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A GIS-based mapping methodology of urban green roof ecosystem services applied to a Central European city

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ABSTRACT

Green roofs provide a number of different urban ecosystem services (UESS), e.g. regulation of microclimate, support of air quality improvement, or stormwater retention. To estimate the spatial variation of green roof UESS across an urban area, a GIS-based mapping and spatial analysis methodology was established and applied to the city of Braunschweig, Germany. Based on the analysis of available geodata, in a first step, a quantity of 14,138 rooftops in the study area (14% of all buildings) was found to be generally suitable for greening. This resulted in a green roof area of 3 km^2. Based on criteria such as roof slope and minimum roof size, nearly two-thirds of these buildings (8596 buildings, 8.6% of total number of buildings) were categorised ‘appropriate’ for greening and subject to green roof UESS analysis.

The spatial distribution of green roof UESS was estimated based on the categories thermal urban climate, air quality, stormwater retention and biodiversity. Due to their potential benefits in the four UESS categories an overall assessment resulted in a number of 867 roofs (0.9% of total number of buildings) categorised as ‘high benefit’ from rooftop greening. Another 3550 buildings (3.5%) and 4179 buildings (4.2%) were defined as ‘moderate benefit’ and ‘low benefit’, respectively. The inner city area of Braunschweig appears as a hot-spot of green roof UESS, i.e. higher percentage of ‘high benefit’ green roofs in comparison to residential areas. The proposed method is a simple but straightforward approach to analyse urban green roof UESS and their spatial distribution across a city but it is sensitive to the quality of the available input geodata.

1. Introduction

Given the ongoing trend of global urbanization and the impacts of climate change on cities, there is an increased awareness and perception of different positive effects of urban vegetation, e.g. as a local climate adaptation measure (Seto et al., 2011; Rosenzweig et al., 2011; Larsen, 2015). A way to assess positive aspects of urban vegetation is the framework of urban ecosystem services (UESS), i.e. the benefits the urban population receives from ecosystems. This concept is increasingly applied in scientific studies (e.g. Gómez-Baggethun et al., 2013; Luederitz et al., 2015). UESS define provisioning (e.g. food), regulating (climate), supporting (habitat) and cultural (recreation) services of ecosystems or of specific components of ecosystems, i.e. trees, parks or street greenery (Luederitz et al., 2015).

Green roofs are one specific type of vegetated urban ecosystems (Berardi et al., 2014; Sutton, 2015). The construction of green roofs concerning number and surface area of green roofs has been globally increasing during recent years (e.g. Charpentier, 2015). As an example for Germany, a leader in green roof construction, it is assumed that about 8 million m^2 of green roof area are installed annually (FBB, 2015). Green roofs are composed as either extensive or intensive roof vegetation systems (cf. Oberndorfer et al., 2007 for a detailed review). While the former have shallow substrate depths (2–20 cm) and primarily are composed of drought-tolerant sedum vegetation and mosses which require little maintenance, the latter have deeper substrates (>20 cm), are more diverse, not limited to specific plant types, and require regular maintenance and irrigation (Oberndorfer et al., 2007; Pfoser et al., 2014). The implementation of a green roof depends on statical characteristics and on roof slope. Generally, green roofs can be installed at slopes between 0 and 30° (FLL, 2008; cf. Section 2.2).

Green roof ecosystems are characterised to provide a range of UESS, e.g. microclimate regulation, air quality improvement, stormwater retention, habitat for flora and fauna, and aesthetic

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values (Oberndorfer et al., 2007). The benefits of green roof ecosystems have been intensively reviewed in scientific literature (e.g. Oberndorfer et al., 2007; Rowe, 2011; Sutton, 2015) and will only be briefly summarised at this point. One of the most recognised environmental benefits of green roofs is the capacity for (local) thermal regulation. A couple of studies report a significant decrease of surface and air temperature above green roofs in comparison to conventional roofs (Gaffin et al., 2009; Teemusk and Mander, 2010; Jim and Peng, 2012; Heusinger and Weber, 2015). Additionally, green roofs were studied for their potential to mitigate air pollution (Getter et al., 2009; Rowe, 2011; Speak et al., 2012), and to reduce rainwater runoff (DeNardo et al., 2005; VanWoert et al., 2005; Mentens et al., 2006; Yang et al., 2015). Furthermore, the positive impact for urban biodiversity, e.g. as additional habitat for different animal species, was studied by a couple of researchers (Francis and Lorimer, 2011; Cook-Patton and Bauerle, 2012). These benefits, most of which are also related to other types of urban green infrastructure such as parks, forests or community gardens (Coutts and Hahn, 2015), are of specific importance especially in dense built inner city areas where the implementation of additional green is limited due to space constraints, space competition and regulative aspects. Green roofs, however, can be implemented on roof area already in existence.

To date relatively little is known about the existing surface area of green roofs in different cities, about potential rooftop areas suitable for future greening, or the spatial variability of UESS provided by green roofs. To foster climate friendly urban planning strategies that benefit from the effects of urban rooftop greening, it is important to assess the status-quo and potential of green roofs. A recent application of a remote sensing approach analysis (combining infrared and visible light orthophotos with building models and ground plan maps) documents the existing green roof area in the German cities of Munich, Stuttgart and Karlsruhe to amount to 1.5 m^2 per inhabitant on average (Ansel et al., 2015). Another remote sensing approach was used to assess the rooftop potential for photovoltaic system installation, green roof implementation and the environmental benefits from green roofs (e.g. carbon sequestration) in a test area in Thessaloniki, Greece (Mallinis et al., 2014; Karteris et al., 2016). The studies were based on high spatial resolution ortho-imagery, digital surface models and geospatial vector data.

In this study we define green roof potential area (GRPA) as surface area that is suitable for rooftop greening given roof dimension and constructional measures. The motivation of the present study is to assess and map the spatial variation of GRPA and their related UESS using a GIS-based methodology. We argue that the potential benefit from rooftop greening is higher in certain areas of a city, the more human well-being or health is limited due to the impact of environmental stressors, e.g. increased levels of air pollution or heat load. Consequently, UESS of green roofs are related to the characteristics and spatial extent of different urban environmental stressors (e.g. heat stress, air pollution, degree of surface sealing). Four green roof UESS were taken into account: thermal urban climate (regulative UESS), air quality (regulative UESS), stormwater retention (regulative UESS) and biodiversity (supporting UESS).

2. Material and methods

2.1. Study area and available geodata

Braunschweig, situated in Northern Germany (52°16‘28′N, 10°30‘38′E), is the second largest city of Lower Saxony with a population of 253,000. The total city area of Braunschweig amounts to 192 km^2 (Fig. 1). Buildings take a total plan area of 12.8 km^2, which represents 7% of the urban area.

The study was performed using different geodata sources in a GIS environment (ArcMap Version 10, Software ArcGIS, ESRI). The geodata was available from the Environmental Agency of the city administration of Braunschweig (Fig. 2). The data basis consisted of

a) a digital elevation model from airborne laser scanning with 2 m resolution and a height accuracy of 0.15 m including buildings and vegetation which was provided as point vector data (generated in 2003),
b) a land use map which was provided as polygon vector data consisting of defined land use types based on a biotope type mapping from 2010,
c) a building ground plan of Braunschweig which was provided as polygon vector data (generated in 2010),
d) a traffic count map giving the annual average daily traffic intensity (AADT) of the urban road network as a projection for 2015 which was provided as line vector data of the major roads (generated in 2012), and
e) a climate function map of Braunschweig generated in 2012 (Steinicke et al., 2012) which was provided as polygon vector data.

2.2. Mapping GRPA

In this study different applications of ArcGIS were used for mapping and spatial analysis, which will briefly be described in the following. GRPA were evaluated by considering the building ground plan and the digital elevation model of Braunschweig. Based on the elevation model, Triangulated Irregular Networks (TIN) were generated using ArcEsri’s 3D Analyst tools to represent surface morphology and calculate roof slopes. TINs represent the surface as a set of contiguous, non-overlapping triangular facets (Peucker et al., 1978). The point input features of the DEM were connected with a series of edges to form a network of triangles. For that purpose interpolation is needed, which in ArcGIS is done by the Delaunay triangulation method. The TIN method allows to preserve the precision of the input data, since the input features remain in the same position as the nodes and edges of the triangular facets.

The resulting roof slopes were assigned to slope classes: (A) <1°, (B) 1°–<5°, and (C) >5°. The classes were defined based on green roof constructive and technical measures that need to be considered for different roof slopes (FLL, 2008). Roof coverings such as tiled roofs are generally not suitable for greening since specific constructional measures would be required (FLL, 2008). To prevent tiled roofs from being classified as suitable, only buildings in classes A and B were accepted, since most tiled roofs were classified into class C. Buildings which did not meet this criteria were classified ‘not appropriate’. Due to roof obstructions such as chimneys, antennas, staircase and elevator shafts the calculated slopes can differ. A homogenous setup of the roof without many obstructions is preferred for greening (cf. Karteris et al., 2016). Hence, we termed buildings that have > = 75% of their roof area in slope classes A and/or B as ‘appropriate’. Building roof areas that fell into classes A or B with a percentage share <75% were categorised ‘limited appropriate’. Furthermore, a minimum roof size of 10 m^2 for a specific building was defined.

In the seven-year difference of publication of the digital elevation model (2003) and the building ground plan (2010) several new housing estates were developed and completed in Braunschweig. Hence, the building ground plan may list buildings while the elevation model still indicates undeveloped flat area, i.e. in recently developed city districts like ‘Broitzem’, ‘Mascherode’, ‘Lamme’ and ‘Volkmarode’ (Fig. 1). To prevent misclassification these buildings were excluded and assigned to the category ‘not appropriate’.