Environmental Research 157 (2017) 135–144

Contents lists available at ScienceDirect

Environmental Research

journal homepage: www.elsevier.com/locate/envres

Regulating urban surface runoff through nature-based solutions – An assessment at the micro-scale

Teresa Zölch[a,*], Lisa Henze[b], Patrick Keilholz[c], Stephan Pauleit[b]

[a] Technical University of Munich, Centre for Urban Ecology and Climate Adaptation, Germany
[b] Technical University of Munich, Chair for Strategic Landscape Planning and Management, Germany
[c] DHI WASY GmbH, Office Munich, Germany

ARTICLE INFO

Keywords:
Climate change adaptation
Ecosystem services
Evapotranspiration
Green infrastructure
Stormwater management

ABSTRACT

Urban development leads to changes of surface cover that disrupt the hydrological cycle in cities. In particular, impermeable surfaces and the removal of vegetation reduce the ability to intercept, store and infiltrate rainwater. Consequently, the volume of stormwater runoff and the risk of local flooding rises. This is further amplified by the anticipated effects of climate change leading to an increased frequency and intensity of heavy rain events. Hence, urban adaptation strategies are required to mitigate those impacts. A nature-based solution, more and more promoted in politics and academia, is urban green infrastructure as it contributes to the resilience of urban ecosystems by providing services to maintain or restore hydrological functions. However, this poses a challenge to urban planners in deciding upon effective adaptation measures as they often lack information on the performance of green infrastructure to moderate surface runoff. It remains unclear what type of green infrastructure (e.g. trees, green roofs), offers the highest potential to reduce discharge volumes and to what extent. Against this background, this study provides an approach to gather quantitative evidence on green infrastructure's regulation potential. We use a micro-scale scenario modelling approach of different variations of green cover under current and future climatic conditions. The scenarios are modelled with MIKE SHE, an integrated hydrological simulation tool, and applied to a high density residential area of perimeter blocks in Munich, Germany. The results reveal that both trees and green roofs increase water storage capacities and hence reduce surface runoff, although the main contribution of trees lies in increasing interception and evapotranspiration, whereas green roofs allow for more retention through water storage in their substrate. With increasing precipitation intensities as projected under climate change their regulating potential decreases due to limited water storage capacities. The performance of both types stays limited to a maximum reduction of 2.4% compared to the baseline scenario, unless the coverage of vegetation and permeable surfaces is significantly increased as a 14.8% reduction is achieved by greening all roof surfaces. We conclude that the study provides empirical support for the effectiveness of urban green infrastructure as nature-based solution to stormwater regulation and assists planners and operators of sewage systems in selecting the most effective measures for implementation and estimation of their effects.

1. Introduction

Urban development leads to changes of surface cover that disrupt the hydrological cycle in cities. In particular, impermeable surfaces, compacted soils and the removal of vegetation reduce the ability to intercept, evapotranspire, store and infiltrate rainwater (Whitford et al., 2001). As a consequence, the volume of stormwater runoff, especially the peak runoff magnitude, and the risk of local flooding rises.

Anticipated effects of climate change leading to an increased frequency and intensity of heavy rain events pose an additional challenge on urban hydrology and further amplify the flood risk (Revi et al., 2014). This can have severe negative impacts on cities (Endreny, 2006), such as Copenhagen has experienced in 2011 during a severe cloudburst event with major infrastructure disruptions and high insurance claims (City of Copenhagen, 2011). Hence, effective urban adaptation strategies are required to mitigate those impacts (Perks, 2011).

In politics and academia, the use of nature-based solutions (NBS) for climate change adaptation is more and more promoted (Eggermont et al., 2015; EC, 2015). NBS can be defined as solutions using nature

Abbreviations: LAI, Leaf area index; NBS, Nature-based solutions; UGI, Urban green infrastructure

* Correspondence to: Technical University of Munich, Centre for Urban Ecology and Climate Adaptation (ZSK), Arcisstraße 21, 80333 Munich, Germany.
E-mail address: teresa.zoelch@tum.de (T. Zölch).

http://dx.doi.org/10.1016/j.envres.2017.05.023
Received 17 November 2016; Received in revised form 23 April 2017; Accepted 22 May 2017

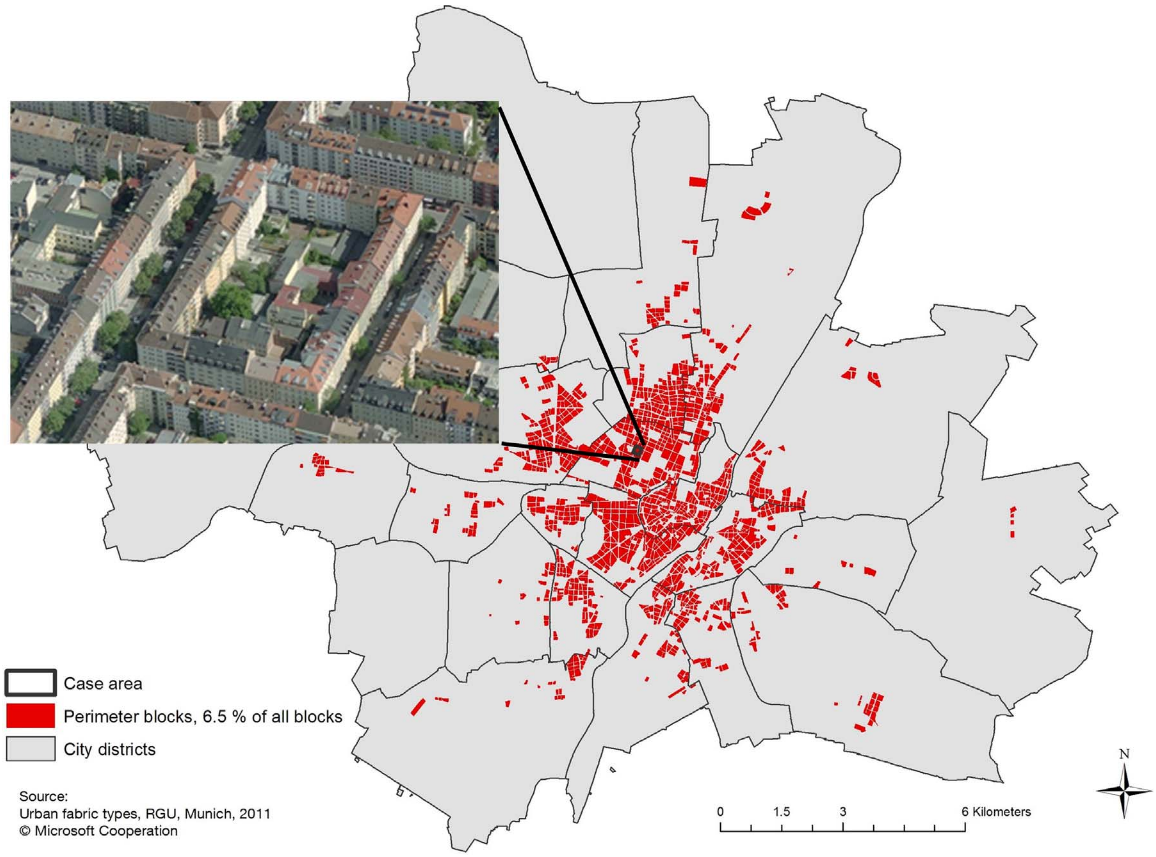

Fig. 1. Perimeter blocks in Munich and location of case area.

and ecosystem services to provide economic, social as well as environmental benefits (EC, 2015; Maes and Jacobs, 2015) and span from natural ecosystems to novel ecosystems that are either intentionally or unintentionally created by humans (Eggermont et al., 2015). In the context of hydrological issues NBS aim to maintain or to return to water flow regimes as close as possible to the natural level by using close to nature practices (Fletcher et al., 2013).

Urban green infrastructure (UGI) as a planning approach for developing coherent networks of green spaces supports the implementation of NBS (Pauleit et al., 2011). UGI contributes to the resilience of urban ecosystems by providing services to maintain or restore ecological, i.e., hydrological functions. For instance, the canopy of trees intercepts rainfall before it hits the ground, green roofs and planting pits reduce the share of sealed surfaces and allow rainwater to infiltrate into the ground. At local scale the most commonly implemented UGI measures for stormwater management are trees, green roofs, rain gardens or swale systems (EC, 2015; Jayasooriya and Ng, 2014).

Positive effects of single UGI measures on urban hydrology and the reduction of flood risk were shown by studies using different modelling approaches and empirical assessments (e.g. Armson et al., 2013; Czemiel Berndtsson, 2010; Gregoire and Clausen, 2011; Nagase and Dunnett, 2012; Schroll et al., 2011; Vanuytrecht et al., 2014; Wang et al., 2008). The potential of trees to reduce surface runoff through interception and infiltration was for instance shown by Armson et al. (2013), who compared plots covered by only asphalt and with a planted tree, and Wang et al. (2008) for complete catchments. To assess the performance of green roofs Czemiel Berndtsson (2010) reviewed existing studies and discussed various influencing factors, e.g., types of green roof and vegetation. Gregoire and Clausen (2011) as well as Trinh and Chui (2013) found a 50% retention of rainfall by an extensive green roof and according to Nagase and Dunnett (2012) grass is most effective compared to other vegetation. Trinh and Chui (2013) further showed that green roofs in combination with bio-retention systems could reduce discharge rates to pre-urbanised levels for a catchment in Singapore.

Nevertheless, it poses a challenge to urban planners in deciding upon effective UGI measures for climate adaptation. They often lack information on the performance of different UGI types or the regulating functions of UGI are unrecognised or not prioritized in urban planning strategies (Ahiablame et al., 2012; Gill et al., 2007; Lee et al., 2012; Matthews et al., 2015). Hence, it remains unclear what type of UGI has the highest potential to counteract climate change impacts by reducing urban surface runoff and to what extent.

Against this background, the study presents the – to our knowledge – first approach to quantify the effectiveness of UGI types, i.e., trees and green roofs, in regulating urban surface runoff after today's and future heavy rain events at the urban micro-scale. A modelling approach with MIKE SHE is used, which enables the calculation of the urban water balance and its complex interrelations. A scenario framework is applied to assess both the effects of different UGI types as well as effects of varying heavy rain intensities, thereof one representing the impacts of future climate change. The study addresses two main research questions: 1) How does urban surface runoff vary under different intensities of summerly heavy rain events? 2) What is the potential of different UGI types and quantities to regulate urban surface runoff after heavy rain events of varying intensities? From the results implications for the implementation of NBS in urban adaptation planning are discussed.

2. Material and methods

2.1. Study area

Munich has been selected as a case study (RGU, 2012) due to its engagement for climate change adaptation and priority being given to nature-based solutions as adaptation. Moreover, the city experiences strong population growth and increasing pressure on open space due to