Semi-Automated LULC Classification of VHR Optical Satellite Data in the Context of Urban Planning

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Abstract. One of the major phenomenon of the ongoing globalization is the rapid growing of urban areas. In the end of the 1970th, 38% of the world population were living in cities. This number increased up to 50% in 2008 and will steady rise up to two third of the world population in 2030 [1]. Urban sprawl is one of the major environmental and social concerns caused by the development of new and the growing of existing cities. Besides a quantitative reduction of land consumption, sustainable handling of the limited resource land and "smart growth" are acknowledged as key tasks for urban planning [2, 3]. Coping with these tasks requires precise and adaptive planning instruments which will be developed in the project "Gaining additional urban space (GAUS) - Detection and valuation of potential areas for inner urban development with remote sensing and GIS". This research project is dedicated to the development of a multi-criteria decision support system (MDSS) as tool for supporting urban planners and municipal management authorities with regard to urban consolidation and smart growth. The description of the framework for a land use and land cover (LULC) classification of very high resolution (VHR) optical satellite data is in the focus. The results of the object oriented analysis acts as basement for the MCDSS. The main objective is to describe a strategy to retrieve comparable classification results of different investigation areas under the preconditions of transferability and firmness to reach semi-automation.

Keywords. urban areas, urban sprawl, very high resolution satellite data, object oriented, land use, land cover classification, multi-criteria decision support system

Introduction

Since the availability of VHR satellite data new application ranges have been developed. With the launch of IKONOS II 1999 and QuickBird 2 in 2001 VHR satellite data reaches an application scale up to 1: 2.500. With a ground resolution of 0.6 m (panchromatic) and 2.4 m (multispectral), QuickBird 2 became interesting for urban planners [4]. But nowadays urban planners are often inhibited in using these data because of absence of remote sensing software and know how. Therefore a semi-automated procedure was developed.

1. Remote sensing for urban planning

1.1. Urban sprawl

The 20th century is characterized by a rapid process of urbanization and an accelerated growth of urban population. The United Nation prospected an increasing of urban population resulting in the fact that 67% of world population will live in cities in the year 2050 [1]. The ongoing augmentation of people living in cities and the quantitative rise of cities causes a spreading of urban land use patterns and the conditions of urban sprawl.

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Although there is no common understanding of Urban sprawl [3,4]: It can be described as expansion of urban development into rural areas in the urban fringe and the development of urban splinter with low density and high land consumption [5]. The main outcomes of urban sprawl are the sealing of ground surface, contaminant loads, loss of flora and fauna, expansion of built-up areas, increasing traffic volume, infrastructural problems and a loss of social interactions [5-9]. Besides a quantitative reduction of land consumption, sustainable handling of the limited resource land and "smart growth" are acknowledged as key tasks for urban planning. Coping with these tasks requires precise and adaptive planning instruments.

1.2. A multi criteria decision support system (MCDSS) for gaining additional urban space

City and regional planning have to take into consideration not only the adequate supply of their population with space, but also the protection and sustainable use of the finite resource land. In this context, smart growth and area economic planning are important [10], following the principle "spare the urban fringe, develop the inner suburbs first". This aim, however, presents challenging tasks to the responsible institutions and departments in densely populated areas, fringe zones and rural communities – tasks which cannot be mastered with traditional planning methods, but require differentiated instruments allowing for quantitative and qualitative appraisals of current building potentials as well as open spaces. Consequently a multi criteria decision support system (MCDSS) should be developed which meets the requirements for urban planners to gain additional urban space within existing urban areas. With the input data of VHR satellite images a LULC classification built the basis for ongoing steps. After the detection of potential areas (open spaces, underdeveloped areas, unused or not completely used patterns, unused buildings etc.) an evaluation of those potential areas will follow. The result is a set of stated parameters for every potential pattern and an up to date land use and land cover map which enables urban planning authorities to make objective decisions for further use.

2. Investigation area and data

The development of the classification algorithms which feed the MCDSS was progressed on two investigation areas in Germany and one in Turkey to guarantee transferability due to different urban structures and typical characteristics of different areas. With Berlin, the Ruhr-Area and Istanbul typical high urbanized parts of Europe were covered. This paper focuses on the two German training sites. The data which were processed are VHR optical satellite data from QuickBird 2 - sensor captured in 2009.

2.1. Investigated area

Berlin as the capital of Germany is emerged within the historic context of the Cold War and therefore within the separation into different states. Nowadays multiple urban cores characterize the city structure [11]. Different land use patterns alternate on small scale ranges and form a differentiated landscape with green spaces like parks and allotments as well as dense impervious structures like infrastructure, housing and industrial area. In the years between 2005 and 2007 a significant growth of the population can be recognized. Until 2020 the population will increase due to migration process up to 2% [12].

The Ruhr-Area is located in the west of Germany and can be described as city region with a total number of 53 cities and municipalities covering over 4000 km². This region has a strong cohesion emerged in a common history as mining and industrial area. The population is decreasing because of decline in mining which affects the core areas of the cities and resulting in a process of de- and suburbanization [13].

2.2. Data

The VHR optical satellite data used for the development of the classification algorithm consist of two scenes of the QuickBird 2 sensor covering a great part of Berlin (350 km²) and parts of the Ruhr-area (Bochum and Herne 240 km²) (see Figure 1). These two scenes were used as treatment group for the development of the semi-automated classification ruleset. In addition there are several IKONOS II and QuickBird 2 scenes covering different parts of the Ruhr-area which were used to check transferability and robustness of the developed classification strategy (control group).

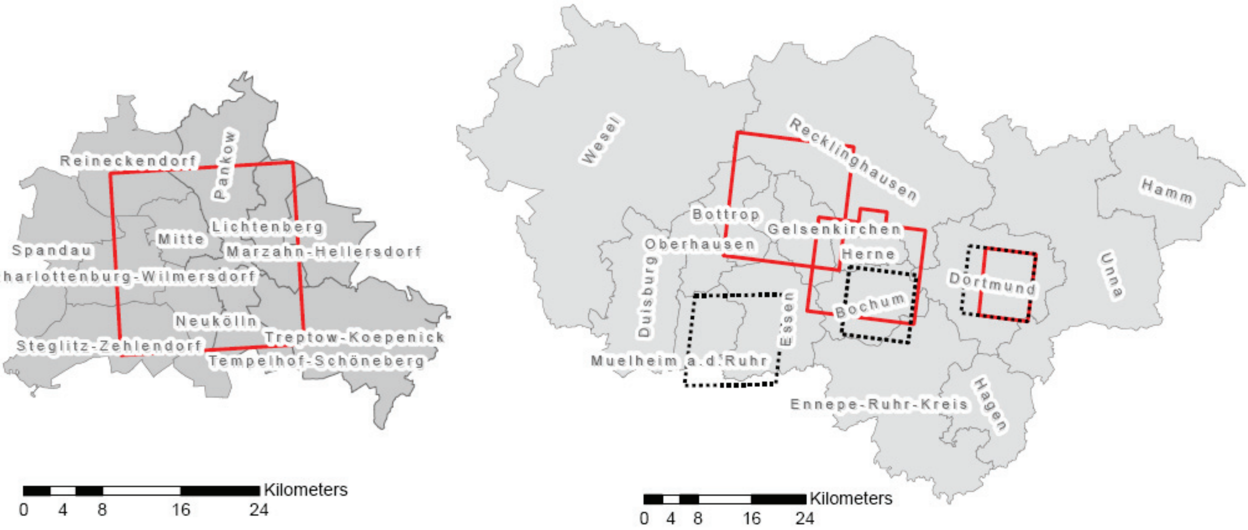

Figure 1. The two German investigation areas of the GAUS project: Berlin [left] and Ruhr area [right] covered by different QuickBird 2 - scenes [solid] and IKONOS [dotted].

Although there are comparable optical satellite data [4] there were differences in their specific characteristic which can be expressed by their metadata (listed in Table 1). Because of the different conditions in the capture task and therefore resulting diversity in image characteristics, the classification algorithm needs flexible parameters. In the case of the GAUS project dynamic thresholds were feasible to extract comparable information from the input data.

Table 1. Metadata of the treatment and control group and their different scenes (QB: QuickBird 2 / IK: IKONOS II)

Scene	GSD (m)	Clouds (%)	Sun el (deg.)	Off-nadir (deg)	Date captured
Treatment group					
QB Berlin	0.6/0.4	1	57.40	8.7	05/09
QB Bochum	0.6/0.4	14	51.10	13.3	08/09
Control group					
QB Recklinghausen	0.6/0.4	1	42.20	13.5	09/04
QB Dortmund	0.6/0.4	1	51.10	7.6	04/06
IK Bochum	1.0/4.0	1	48.77	25.5	04/05
IK Essen	1.0/4.0	0	44.54	26.2	06/05
IK Dortmund	1.0/4.0	1	41.69	22.7	04/07

3. Classification strategy

A LULC classification scheme was elaborated with regard to the overall goal of developing a transferable tool for urban planning tasks in the context of the project GAUS. In order to meet the specific requirements the classification results should include urban structures which are common to most parts of European cities. As shown in Figure 2 a specific nomenclature was developed containing land use and land cover classes. The hierarchical structure within the nomenclature doesn't represent real world relationships between those objects and classes but is useful for automatic image recognition within an object-oriented approach. There are a lot of nomenclatures for common land use classifications like *CORINE* project [14,15] or *GSE Land* project [16]. In the case of the GAUS project it was necessary to create an adjusted nomenclature which meets the requirements for use by urban planning authorities. The careful distinction between land use and land cover is a fundamental one due to different approaches in urban planning practice. The result of the classification process lead to three different maps:

- land cover extracted automatically (includes open surfaces, grass and mixed vegetation, trees, shrubs, water bodies and built-up areas),
- land use extracted automatically (with residential, industrial, commercial/services, agricultural and semi-natural),
- land use/ cover extracted manually (airport, harbour, mining and dump sites, sport and leisure facilities, parks and hobby gardens).

The classification is realized with the *eCognition Developer 8.0* software of *Definiens* which allows creating sequences of rules for image analysis. This opportunity is essential due to the requirements of transferability while these rulesets can be applied to different input data sets again.

The classification strategy contains not only automated feature extraction but also land cover categories which were extracted using additional GIS data or a manual classification by user interaction (see 3.1). Thus the process algorithm can be described as a semi-automated workflow.

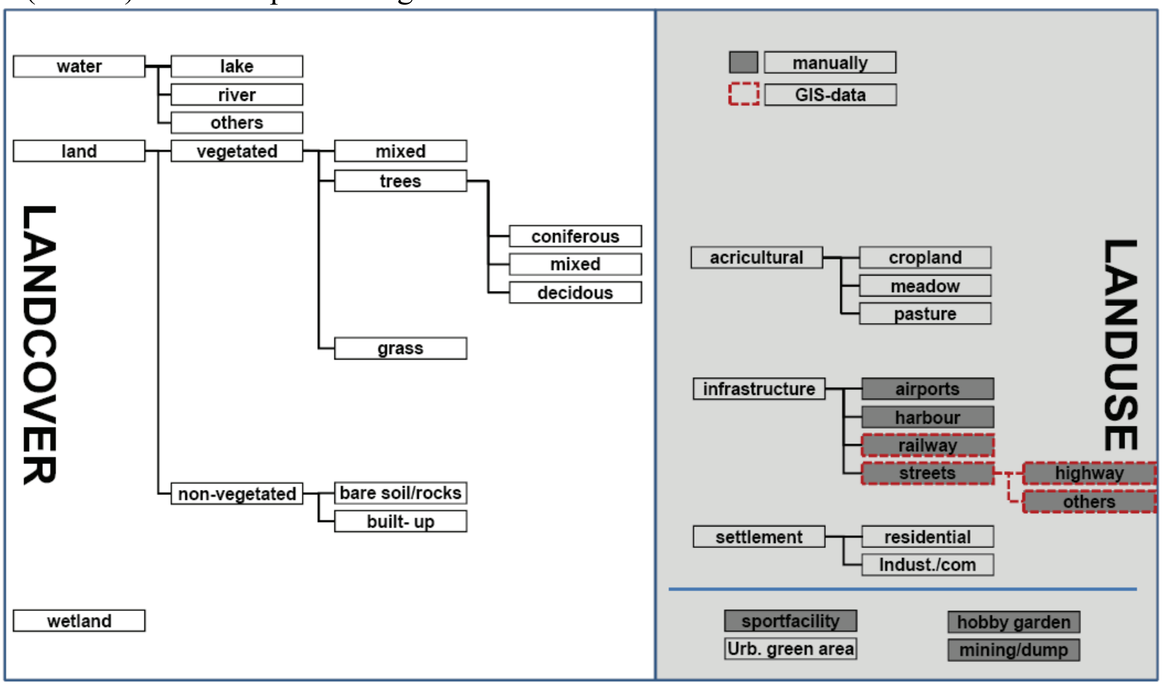

Figure 2. Nomenclature for the LULC classification of urban areas within the GAUS project divided in land use (white) and land cover (grey). (Classes with dark signature were classified manually, surrounded with the dotted line were extracted using additional GIS data.)

3.1. (Semi-)Automation of the classification procedure

Following the concept of GEOBIA [17] the automation of interpreting earth observation (EO) data is an intention of the classification algorithm. Besides this objective there is a complex area of conflict. While the framework for the project is a transferable method to extract as much information as possible with high accuracy disembogue in a predicament of finding a balance without concede between the aspects of transferability, automation and information (see Figure 3). With the embedding of additional information from GIS data and/or user interaction the relationship of the three parameters can be dissolved.

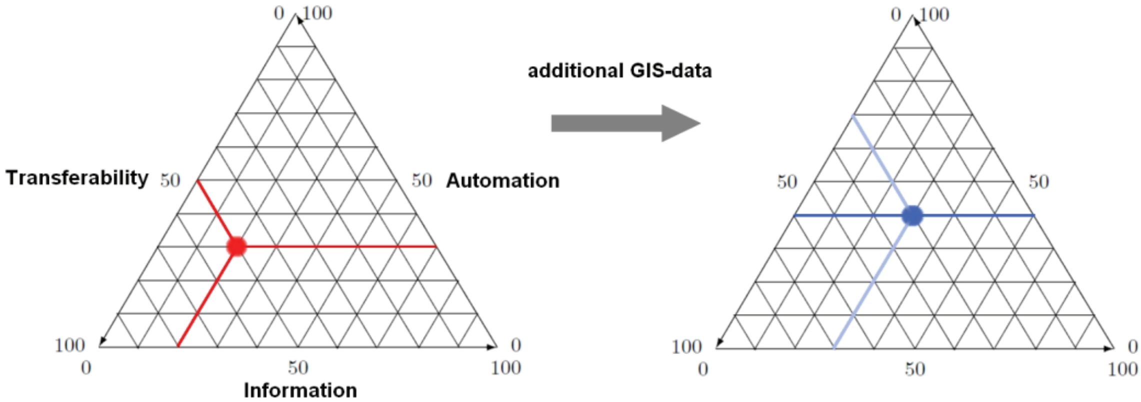

Figure 3. Automation, transferability and information in the relationship of dependence.

The dot in the left triangle of Figure 3 indicates the situation without user interaction or additional GIS data. In this case high automation can be reached only with low level of transferability and information, these are bad preconditions for urban planning purposes. The blue dot shows the situation with additional information, in this case only transferability and automation have to be in balance. The strong relationship to the information accuracy can be interrupted.

3.2. Workflow of the classification

The workflow of the classification consists of two general steps. In the first part of the semi-automated classification process the manual classification is focused. Using the graphical user interface of *Definiens eCognition Architect* the user is guided to the classification process. Some manual classification categories (see Figure 2) have to be done by simple selecting objects after automated segmentation and assign them to their belonging land use class. After that the processing goes on with the use of additional GIS data to include infrastructural information.

The extraction of the remaining LULC information is completely automated and follows a second part of the workflow. Alternating steps of segmentation and classification gain the necessary land use classes and some land cover patterns. During this step the analysis will be interrupted to get the necessary dynamic thresholds (see section 2.2) by simple user interaction. Few specific thresholds have to be adjusted by a sliding controller to reach the necessary accuracy in compliance with the criterion of automation and transferability. The results of the manual and the automated classification get merged together and can be exported in a GIS ready format to feed the MCDSS.

3.3. Classification results

The final result of the classification consists of three different maps due to classification strategy (see section 3). Most of the objects, treated during the classification procedure, belong to multiple LULC classes like an airport which is part of the classes airport, built-up, impervious and also services (see section 3). Figure 4 shows a prioritized result map where different classes from different resulting maps are merged together.

The different outputs of the LULC classification have been evaluated using an error matrix, listed in table 2. With an overall accuracy of 87.25% the results of the classification procedure for the classification area of Berlin are of acceptable precision for feeding a MCDSS in the context of urban planning.

Table 2. Error matrix of the results from classification process for the study area of Berlin

Reference/ User	Built-up	Trees/Shrubs	Grass/Mixed	Open space	Water
Built-up	19634	0	0	1540	143
Trees/Shrubs	456	14013	1639	0	67
Grass/Mixed	109	1215	10099	1382	0
Open space	1660	44	0	9054	0
Water	89	0	0	0	4278
Sum	21948	15272	11738	119776	4488
Algorithm	0.89	0.92	0.86	0.76	0.95
User	0.92	0.87	0.79	0.84	0.98
Accuracy			87.25		

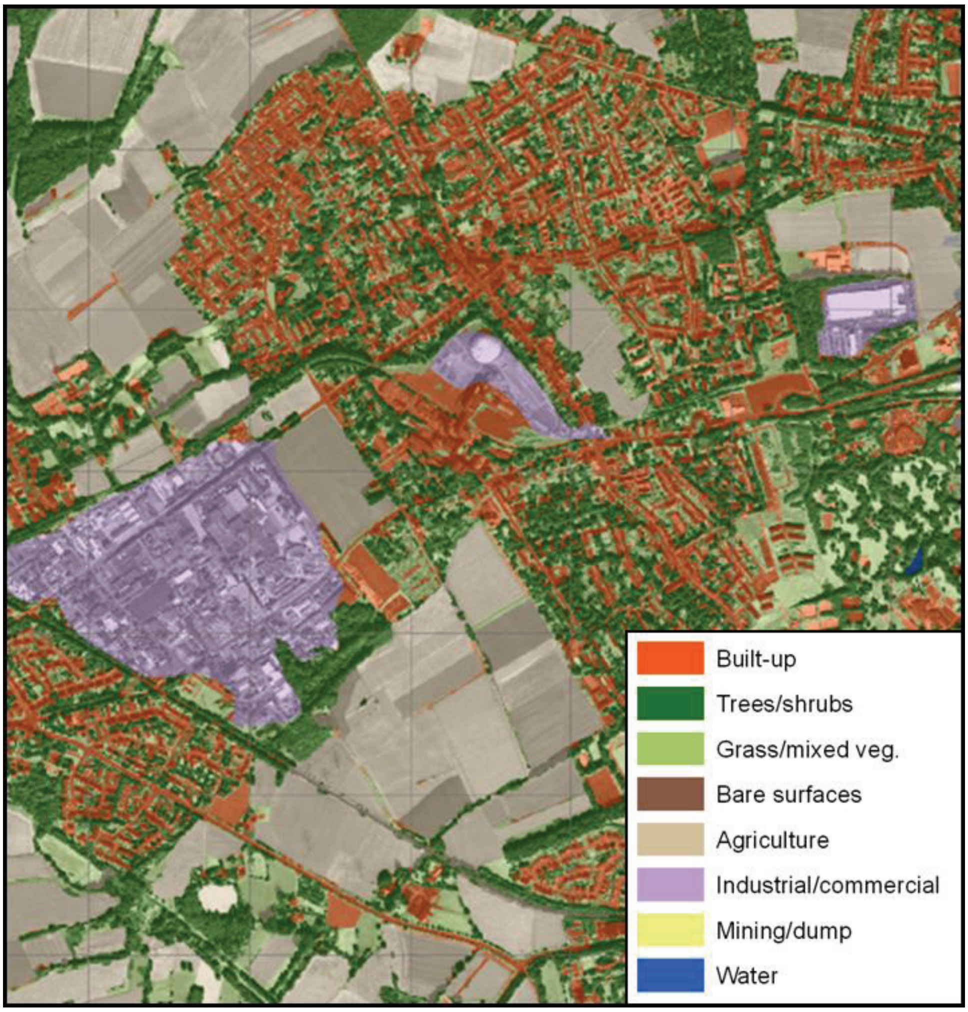

Figure 4. Regional example of a prioritized classification output of the semi-automated classification algorithm.

4. Conclusion and future work

The research for a semi-automated LULC classification for adaption in urban planning practice has shown that there is a feasible strategy to retrieve comparable classification results of different investigation areas under the preconditions of transferability and firmness. The extracted information about urban environment with a semi-automated procedure are adequate for feeding a MCDSS.

Further work is earmarked with the development of the MCDSS and the area-wide valuation of potential for inner urban development including spaces with unused buildings. The design of the planning tool is user oriented and should enable planning authorities to use remote sensing data without experiences in image interpretation.

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