GreenCities – Monitoring Cities for Nature Based Urban Solutions and Ecosystem Services

GreenCities – Erdbeobachtung für urbane, naturbasierte Lösungen und Ökosystemdienstleistungen

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Abstract: Cities are unique living entities that evolve and require care to thrive. Earth observation of the urban environment is therefore essential to keep a watchful eye on their condition. In-situ measurements are also needed to provide details that cannot be easily derived from remotely sensed imagery. Green infrastructure and the ecosystem services they provide play an important role for the wellbeing of city populations and provide resilience against the effects of climate change. EO is essential for mapping the relevant details to produce information on which to base healthy city evolution.

Keywords: Earth observation, remote sensing, sustainable cities, ecosystem services, green infrastructure

Zusammenfassung: *Städte sind besondere Lebensräume, die sich kontinuierlich entwickeln. Um sie für ihre Bewohner zu lebenswerten Orten gestalten zu können, benötigen Stadtplaner zuverlässige Daten und Werkzeuge. Die Fernerkundung ist eines dieser Werkzeuge. Zusammen mit In-situ-Messungen ermöglicht sie ein kontinuierliches Monitoring der städtischen Umwelt und die Kartierung aller relevanten Details. Dies gilt in besonderem Maße für grüne Infrastrukturen und die von ihnen erbrachten Ökosystemdienstleistungen. Sie spielen eine wichtige Rolle für das Wohlergehen der Stadtbevölkerung und sie machen Städte widerstandsfähiger gegen die Auswirkungen des Klimawandels. Durch die regelmäßige Kontrolle von Parks und Straßenbegleitgrün, die Ableitung von potenziellen Gründächern oder das Monitoring von Hitzeinseln kann die Fernerkundung Informationen liefern, die zu einer nachhaltigen Stadtentwicklung beitragen können.*

Schlüsselwörter: Fernerkundung, nachhaltige Städte, Ökosystemdienstleistungen, grüne Infrastruktur

1 Introduction

The GreenCities project is developing innovative big data methods and applications that can help to improve the planning, management, reporting, and control of urban green infrastructure. Big data applications require relevant and up-to-date input data and measurements and the GreenCities project is concentrating on integrating and applying remotely sensed imagery, Internet of Things (IoT) sensor networks as well as inputs from local citizens. Today, Earth observations (EO) from space are one of the most accessible sources of data capable of monitoring large urban areas (Taubenböck et al., 2010). However, not all cities have the data, information, or resources to capture and take advantage of these different sources and types of useful information. The GreenCities project therefore looks at providing preparatory services related to the acquisition and integration of a variety of wanted data sources such as the locations of trees and their physical characteristics. The goal is to bring city cadasters and paper based or out-dated databases into the digital world so that they can be more easily

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accessed, integrated into different virtual models and help improve decision-making processes. The digitization of public assets around the city together with the monitoring capabilities of EO, IoT infrastructures, and the help of those living in the city can help improve the understanding of urban systems and communicate urban needs better across different city authorities and government bodies. Furthermore, the digitization of urban data can also lower maintenance costs and helps make the decision making process more transparent which hopefully improves urban life in general. The following paper presents two services developed within the GreenCities[1] project: information on the provision of ecosystem services of urban trees as well as urban sustainability indicators. Moreover, we look to the UN Sustainable Development Goals (SDG) and how EO can contribute to their reporting especially in the context of Goal 11: Make cities inclusive, safe, resilient and sustainable.

2 Activities and Results

Green infrastructure, nature based urban solutions as well as ecosystem services all contribute to making cities more liveable and sustainable while reducing the potential impacts of climate change. A number of services based on big data applications are being developed for the GreenCities project in order to prepare urban nature-based solutions and monitor ecosystem services (Kabisch et al., 2017). A simple example of a nature-based solution is the planting of urban trees for shade and temperature cooling effects. GreenCities services include the mapping and monitoring of green infrastructure, the monitoring of urban heat island effects and the determination of building roofs that are suitable for greening. Two additional services for the provision of information on ecosystem services of urban trees and the delivery of urban sustainability indicators complement the service portfolio.

2.1 Ecosystem Services

Green infrastructures, especially urban trees, provide a variety of ecosystem services. Such services can bind carbon, reduce air pollution and improve water runoff but have also positive effects on people's lives and health (Davies et al., 2017; Escobedo et al., 2019, Kardan et al.; 2015). Modelling these services and informing citizens about them is an important way to increase their awareness about the important role trees play in an urban setting and to teach about their care and maintenance. To model ecosystem services of urban trees the i-Tree[2] tools of the US Department of Agriculture were used. The underlying Urban Forest Effects model (UFORE) requires several parameters (e. g. tree species, tree height, crown diameter, weather information and air quality data) (Nowak et al., 2007). The tree related information can be determined from tree cadasters or can be assessed local surveys when public data is not available. Table 1 presents the types of services that are provided by the urban trees in Berlin. Overall, the ecosystem services provided by the 237,932 trees were analyzed. They sequester more than 4,000 tons of carbon and remove more than 120 tons of pollutants each year. Estimating the economic value of these services is another way to emphasize the benefit which urban trees provide. For example, the carbon storage of all trees from Berlin is valued at more than € 24 Mio annually.

1 https://greencities.terranea.de
2 https://www.itreetools.org/

Table 1: Ecosystem Services provided by trees in Berlin

Ecosystem services	Metric
No of trees	237,932
Carbon sequestration [ton / yr]	4,357.74
Carbon sequestration [€ / yr]	635,128.04
Carbon storage [ton]	168,878.87
Carbon storage [€]	24,614,861.69
Pollutants removed each year [ton]	123.43
Pollutants removed each year [€]	652,292.53

Since the input data derived from a tree cadaster usually includes location information for each tree, the model output can be visualized using a map. Figure 1 shows a screenshot of the developed web interface. Depending on the zoom level of the map, ecosystem service information on city and quarter level down to each individual tree is shown. To show an image of the related tree, the closest Google StreetView image is displayed, too.

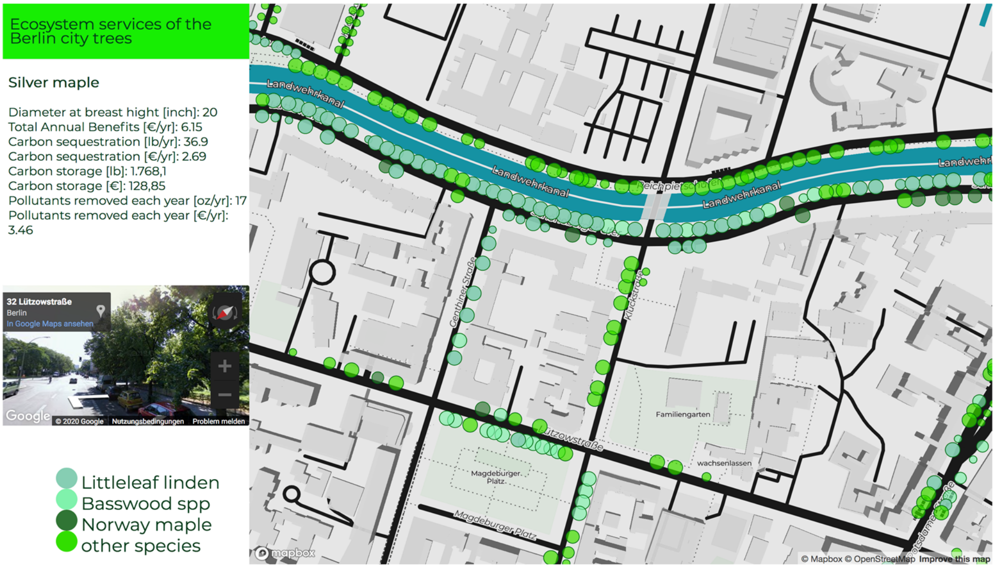

Fig. 1: Visualization of ecosystem service analysis

In its current version, however, the i-Tree tools have deficits similar to other models for evaluating ecosystem services: many of the functions estimated by the model are difficult to measure in the field thus validating the model output is challenging. Moreover, the model is unable to comprehensively quantify and assess the biodiversity or the social and cultural welfare effects of trees, even though these valuable components are often described as the most important ecosystem services for society.

2.2 Urban Tree Locations – Mapping Green Urban Infrastructure

Knowing where trees are located and the characteristics of those trees is paramount to understanding their benefits within the urban context. Most European cities do not have a digitized tree cadaster even though such information on urban green is beneficial to local authorities. This is linked to both urban planning documentation and plant management. Tree cadasters are official references that help manage public trees in a city. Due to the fact that many cities do not have this information or it is not digitized, one of the project goals was to develop an approach to accurately and automatically detect green urban areas and classify them. The goal of this service is to provide a level of detail applicable to urban planning and appropriate for the creation and maintenance of green cadasters to record green infrastructure. As shown in figure 2, automatically delineating tree crowns and their size as well as location from imagery with high accuracy is a first step in setting up such cadasters. By applying automated EO techniques, it is much faster to locate trees within cities and characterize certain properties such as crown diameter. This can help manage the more labour intensive process of in-situ measurements such as tree species identification, trunk diameter and/or tree height. While the project is also working on automating these tasks through artificial intelligence solutions based on ground measurements and photos, they are not presented in this article.

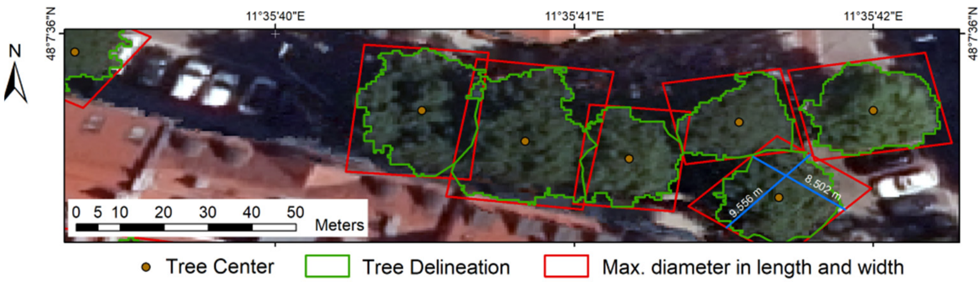

Fig. 2: Tree crown delineation with estimated stem center. These results are based on fine spatial resolution imagery already being acquired by public government agencies. The estimated stem center can be used for the geographical location of the tree.

Due to their very fine spatial resolution, orthophotos are suitable to determine detailed objects from an urban environment such as individual trees (Zhang & Qiu, 2012). However, the high temporal resolution of satellite imagery (especially Sentinel-2) allows a more frequent monitoring. Tree classifications (Zhang & Hu, 2012) and the identification of damaged trees (Malthus et al., 2000) are only two examples of using EO in an urban forest context. Figure 3 shows a comparison between a digital orthophoto (40 cm spatial resolution) and a Sentinel-2 satellite image (10 m spatial resolution).

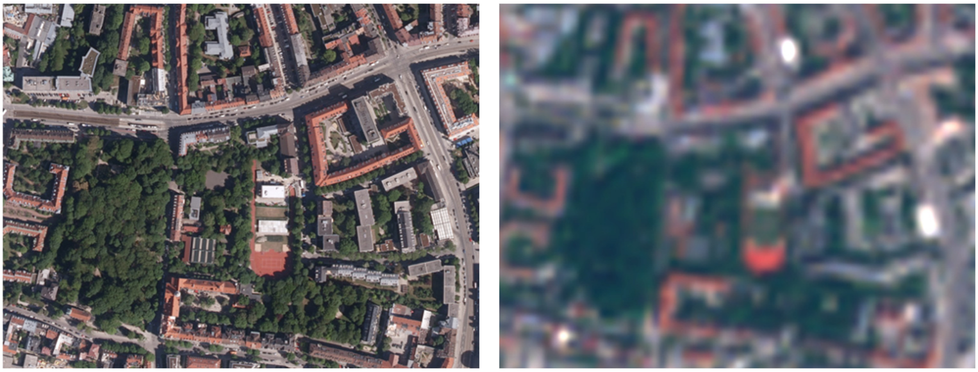

Fig. 3: Comparison of digital orthophoto and Sentinel-2 satellite image from a part of the city of Munich

It obviously depends on the use case which type of imagery is best suited for the application. Mapping individual trees requires very high resolution data while for the calculation of indicators information derived from high-resolution satellite imagery may suffice. The accuracy of the determined objects does not only depend on the spatial, spectral and temporal resolution of the available imagery. The applied classification approach as well as the available training data have also influence on the quality of the classification result.

2.3 Urban Sustainability Indicators

As part of GreenCities, different EO-based approaches were analyzed to determine green urban infrastructures. Moreover, it was examined which indicators of urban green can be calculated using remote sensing. Key criteria were the ability to deliver reliable and complete results, the calculation based on image data available to city administrations and the possibility of a highly automated implementation. Urban sustainability indicators are instruments, which urban planners can use to measure the socio-economic and environmental impact of the current urban design. They enable the diagnosis of problems and stressors and thus the identification of areas that could be addressed through good governance and scientifically sound approaches. They also enable cities to monitor the success and impact of sustainability measures. Research has developed a large number of urban related indicators and metrics (Lehner et al., 2018; Grunewald et al., 2017).

Within the GreenCities project urban sustainability indicators are created based on the Singapore Index on Cities' Biodiversity which focus on the quality and quantity of the existing green urban infrastructure (Chan, 2012). The developed indicators are easy to use and offer local decision-makers and other interest groups an efficient tool to measure the state of the local green infrastructure and identify the potential for improvement. Moreover, the use of indicators enables standardized results and allows the comparison with other cities, which can help stimulating the dialogue to develop common approaches between different municipalities. Table 2 lists the seven sustainability indicators provided by the service as well as their calculation formula, brief description and data source.

Table 2: Urban sustainability indicators provided by the GreenCities service

Indicator	Calculation Formula	Description	Data Source
1. Green Urban Infrastructure (GUI) share of city area	Area of urban green infrastructure / area of city * 100	Indicates what percentage of the city area occupies green infrastructure.	Remote sensing and earth observation data, city planning and surveying offices
2. Protected area share of GUI	Area of protected areas / area of urban green infrastructure * 100	Indicates what percentage of green infrastructure is protected areas.	Remote sensing and earth observation data, city planning and surveying offices, data on nature conservation
3. Water infiltration area	Infiltration area / city area * 100	Indicates what percentage of the city area can allow rainwater to seep away.	Remote sensing and earth observation data, city planning and surveying offices, Copernicus Imperviousness, Urban Atlas
4. Tree top cover	Area of tree tops / area of city * 100	Indicates what percentage of the city area is covered by temperature regulating tree tops.	GreenCityMap, Open Street Map, Urban Atlas
5. Leisure and educational services	Area of urban green infrastructure / 1000 inhabitants	Indicates how much area green infrastructure is accessible to 1,000 city residents.	Remote sensing and earth observation data, city planning and surveying offices, city offices, public census data
6. Accessibility of the GUI	Share of the city population living closer than 1 km from the city park / city population * 100	Indicates what percentage of the population lives less than a kilometer from the nearest city park.	Remote sensing and earth observation data, city planning and surveying offices, Urban Atlas, public census data
7. Ecosystem service per capita	Value of ecosystem service / urban population	Indicates the value of ecosystem services of green infrastructure per city dweller.	UrbanTree, public census data

2.4 UN Sustainable Development Goals

Today more than 70 % of the European population is living in cities and it is expected that the global urban population will further increase in the future (Eurostat, 2015). The United Nations (UN) identified a set of goals to help countries become more sustainable These Sustainable Development Goals3 (SDG) are objectives to implement the UN 2030 Agenda and are meant to help with understanding, reporting and planning in a more globally standardized manner in order to monitor their implementation. Overall, there are 17 SDGs addressing different domains and each has a list of targets which are measured through different indicators. As mentioned above, the indicators are tools to monitor the progress of the SDG achievements at different scales. The SDG 11 has the objective to make cities inclusive, safe, resilient and sustainable and target 11.3 aims to enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries by 2030. One indicator to monitor is 11.3.1, measuring the rate at which cities expand spatially versus the rate of their population growing. Cities evolve and transform like living organisms and a dedicated measure such as indicator 11.3.1 helps governments to better understand the urban dynamics and the speed, direction and type of growth. This can help estimating the demand of services, necessary investments or the development of policies for sustainable urbanization. EO provides not only the necessary tools to monitor how cities are spatially expanding but support the SDG monitoring in general (Andries et al., 2019). The Copernicus land monitoring program provides several products delivering the spatial information required for the calculation of the indicator. Population information is usually provided through the countries or regions statistical offices. In Europe, one applicable geospatial data source for the calculation of SDG 11 indicators is the Urban Atlas product. The Urban Atlas4 is a fine spatial resolution land cover dataset available for more than 750 European cities and functional urban areas. It was produced for the reference years 2006 and 2012. Another suitable geospatial dataset is the Imperviousness5 product that captures the percentage and change of soil sealing and the spatial distribution of artificially sealed areas. This dataset is available for the reference years 2006, 2009, 2012, 2015. The corresponding imperviousness change layers allow the identification of related land cover / imperviousness changes over time. Figure 4 shows the change of imperviousness in Berlin for the period 2006 – 2012. Red areas are newly sealed surfaces. At the bottom of the figure the newly developed airport is clearly visible. Nevertheless, many additional areas of different sizes were sealed during the six years of observation whereas no areas of significant size show a loss in soil sealings, i. e. a change from urban to natural.

[3] https://sustainabledevelopment.un.org/sdgs
[4] https://land.copernicus.eu/local/urban-atlas
[5] https://land.copernicus.eu/pan-european/high-resolution-layers/imperviousness

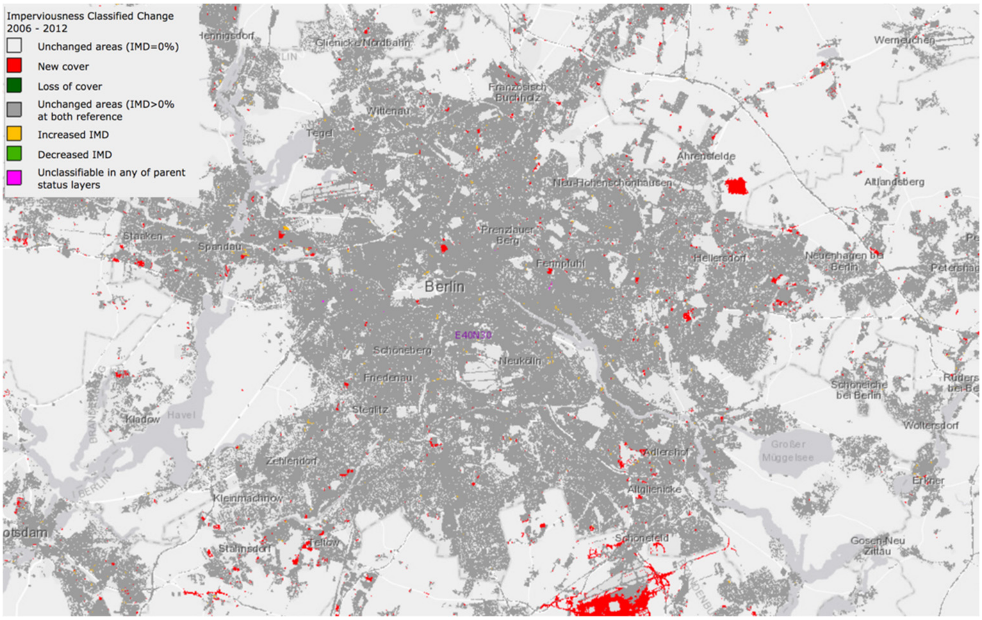

Fig. 4: Change of artificially sealed surfaces in Berlin between 2006 and 2012 as seen by the Copernicus pan-European Imperviousness Change dataset

3 Discussion

The development of nature based urban solutions as well as ecosystem services based on big data analysis techniques to identify, monitor and model urban areas show great potential for supporting public authorities, decision makers and city dwellers to help identify potential improvements to the urban environment. EO is an important data source to not only provide insights into the city's current green assets but also to monitor them and help provide insights for new developments. The developed GreenCities approaches have proven to be suitable for the differentiated detection and monitoring of urban green areas. Ground-based measures using a hand-held GPS linked to pictures taken at the tree locations were used to validate part of the data. Depending on the underlying imagery, the resulting information can be input to the modelling of ecosystem services as well as the calculation of sustainability indicators. However, the availability and accuracy of the geospatial data, and the algorithms applied are important factors influencing the amount of effort needed to acquire the wanted information and the quality of the output.

Even though the described developments were applied only to a few sample cities, the project findings demonstrate that EO-based mapping and monitoring of the urban green and the calculation of related indicators can be applied for practical use-cases. Big Data applications are the foundation of future information requirements and Smart City applications can help to face the challenges of worldwide urbanization in the context of climate change (Yigitcanlar, 2015).

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