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Classification and quantification of green in the expanding urban and semi-urban complex: Application of detailed field data and IKONOS-imagery

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ABSTRACT

Urban land cover is expanding rapidly worldwide. This major phenomenon is often accompanied by an expansion of a green component. Urban green can itself be considered as a most important but often ignored land cover category. With this study we investigate how IKONOS data can be used more exhaustively for the detection and more importantly the quantification of urban green, compared to state-of-the art investigations. This paper demonstrates how a combination of specific techniques, including pansharpening, the use of vegetation indices and object detection can enhance the possibilities to map vegetated elements and even estimate volumes of woody patches in the southern fringe of Roeselare (Belgium). The values of the soil adjusted MSAVI index are found to be related to the increase in volume of the trees (coniferous and deciduous). To analyze the vegetation in more detail, we use an object-oriented classification with MSAVI to exclude the sealed areas from the further analysis. With a rule set of segmentation and classification steps, the vegetation is defined on a higher level. Especially textural measures are of importance to separate grass from high vegetation.

1. Introduction

According to the UN compilation of global demographic data, the urban population will have increased from 48.7% in 2005 to 59.0% in 2030 (United Nations, 2006). Estimations by the World Bank show that urban built land covered some 400,000 km^2 in 2000, one half covered by cities in excess of 100,000 inhabitants. The latter fraction of global urbanization will have expanded 2.5 times by 2030, under the assumption that each new resident consumes some 500 m^2 of non-urban land, and that average urban density decreases over time with 1.7% per year (Angel et al., 2005).

The dominance of the ‘‘hard’’ elements and functions of urban areas and urbanizing areas in land cover/use schemes and in urban policies helps to fuel the perception of a permanent erasion of openness and greenness, at the cost of ecological, agricultural and other assets of the land surface. The urban category or categories are in most cases defined and described in terms of the fabric of buildings and hardened surfaces, infrastructures and the many functions linked to these artificial elements.

Beyond this built-up façade however, lies an important fraction of patches of urban green, both private and public: parks, backyards, cleared lots with regrowth, avenues with tree lines, and even fields with horticultural or agricultural use. The totality of these elements can be called the ‘‘garden complex’’, a phenomenon not sufficiently acknowledged in spatial planning and in environmental research and management (Banzhaf and Netzband, 2000; Mathieu et al., 2007). In a detailed analysis of Akbari et al. (2003) for instance, the vegetation cover of downtown Sacramento was estimated at 30%. In Flanders (northern Belgium) this garden complex can be roughly estimated (own estimations based on topographic maps) as about 13% of the territory, which is more than the regional forest cover.

Investigations of urban and peri-urban green are on the rise (Frischenbruder and Pellegrino, 2006; Kong and Nakagoshi, 2006). The reason for this increased attention is the assets of green in the urban environments varying from contributions to biodiversity (Daniels and Kirkpatrick, 2006) over positive impacts on the urban climate (Hardin and Jensen, 2007) to benefits for public health, amenity and general wellbeing (Ousset et al., 1998; Kaplan and Austin, 2004; Nielsen and Hansen, 2007), and survival strategies for residents (Seeth et al., 1998).

The problems in the monitoring of the garden complex are linked to the extreme heterogeneity of this category, in terms of spatial distribution, composition, and association with other categories, a complexity that increases from coarser to finer resolutions of observation. In global land use and land cover classification schemes developed at coarse spatial resolution, urban and urbanized areas are generally considered as one or a few classes, in contrast with the differentiation of non-urbanized cover as arable land, grassland, forestry, wasteland etc. In fine mapping

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resolution approaches, elaborated classification schemes of the non-sealed parts of urbanization have been elaborated such as in Kong and Nakagoshi, 2006.

Remote sensing is increasingly been applied as source for quantitative and qualitative analysis and mapping of urban green (Weng et al., 2004; Song, 2005; Yunhao et al., 2006; Powell et al., 2007, 2008; Yuan and Bauer, 2007). This study investigates the possibilities of an original combination of a number of techniques applied on very high-resolution satellite imagery (IKONOS) for the quantification (from area to volume) of urban green in a pilot area in Flanders (Belgium). In this way, we hope to contribute to the development of a toolbox for the monitoring of an increasingly important, but still insufficiently acknowledged category of land use.

2. Very high-resolution remote sensing of urban green: state-of-the-art

The Flemish Geographical Information Agency (FGIA—AGIV) already executed an urban green classification of the region of Flanders (2003). They used an object-classification approach based on NDVI and brightness values from IKONOS data. The overall classification accuracy of 70–80% was reached for Flanders with a kappa coefficient of 81%. Taking the region of Roeselare separately, the overall accuracy was 76%. The limitations of this classification are threefold: (1) the differentiation between vegetation and non-vegetated areas is not satisfying, (2) differentiation is made between 'grass' and 'high vegetation' only and (3) the differentiation between these 'grass' and 'high vegetation' classes is not satisfying.

The analysis of urban areas asks for a spatial resolution of less than 5 m (Herold et al., 2003). The necessary resolution is available in orthophotographs derived from standard aerial photographs (Akbari et al., 2003). Alternatively IKONOS data contains 1 m panchromatic and 4 m multispectral images. The 11 bit depth of the IKONOS pixels allows a much more detailed analysis in the intensity range compared with the 8 bit range of standard digital orthophotos, for instance in the analysis of shadowed areas (Nichol and Lee, 2005). After an independent accuracy assessment performed by the Joint Agency Commercial Imagery Evaluation Team, IKONOS (GeoEye) provides reliable datasets according to the accuracy (Zanoni et al., 2003). Therefore, we decide to work with this data instead of other very high-resolution satellite data, for instance Quickbird (DigitalGlobe).

Pansharpening is a very useful technique for IKONOS data. It refers to a series of algorithms to fuse the spectral information of the multispectral images and the spatial information of the higher resolution panchromatic images. The classical pansharpening techniques may cause color distortion in the multispectral images (Alparone et al., 2007). Nowadays the best results for this type of image fusion are derived from a combination of wavelet and intensity-hue-saturation (IHS) transformations (Alparone et al., 2007; Zhang and Hong, 2005; Otazu et al., 2005). The wavelet fusion technique only uses a part of the information in the panchromatic image, which reduces color distortions.

Next to pansharpening issues, the low spectral but high spatial information of IKONOS demands adapted classification techniques, especially for elements with similar reflectance values. Object-based classification containing a variety of input information performs better than spectral based pixel classification, which often returns a 'salt and pepper' effect (Smith and Fuller, 2001; Blashke et al., 2000; Bauer and Steinnocher, 2000; Guanaes Rego and Koch, 2003; Bock et al., 2005; Zhang and Feng, 2005).

Vegetation indices, based on the spectral values of the multispectral images, are often used for the delineation of vegetation from sealed or other not vegetated elements. Usually the Normalized Difference Vegetation Index (NDVI) is used (Greenhill et al., 2003; Zhang and Feng, 2005; Tunay et al., 2007; De Kok et al., 2003; Esch et al., 2003; Yuan and Bauer, 2007).

Other interesting information to include in the analysis of IKONOS data is textural information and spatial characteristics of the objects or the so-called spatial metrics (Puissant et al., 2005, Greenhill et al., 2003; Herold et al., 2003). The first aims for the variation of pixel values within a certain neighborhood, while the second one describes the spatial characteristics by the regions. A problem related to the textural measures is to define the optimal size of the neighborhood of pixels, or window, to take into account (6 × 6pixels by Colombo et al., 2003, 7 × 7 pixels by Puissant et al., 2005, 7 × 7 by Zhang and Feng, 2005 and Greenhill et al., 2003). Above this, the use of the moving window blurs sharp edges, which is especially problematic for borders of man made constructions (Zhang et al., 2004).

3. Methods and techniques

3.1. Study area and reference vegetation data

The area of interest is the suburban region of Roeselare, a city in the western part of Flanders, Belgium. The region is largely occupied by suburbanization and typical Flemish ribbon development (Fig. 1).

The reference field data are collected in July 2006 and in November 2007, in nine square samples of 500 m × 500 m in the southern fringe of the city. This data include qualitative information of vegetation types and quantitative information on coverage. The vegetation height of a selection of trees and hedges are measured by using a Haglöf Vertex Hypsometer. In addition, field photographs capture surrounding vegetation silhouettes and GPS (Trimble Geo XT) measurements define the exact location of the pictures with a precision within a decimeter.

Whereas the data of 2006 is particularly interesting since it is gathered shortly after the date the IKONOS imagery was captured, the collection of 2007 is more detailed and contains the field photographs. The height estimation of the other vegetation elements H_{ve} is derived from the height of the elements in the photographs (h_{ve}), referring to the measured height H, the GPS location of the pictures and the distance L_{ve} to the elements mapped in ArcGIS, according to the following formula:

$$H_{ve} = h_{ve} \times \frac{L_{ve}}{a}$$

with $a = h \times L/H$

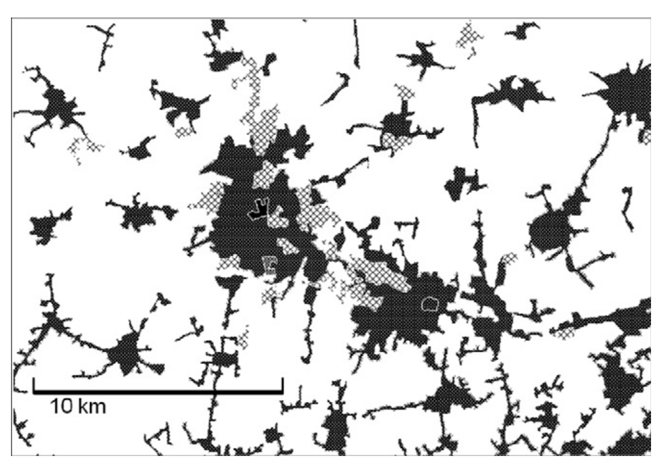

Fig. 1. Classical classification of the urban area, representing ribbon development along the main intercity roads around the city of Roeselare (extract from 'nature value map' INBO).