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Comparing Metropolitan Areas – A Transferable Object-Based Image Analysis Approach

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Abstract: Existing methods for the detection and mapping of land use/land cover (LULC) for urban areas are mainly based on a Maximum Likelihood statistical image analysis approach. These methods all have one thing in common: the user has to define and outline training samples, which are drawn in an interactive process manually by on screen digitizing. Spectral characteristics of these training samples will then be used in the classification process to define the spectral ranges of the desired classes. This process cannot be automated because the training samples have to be defined for each classification. This paper presents a reproducible classification algorithm based on image objects without any additional search for training samples. In the first step ASTER imagery of the metropolitan area Phoenix has been used for the development of the algorithm. In the second step the classification scheme was applied to another ASTER image data set of Las Vegas, located in a similar natural environment. The resulting classification on a medium scale level shows a reliable accuracy of 83.33%.

Zusammenfassung: *Metropolregionen im Vergleich – ein übertragbarer objekt-basierter Ansatz der Bildanalyse*. Bestehende Methoden für die Erfassung und Kartierung von Landnutzung/Landbedeckung (LULC) für urbane Gebiete basieren hauptsächlich auf statistischen Bildanalysemethoden der größten Zugehörigkeitswahrscheinlichkeit (engl. *maximum likelihood*). Diese Methoden haben eine Sache gemeinsam: der Interpret muss zunächst Trainingsgebiete definieren, welche interaktiv vom Bildschirm abdigitalisiert werden. Die spektralen Eigenschaften dieser Trainingsgebiete werden dann im Klassifikationsprozess verwendet, um die spektrale Ausprägung der jeweiligen Klassen zu definieren, ein Prozess, der nicht automatisiert werden kann. In dieser Publikation wird ein reproduzierbarer Klassifikationsalgorithmus vorgestellt, der einzig auf der Analyse von Bildobjekten basiert, ohne die zusätzliche Definition von Trainingsgebieten. Zunächst wurde eine ASTER Szene der Region Phoenix für die Entwicklung dieses Algorithmus' verwendet. Im zweiten Schritt wurde das Klassifikationsschema auf eine andere ASTER Szene der Region Las Vegas übertragen, welche in einem ähnlichen Naturraum liegt. Die resultierende Klassifikation auf einer mittleren Maßstabsebene zeigt eine hohe Genauigkeit von 83.33%.

1 Introduction

1.1 *Motivation*

Urban metropolitan areas are the regions on Earth that exhibit the most rapid changes and the fastest growth. Rapid development can be typically observed in areas where the surrounding space is not limited and land is cheap for purchase. The two metropolitan regions of Las Vegas, NV and Phoenix, AZ belong to these typical boom areas in the South West of the United States. The dynamic development and rapid expansion of these areas demands a detailed mapping of the newly constructed sites at least once a year.

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Both Las Vegas and Phoenix are included in the 100 cities project, which focuses on the intense and frequent monitoring of major cities worldwide. Remote sensing has become the key role in this project and provides a huge database with permanently updated imagery (http://elwood.la.asu.edu/grsl/UEM/). The 100 cities project is embedded in the framework of the Urban Environmental Monitoring project (UEM) located at Arizona State University. In this project ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) image data has been selected as a standard image because of its high spectral resolution in the mid to short wave infrared spectrum and the relatively high spatial resolution in the visible green, red and near infrared.

Based on recently acquired ASTER image data a robust and transferable algorithm for an automated detection and analysis of urban features, that is valid for these two natural regions (deserts), was developed. Major task was to establish a classification algorithm for one particular metropolitan urban area and to apply it to an ASTER image of a different urban area. This test was necessary to ensure that the newly developed algorithm can be applied – only with minor changes – to a different urban area located in a similar natural environment.

1.2 *Land use/land cover analysis of remotely sensed imagery*

This study applies an object-based image classification approach (Baatz & Schaepe 2000, Benz et al. 2004, Blaschke et al. 2000), since this method has been successfully applied on image data of different sensor types. The classification results for the Phoenix area lead to an increased accuracy compared to other methods based on a statistical spectral pixel by pixel analysis (Moeller 2005). Disturbed image recognition quality, especially the 'salt and pepper effect' known from common statistical approaches, is absent in the object-based classification result (Blaschke & Strobl 2001). One important task of this study is to apply the newly developed classification rules to satellite data from the same sensor acquired for another region with a similar natural environment. In this study, the Las Vegas area has been selected as the test site. The date of image acquisition for both sites has been chosen carefully to ensure that nature appears with a more or less identical phenology.

2 Study area and data sets used

2.1 *Study area*

The Las Vegas and the Phoenix metropolitan area are located in the western part of the U.S. (see Fig. 1). Both metropolitan areas belong to very similar natural environments, i. e. the desert. Both regions show more or less the same meteorological values, which are typical for an area with a minimum annual precipitation. Phoenix is embedded in the Sonoran desert, characterized by an annually unequally distributed and relatively low precipitation of 196 mm/year. Las Vegas is an even dryer place and in close proximity to the hottest place in the U.S., the Death Valley. It receives an annual precipitation of 114 mm/year (for the 30 year period from 1971–2000; NOAA 2005). The mean elevation of Phoenix is about 300 m above sea level and it is surrounded by some higher mountains with altitudes up to 700 m. Las Vegas is also located in a valley with an average elevation of 600 m above sea level and surrounded by high mountains with elevations up to 3500 m.

Natural land in the surroundings of both metropolitan areas is available almost without any limits making it comparatively cheap for real estate purposes. Developing of these new housing sites is easy and can be performed with minor costs. The only limiting and expensive factor so far is water supply. Water has to be directed over large distances to the Phoenix area. For the monitoring of the growth of these areas remotely sensed imagery are most suitable. This imagery is available since the early 1970s and has been used successfully for the monitoring the growth of Phoenix (Moel-

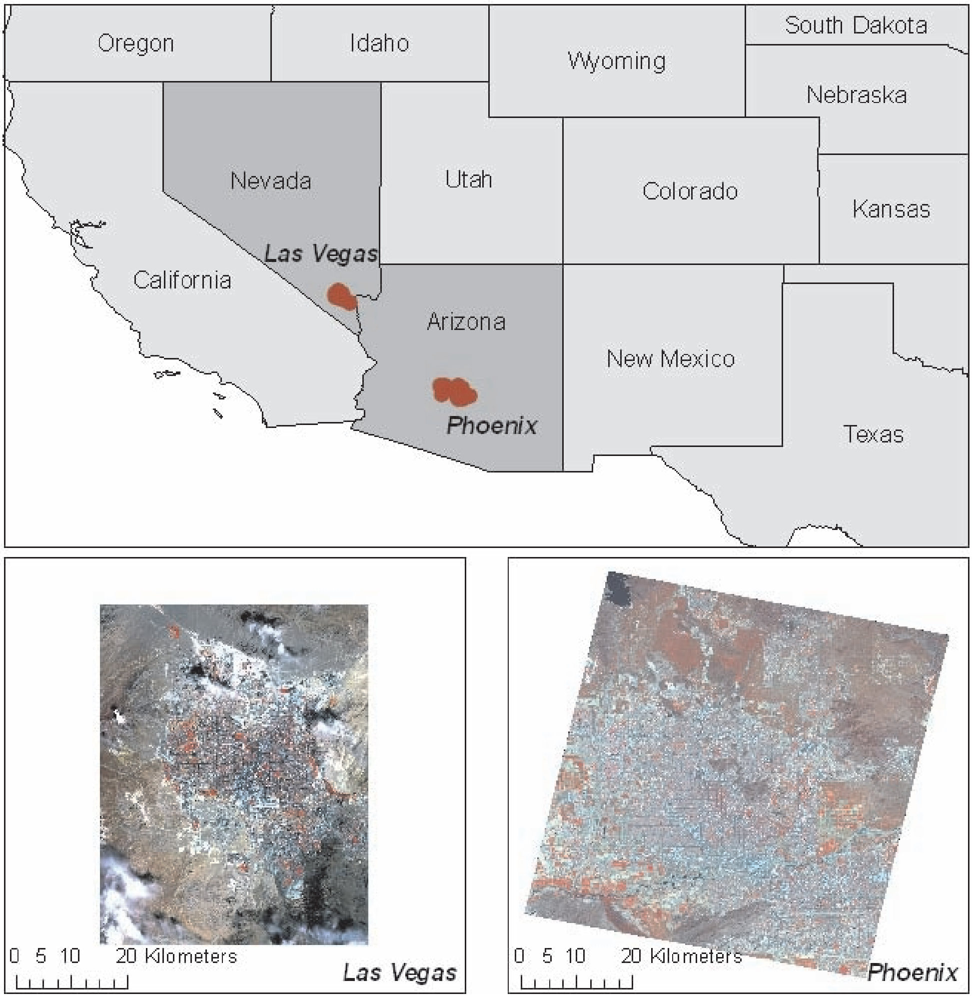

Fig. 1: Location of the two test sites in the Western States of the USA. The insets show the data used for Las Vegas and Phoenix.

LER 2005). The resulting time series of classified imagery can be analyzed in a spatial-temporal way for the detection of special growth pattern.

2.2 *Data*

The Landsat sensor typically provides remotely sensed imagery with a medium application scale (e. g. 1:50.000). Landsat has been proofed successfully for several Nation-wide studies (e. g. NLCD for USA, Corine for Europe). Since Landsat ETM (Enhanced Thematic Mapper) image data is affected by technical failure (the scan line corrector is permanently off), ASTER is the only operational sensor system for image data acquisition on a medium application scale. ASTER provides data with a medium spatial resolution in three wavelength regions, useful for investigating a wide range of urban processes. The high spatial resolution of ASTER in the visible to near infrared bands (15 m/pixel) permits detailed land cover classification of urban and peri-urban regions. Additionally it provides a validated sensor calibration and image processing for worldwide locations. This calibration of image data is crucial since the extension and adoption of the newly developed algorithm to metropolitan areas all over the world is a major task. The long-term perspective of the 100 cities project is to map urban areas worldwide and to provide a reliable image data source as well as a consistent classification method.

For this study ASTER satellite data recorded April, 1st, 2005 for the Phoenix site and recorded May, 1st, 2005 for the Las Vegas region has been used. For Las Vegas two scenes had to be mosaiced since the area was covered by two adjacent images. Las Vegas comprises an area of approximately 48 km × 60 km, whereas Phoenix spans 60 km × 60 km (see Fig. 1). The data were preprocessed to a level 1b product. Due to an undisturbed atmosphere without any meteorological influences such as fog and clouds and in addition a very low absolute air humidity, an atmospheric correction was not found necessary.

3 Methods

3.1 *Segmentation*

Segmentation of images is an important research area and vast number of segmentation algorithms has been proposed over the past three decades (FREIXENET et al. 2002). Recently, algorithms have been developed or were adopted for segmentation of remotely sensed imagery (MEINEL & NEUBERT 2004). Remote sensing applications increasingly use image segmentations as a first step to derive image objects and subsequently process these relatively homogeneous objects rather than single pixels. These objects contain spatial and geometrical information and additionally provide relationships information between objects. These interrelations can improve the classification result in a way that is difficult to achieve using the pixel-based approaches. The object-based approach can be used for a semi-automated analysis for the majority of remote sensing applications. This study will demonstrate that classification schemes based on image objects are transferable between different scenes (BLASCHKE & STROBL 2001, FLANDERS et al. 2003, BENZ et al. 2004, SCHÖPFER et al. 2005).

The segmentation algorithm used in this study is a region-based, local mutual best-fitting approach (BAATZ & SCHÄPE 2000). This bottom up region merging technique is implemented in the commercial software eCognition (BENZ et al. 2004). Initially each pixel forms one object or region. At each step a pair of image objects is merged into one larger object. Throughout this pairwise clustering process, the underlying optimization procedure minimizes the weighted heterogeneity nh of the resulting image objects, where n is the size of a segment and h an arbitrary definition of heterogeneity (BAATZ & SCHÄPE 2000).

For the study of the metropolitan areas Phoenix and Las Vegas a sophisticated cognition network (BINNIG et al. 2002) has been established to generate the class hierarchy (see Fig. 2). The developed system is based on classes which were proposed by STEFANOV et al. (2001a, 2001b). The network controls the number of segmentation levels and the definition of classes. In this case study we used two classification levels, an approach called MSS/ORM (BURNETT & BLASCHKE 2003).

Image segmentation was performed in three steps in order to obtain optimized image segments. First a fine level with a scale parameter of 10 has been calculated, followed by the second level with a higher weight on the compactness of the objects.

Tab. 1: Parameters of segmentation of the ASTER satellite data and the number of objects.

Level	Layers	Scale parameter	Color	Compactness	Number of objects
1	1, 2, 3	10	0.9	0.5	294020
2	1, 2, 3	25	0.9	0.8	54563
3	1, 2, 3	12	Spectral difference segmentation		26654

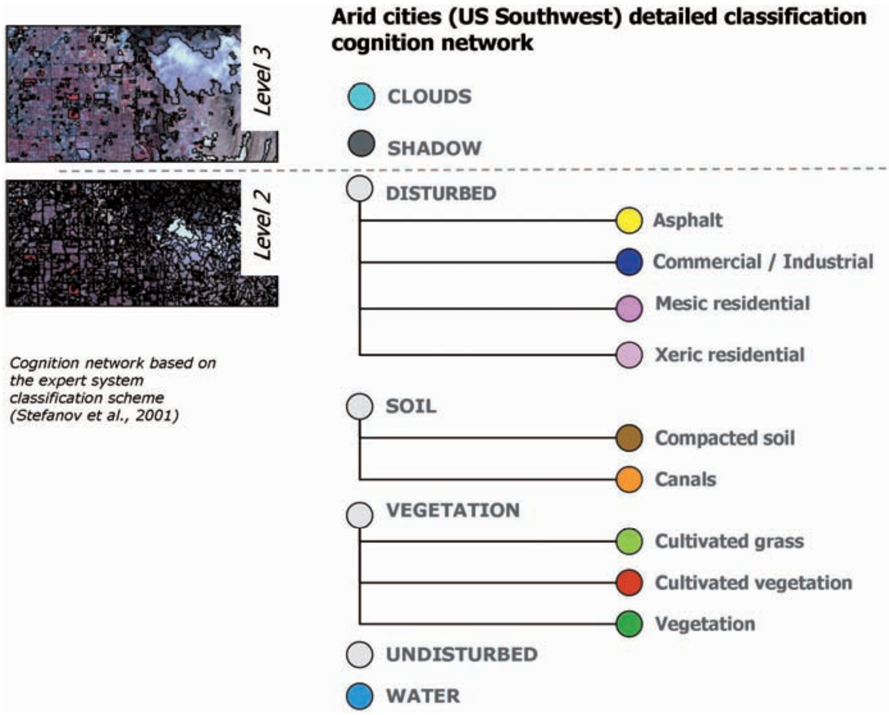

Fig. 2: Cognition network.

Finally spectral difference segmentation was used for the classification level (level 3, see Tab. 1). For the classification we focused on level 2 and 3.

3.2 *Object-based classification of the Phoenix test site*

The classes and their definitions have been given from the UEM project for the metropolitan area Phoenix (Stefanov et al. 2001a). Those classes have been set up for an expert classification scheme based on additional information, so called 'a priori knowledge' (see Tab. 2).

Several ancillary vector datasets were incorporated into the expert system model including water rights data, city and Native American reservation boundaries, and land use maps. Ancillary data provided additional useful information for the land cover classification (Stefanov et al. 2001b). This study does not use any kind of ancillary data. However, relationships among objects were utilized in order to fulfill the given class set. Thus different neighborhood relations between classes were defined as well as shape (form) parameters of objects. Only one class from the expert classification system (Stefanov et al. 2001a), *compacted soil (prior agricultural use)*, could not be adopted without utilizing ancillary data. Nevertheless, the approach presented in this paper might be used for analyzing satellite raw data and does not need any additional information.

The ASTER scene of the Phoenix area was used to develop a classification hierarchy that can be transferred to other scenes covering semi-arid environments. The developed classification scheme relies on spectral information rather than on structural features. The image data of Phoenix is absolutely cloud free and the classes *clouds* and *shadows* were therefore not necessary for this scene. They have to be introduced for the detection of these objects in the data set of the Las Vegas area only.

Tab. 2: Expert system class definitions.

Class Name	Properties
Cultivated vegetation	Actively photosynthesizing vegetation, with agricultural water rights
Cultivated grass	Actively photosynthesizing vegetation, in urban park areas
Vegetation	Actively photosynthesizing vegetation
Fluvial and lacustrine sediments (canals)	Mixed lithology gravels and soil associated with water transport features
Water	Standing or flowing water
Undisturbed	Undisturbed soil and native vegetation, bedrock out-crops
Compacted soil (prior agricultural use)	Disturbed soil with agricultural water rights
Compacted soil	Disturbed or bladed soil
Disturbed (commercial/industrial)	Mixed asphalt, concrete, soil, vegetation, and building materials, dense spatial texture
Disturbed (asphalt and concrete)	Mixed asphalt and concrete
Disturbed (mesic residential)	Built materials; vegetation cover greater than bare soil; dense spatial texture
Disturbed (xeric residential)	Built materials; vegetation cover less than bare soil; dense spatial texture

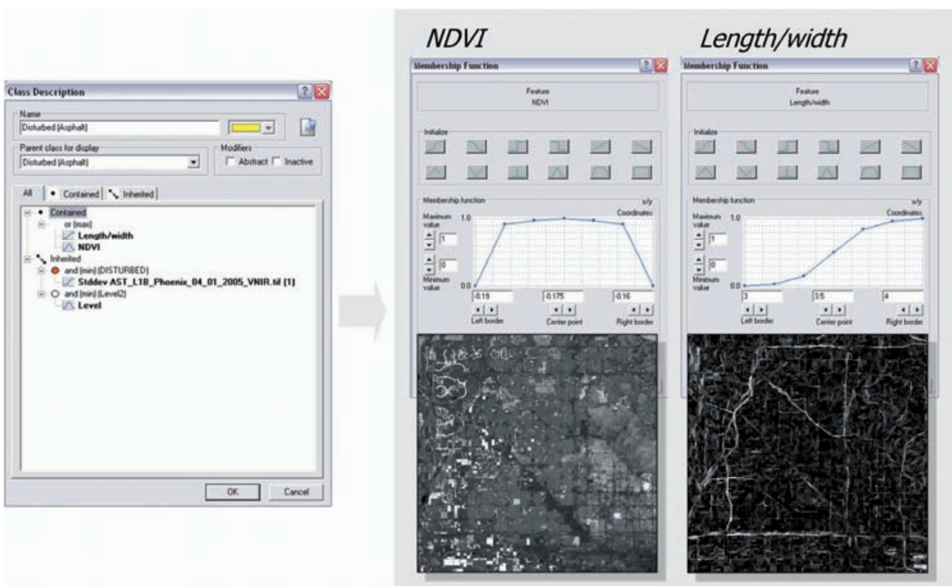

Fig. 3: Sample class definition.

In a first step the classes *clouds* and *shadows* have been classified in a higher level and used for the creation of a mask on the respective reporting level. Therefore a new feature has been calculated which is defined by the mean values of thermal band (4) divided by mean values of the thermal band (5). Additionally the size (sqm) has been considered for the classification of relevant objects. Water bodies and rivers were classified using red band mean values. Afterwards the *disturbed* and *undisturbed* areas were separated using the standard deviation of the green band. The disturbed areas were further subdivided into child classes utilizing the normalized difference vegetation index (NDVI). Different thresholds were defined to distinguish between *mesic residential* and *xeric residential areas*. The classes *commercial/industrial* and *asphalt* were separated using the NDVI and additionally the form feature length/width (see Fig. 3).

The NDVI was utilized also to detect vegetated areas, a class which has been split into subclasses *vegetation* and *cultivated land* by given thresholds for a certain area (sqkm) and a rectangular fit of the objects. Afterwards *cultivated grass* and *cultivated vegetation* could be classified by defining a new threshold for the NDVI. For the classification of *soil* a ratio of the standard deviation of the green and red band was used. The subclasses *canals* and *compacted soil* could be separated utilizing two class-related features named 'Rel. Border to *water* neighbor-objects' and 'Distance to *water* neighbor-objects (m)'.

3.3 *Transferability*

In order to test the transferability of the developed classification scheme to another image data set of a semi-arid environment the class hierarchy was exported. The workflow

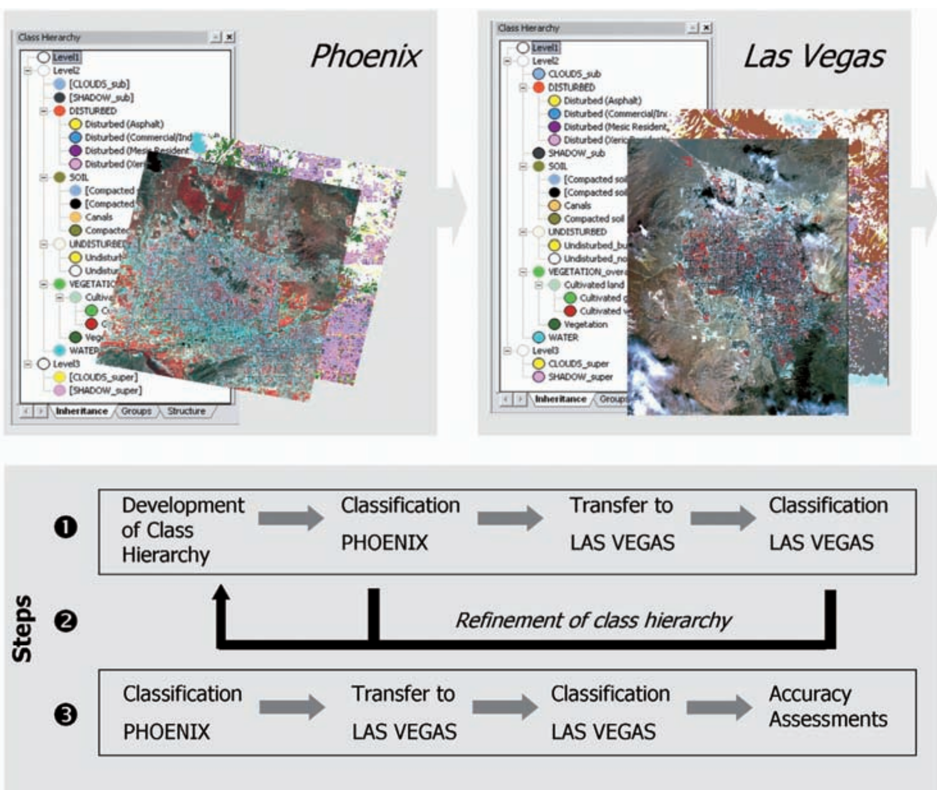

Fig. 4: Workflow of transferability between two scenes.

of the transferability between the two scenes can be seen in Fig. 4.

The ASTER image of Las Vegas was segmented using the same parameters described in chapter 3.1. In a first step ❶ the image was classified by importing the classification scheme and starting the classification process. To provide similar accuracy for the classification for both areas an iterative process has been started. The values defining membership function(s) of each class were tested and adapted and the final class hierarchy exported. The adjusted class hierarchy was then applied to the Phoenix data (step ❷) and the membership values were customized again and saved. This procedure has been repeated three times. In a last step ❸ the Phoenix data has been classified and the same class hierarchy directly transferred to the Las Vegas data set. At this time the values for defining membership functions of the classes were not adjusted in order to test the ability for an automated transferability of the class hierarchy.

4 Results and discussion

4.1 *Classification accuracy*

An automatically stratified random distribution of 195 points has been used for an accuracy assessment of the classification result. The reference values were based on visual interpretation of the spectral image data. The basic descriptive statistic is the overall accuracy, which is computed by dividing the total number of correctly classified pixels by the total number of reference pixels. The Kappa coefficient is calculated from the error matrix and is a value of the classification performance compared to the reference data. The coefficient also considers misclassified, as well as correctly classified, pixels. The classification of the Phoenix ASTER scene resulted in an overall accuracy rate of 84.24% ($K^{\wedge} = 0.8268$). The accuracy of the transferred classification scheme applied to the Las Vegas image resulted in 83.33% ($K^{\wedge} = 0.8148$).

4.2 *Usability and transferability*

When investigating the transferability of classification rules potentially influencing factors have to be considered. LEUKERT et al. (2004) listed the following items which may influence the transfer of knowledge-based classification rules: (1) date of image acquisition, (2) relief, (3) atmospheric impacts and (4) geographic region. The landscape and its topographic features appear in a broad variety and under different illumination effects. Consequently the high spectral variance, especially occurring in heterogeneous areas, such as urban areas, is represented in remote sensing imagery. Using an object-based approach might reduce the scattering by generalizing the landscape into meaningful homogenous objects. Thus the transferability of classification rule sets for a specific geographic region is still a challenging task, depending on the comparability of the image segments.

During the development of a transferable, flexible and transparent class hierarchy some difficulties were encountered. The accuracy of the classification result and the degree of transferability depends on the features used for the class descriptions. The most time-consuming task of the approach (apart from defining adequate scale parameters) is the development of a transferable class hierarchy. This research has demonstrated that form and shape properties of objects are stable parameters for class descriptions, whereas spectral properties appear to be slightly variable. Nevertheless, the NDVI could be transferred with only minor adaptations. Finally it could be demonstrated that the used rules sets lead to similar overall accuracies for both scenes.

The efficiency of image analysis and image processing regarding the usability and reusability of rule sets has also been tested. The target classes and the classification procedure itself can be reproduced by any user without the necessity of defining new training areas. The software used for this study allows an exchange of the developed object class descriptions. This portability of the embedded class definition may improve flexibility, cooperation and exchange between project partners.

ASTER images combined with a knowledge-based classification approach are suitable for an automated workflow of scenes belonging to similar natural environments.

5 Outlook

The research presented here is part of the 100 cities project. A major task of this project is to develop standardized and transferable methods that permit a reliable and reproducible comparison of different urban areas. The transferability of the developed classification approach could significantly improve this comparison based entirely on satellite remote sensing imagery. The next step in the 100 cities project will be to determine key cities that represent specific natural environments around the globe. Standardized classification schemes will be developed for each key city, which can then be transferred to cities of the same natural environment. The ASTER sensor could demonstrate its high potential for urban mapping on a medium application scale level.

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