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Application of sub-pixel based classification for the analysis of urban land cover and land use

Theses of PhD Dissertation

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1. Introduction

Currently, more than half of the world population (52,1 %) lives in urban areas, and this is expected to increase to 67 % in 2050 (**United Nations, 2012**). Therefore, nowadays more and more emphasis is given to the urban development, and to the analysis and interpretation of the effects of processes taking place in the urban environment on the population. The task of urban ecology is to study this environmental effects and conflicts. The critical point of urban planning is the urban land use planning that requires complex thinking (**Mucsi, 1996**). Dynamically changing land-use and land cover, as spatial variables play an important role in planning and geoinformatics models. Therefore, remote sensing data and methods are becoming increasingly important in urban ecology, Furthermore, satellite imagery and aerial photography are up to date, have a good spatial extent and are cheaper in use than field work, and therefore they provide a good basis for urban analysis. The last decades have shown considerable digital image processing technological advances in geoinformatics, and provide the opportunity to acquire new spatial information and results.

Through the detection of landcover changes and the environmental and social effects of those changes, the reason of conflicts can be determined, which provide useful information to decision-makers and urban planners in future developments.

I will present the results of my research for the city of Szeged. When I defined my objectives, I tried to solve geoinformatics methodology problems, that occur in urban remote sensing and I tried to analyze and interpret geographical processes and environmental conflicts in the urban environment.

Therefore, I defined the following geoinformatics aims in my Ph.D thesis:

(1) I would like to devise a new methodology, which can determine the size of formations and objects in the urban environment. I will calculate the size of patches for census districts, than I can choose the satellite images with optimal resolution for my analysis.
(2) The amount of coverage of anthropogenic surfaces by the canopy varies during the different periods of year, spectrally mixed pixels – the pixels, that contain more than one landcover type simultaneously – the result is influenced by acquisition date of satellite imagery. Therefore, I try to find a statistical parameter, which can model the urban landcover and which is suitable for mapping the urban landcover changes.
(3) Due to the high amount of mixed pixel, urban landcover cannot be mapped with high accuracy using traditional pixel-based classification methods based on medium resolution satellite imagery. Hence, I would like to apply a methods in my research, that is able to calculate the spatial ratio of spectrally homogeneous land cover types within a pixel, and that can be used to create a better than medium resolution land cover map for the whole area of the city.
(4) Furthermore, my aim is to establish a quantitative relationship between urban land cover and land use, which can be used to objectively and automatically map the urban land use.

Decision-makers and planners have limited data and information about the societal and environmental effects of the increasing built-up area at district level. Cities consist of different districts, which all have their own demographical and infrastructural parameters and independent properties (Downtown, Inner residential area, Housing estates, suburban residential area). They require their own planning and development aims, but the collection of updated district data for the whole area of a city is slow and an expensive process.

Therefore, I defined the following geographical aims in my research:

(1) I would like to present the urban built-up map, and in general the changes and processes at district level through the spatial and temporal analysis of landcover changes. I describe the census districts of Szeged with different statistical parameters from 1980 to present, which provide a suitable basis for urban planner.

(2) Urban heat island (UHI) refers to phenomenon of higher atmospheric and surface temperatures occurring in urban areas compared to the surrounding rural areas due to urbanization. I formulated as an aim of my research, that I model the urban heat islands in Szeged by calculating the spatial and temporal distribution of the spatial ratio of artificial surfaces. Furthermore, I would like to interpret the increasing environmental impact by the increasing built-up area from the perspective of urban ecology and climatology.

(3) I would like to analyse the green space system of Szeged with indicators, which qualify and quantify for each census district the supply of vegetation and the level of conveniences. With this, I can provide information at district level to city leaders and urban planners for short-term and long-term development plans.

2. Data and methods

The basic spatial scale for the reflectance calculation was determined by a multispectral RapidEye satellite image, which was acquired from Szeged on March 24, 2011. The constellation consisting of 5 satellites is able to make acquisitions of the same area on a daily basis, producing 5-band (blue, green, red, red edge, near IR) images with 5 meter spatial resolution. Those patches that differ from their surroundings in nature or appearance were selected. These patches are relatively discrete, individual spatial shapes, which vary in size and internal homogeneity from their surrounding pixels. The segmentation method was found to be the most suitable to determine patches of homogeneous land cover. The segmentation module of ERDAS IMAGINE 2011 applies a region growing algorithm to extract homogeneous land cover patches and the groups of pixels that represent those, for the whole area of the city. Subsequently, the landscape metrics of the patches (mean patch size, edge density) were calculated and analyzed.

From the viewpoint of geographic research, it was important to use satellite imagery in change detection that have the same spatial and spectral resolution for a long period of time (30-40 years long). In the interest of being able to use the long term satellite data set, it was necessary to scarify higher spatial resolution. Therefore, the Landsat data set was selected, which is used in a large variety of applications in agriculture, geology, forestry, regional planning, education, mapping and global change research. The TM sensor on the Landsat 4 and 5 satellites collects data in 6 bands with 30 m spatial resolution, and has a 120 m resolution thermal infrared band as well. The intensity values were transformed to reflectance values using an atmospheric correction model created in Erdas Imagine.

Due to the medium resolution, in case of urban surfaces, a large number of mixed pixels may appear. The aim of Spectral Mixture Analysis (SMA) is to determine the spatial ratio of the spectrally homogeneous land cover types, the so-called endmembers, within a pixel. The Linear Spectral Mixture Analysis (LSMA) is the improvement of the SMA method, by which the ratio of land cover types can be determined by using minimum two, and in case of a Landsat image, maximum six endmembers. To be able to solve the linear system of equations of the SMA, the number of the endmembers has to be less than or equal to the number of the spectral bands of the image.

$$R_b = \sum_{i=1}^{N} f_i \cdot R_{i,b} + \varepsilon_b$$

R_b: the reflectance value of the image in band b;

N: the number of endmembers;

f_i: the ratio factor of endmember i;

R_{ib}: the reflectance value of the i^{th} endmember in band b;

ε_b: residual error.

In this research, 3 endmembers (impervious surface, vegetation, soil) were used in the normalized spectral unmixing. Because spectra for urban land cover components show significant brightness differences, it is possible to minimizing the effects of absolute reflectance values through a normalization method. Although, the spectral normalization process can reduce the spectral variation within each land cover type, it does not cause significant loss of information.

3. Results and conclusions

1. In my Ph.D. thesis I managed to work out a methodology, by the aid of which the size of objects making up city landscape and thus the spatial scale of reflectance of the city are also possible to determine (**Henits and Mucsi, 2012**). I derived the general shape sizes based on a high-resolution RapidEye (5 metres) satellite image using the method of segmentation. The size of the shapes are typically between 475 and 1050 square metres in the Downtown area, 425 to 980 square metres in the inner residential area, 475 to 1100 square metres in the housing estate area, 475 to 1100 square metres in the industrial, while in the suburban residential area they are between 450 and 1050 square metres, respectively.

2. Furthermore, I managed to find out that the average shape size throughout the whole city area is between 400 and 1100 square metres. Taking this for my basis I concluded that in the case of 30 metres spatial resolution Landsat TM satellite images, because of 30 × 30 metre cell size, a great amount of spectrally mixed pixel may appear (**Henits and Mucsi, 2012**). Thus, by means of using traditional pixel-based classification, effective urban land cover mapping is not possible to execute.

3. I succeeded in solving problem of mixed pixels via applying spectral mixture analysis (SMA) as by the aid of this subpixel-based classification method clear-cut, homogeneous surface cover (endmembers) ratios inside picture elements are possible to determine. During my analysis I applied three endmember (impervious surface,

vegetation, soil) normalised spectral unmixing and the results were fraction images belonging to the given land cover types. By this means the resulting land cover map of the total settlement area became finer than medium scale. By unsupervised (ISODATA) classification of the composites created from the fraction images I could successfully establish a relation between urban land cover and land use, hence mapping urban land use in an objective, qualitative manner.

4. Since the class dividing lines of the V-I-S model created by **Ridd (1995)** are not valid in every case (as the classes were established on the basis of samples taken from ortoimages of Salt Lake City) I created a new triangular diagram by which land use mapping in Szeged was possible to carry out.

5. By creating the vegetation map based on 8 Landsat TM satellite images taken in 1986, I managed to conclude that, because of vegetation changes taking place in the course of a year, a static NDVI image cannot be sufficient for mapping urban land cover. Furthermore, I succeeded in pointing out that there is a significantly negative relation (R^2=0,89) between yearly NDVI standard deviation and impervious surface ratio within pixels (**Henits and Mucsi, 2010**), which can be determined by the following equation:

$$y = (10{,}6 - 58{,}2 \cdot x)^2$$

y: percentage of impervious surface (0-100);

x: standard deviation calculated from NDVI.

Consequently, by employing the regression equation, although by applying several input images, and by the aid of traditional pixel-based classification I managed to extract information from sub-pixel level, therefore proving the possibility of mapping urban land cover via such method.

6. I managed to establish such a territorial statistic database via ratio maps resulting from spectral unmixing, ranging from the 1980s up to recent times, which describes processes taking place in an urban environment in a quantitative manner and, additionally, provides information about the nature of the environmental changes. With the help of maps showing the changes and statistic series of data both related to census districts I monitored the construction of apartment complexes, the building of commercial, service and industrial complexes occupying up vast pieces of land and the growing amount of built-up density the suburban residential area with detached houses.

7. By the aid of impervious surfaces ratio maps I managed to map the spatial distribution of the urban heat island from such input data that may provide more accurate results about the ratio of built-up density than previous studies based on NDVI values (**Mucsi and Henits, 2010**). In heat island intensity maps derived from the fraction images taken at different times I succeeded in identifying heat surplus resulting from built-up density and cooling areas the keeping of which might be an important factor in shaping favourable human comfort sense for citizens.

8. Based on the vegetation ratio map I managed to estimate the city's urban open space system from a qualitative aspect for each district of the city. On the basis of the fractional image of the vegetation I calculated such urban open space state indicators (urban open space size, ratio of biologically inactive surfaces, availability of urban open spaces) the characterization at district level of which in urban ecological studies due to lack of input data would be difficult to carry out.

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