the height of all infrastructure and trees (to model shadow effect).

Combining the elevation model, the dataset with buildings and aerial photographs, a model of the city is constructed to get a better overview of the outcomes of the model. The maps give a detailed estimate of the maximum physiological equivalent temperature (PET) during a heat wave. PET is a measure of thermal comfort.

Findings

The heat stress map and topographic map of Johannesburg (**Figure 4**) made for this study indicates in red colour open, unshaded areas where high PET (thermal comfort) values can be expected, as in other pilots around the world. The heat stress map and topographic map of Johannesburg made for this study indicates hot areas in red to purple ('much warmer' and 'very much warmer') where high PET (thermal comfort) red values can be expected. Those are generally open spaces with hardly any shadow and greenery. The thermal maps for the African, Dutch and Asian cases are used to compare the differences in simulation results between different climates zones.

Figure 4 *Heat stress map for Johannesburg (Source: Authors own)*

The dark red areas in **Figure 4** indicate 'very much warmer' (corresponding to the legend) areas where heat stress or thermal discomfort will be most experienced, and measures to mitigate these high temperatures will be advised. Measures that provide shading (trees or fabric) or minimize paving (replacing stones by green) are mostly implemented to lower temperatures in the urban dense area.

Figure 5 implemented measures to tackle climate change effect such as heat stress. Left: shading provided by cloth over shopping streets in Coimbra, Portugal. Right: stones removed from urban dense area of Amsterdam for lower temperatures and infiltration of stormwater (source: www.climatescan.nl)

Conclusion

With previous climate modelling around the globe, the end result is an international comparison of the potential use of heat stress-maps under different climates in Europe, Asia and Africa. These maps are ideal quick-scan tools for urban planners who, in combination with other tools, use it to plan. In the city selected for this study, Johannesburg, as in other cities such mapping tools have proven valuable in the decision-making process and it is envisaged that they will have similar successes in other cities the world over. In Europe and Asia, these maps have been an important input for master classes on climate adaptation in The Netherlands and Taiwan. It raised awareness on the need to implement measures to tackle heat stress and has led to consideration of implementation of various sustainable urban drainage systems in The Netherlands (Kluck et al., 2018).

Next steps

The heat stress maps are intended for use by urban planners and other stakeholders and decision makers to assess the resilience and well-being of cities. Such use will be tested in 2019 in the project by the province of Gauteng of which Johannesburg as part of a research project on the use of Sustainable Urban Drainage Systems.

Johannesburg is engaging on a process to develop a 'Greening and Green Infrastructure Strategy of Johannesburg' headed by the Gauteng City Region Observatory, in which the maps can be studied as information. It would also be useful to find out if the maps are convincing for property developers.

The heat stress maps are clearly related with land cover (water, green), which gives an argument for urban planners for implementing green and blue measures from the perspective of mitigation of heat stress. The next step would be, funding permitting, that verification of this model outcome will be conducted with field data from weather stations in the city as well as field visits with surveys and measurements. TAHMO and SAWS weather stations in Johannesburg are measuring all heat stress related parameters, including temperature, solar radiation, humidity and wind speed. These are useful for detailed calibration of the maps and outcomes of fieldwork.

References

Boogaard F., Kluck J, Schoof G, Bosscher M. (2017). '*The need for Inovations for eXtreme Climatic EventS (INXCES), the progress of flood modeling case Bergen Norway'*. Procedia Engineering Volume 209, 2017, Pages 56–60. Elsevier, Bucharest, 2017. Available: https://doi.org/10.1016/j.proeng.2017.11.130,

Boogaard F., Vojinovic Z., Yu-Cheng C., Kluck J. Lin T. (2016) '*High resolution decision maps for urban planning: a combined analysis of urban flooding and thermal stress potential in Asia and Europe*'. ICSEWR, Melaka. Malaysia.

Kings, S. Beyond the inferno: How SA cities must green up or burn out Newspaper article Mail&Guardian South Africa, 15 Jan 2016

Klok L. and Kluck J. (2016), Reasons to adapt to urban heat (in the Netherlands) November 2016, Urban Climate, DOI: 10.1016/j.uclim.2016.10.005

Kluck J., Loeve R., Bakker W., Kleerekoper L., Rouvoet M., Wentink R., Viscaal J., Klok L., Boogaard F. (2018). '*The climate is right up your street, The value of retrofitting in residential streets, A book of examples*'. ISBN 978-94-92644-06-0, Amsterdam, The Netherlands.