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MONITORING LULC DYNAMICS IN THE URBAN - RURAL FRINGE

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Abstract. The permanent growth of metropolitan areas is a phenomenon which can be observed world wide in a huge number of countries. One of these boom regions is the Phoenix (PHX) metropolitan area, located in the south western part of the U.S. It shows an impressive growth starting in 1960. The use of satellite remote sensing imagery enables the synoptic monitoring of the growth pattern and their specific dynamics. The main research questions are: where did the growth took place and when did it happen? To answer those questions the remotely sensed satellite imagery has been analyzed in terms of land use/land cover (LULC) changes. This paper describes a new segment based and object-oriented image classification approach as an alternative to the pixel based classification.

Keywords: remote sensing, urban growth, object oriented image analysis, Phoenix metropolitan area.

1. Introduction

Cities and urbanized areas with their surrounding and bordering regions are the most dynamic places in terms of human activity regarding the transformation of landscapes. These urbanized regions do provide the complex social and economical environments for their inhabitants. Due to the permanent overall increase of population on the one hand and the raising attractiveness of urban areas to humans on the other hand, these urbanized areas develop more and more into metropolitan regions with growing extends. The development also can be expressed and measured in an increase of building activities and so has a direct impact on area consumption. The expansion or the growth of metropolitan areas is strongly depending on the accessibility and as a consequence on the value of available land. Metropolitan areas with a limited expansion area convert more inner urban lands into an efficient use for humans the others extend their limits in the urban fringe.

This paper focuses on the monitoring of the growth of the Phoenix, Arizona, USA metropolitan area from 1973 - 2003. During the 40 year period from 1960 until 2000 PHX has become one of the boom regions in the U.S. Most parts of PHX can be considered as residential areas, mainly consisting of family homes in 2003. **Table 1** outlines the increase of population and households for the PHX area. It also indicates a dramatic decrease of persons/household during the observed period, which results in the opposite in an increase of area consumption per capita.

Main parts of this region have been used as farmland by western settlers since the late 1890. An irrigation and water management system has been developed by the local authority guaranteeing a sustainable usage of this natural resource for agricultural purposes.

We will show the use of remote sensing images from various sources for the growth analysis of PHX. We also will make use of an object – oriented image analysis approach which is more feasible for the analysis of remotely sensed image time series compared to the common statistical approach.

Table 1: Human Dynamics in the Phoenix area

year of observation	1960	2000
population	663510	3072149
households	211865	1250231
persons/household	3.13	2.45

source: US census bureau (2004), FAO (2004)

Phoenix is located in the heart of the Sonoran desert, an area with extreme limitations to natural life, e.g. the annual average rainfall is about 200 mm, with a strong annual variability World Weather Information System (2004). Providing enough water for the residents and their life activities is one of the biggest challenges. The state of Arizona provides a giant reserve of cheap natural land. This land -from an economical point of view- is from low value and it sells for cheap prices. For an untrained observer it may look like wasted land and seems to be dead to most people. But in fact it provides home for some of the most adopted species, both plants and animals.

2. Satellite Imagery

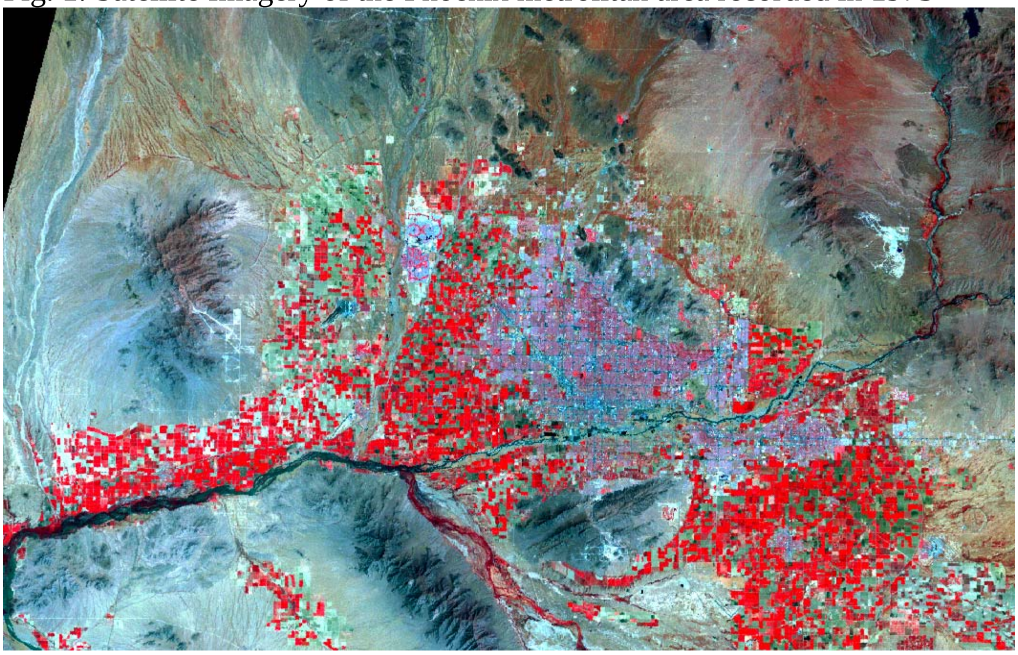
Satellite imagery is a reliable source for the monitoring of LULC as well as for the changes of LULC taking place over time. 'An image never lies' and represents the exact and objective conditions on Earth surface, which is important with regards to urban monitoring. It also guarantees a synoptic overview of a large area at one time. Imagery is available from several sources (e.g. airborne or space borne sensors) providing imagery with different specifications. One of the most crucial criteria is the spatial resolution ranging from 0.15 m (for extremely high resolution from airborne scanner data) to 30 m (medium resolution from satellite sensors) Moeller (2003). Also spectral, radiometric and especially temporal resolution should be considered if remote sensing data is used for urban purposes. The data availability is another important factor for an analysis of changes over times. Recently an increasing number of permanently updated and filled image data archives have been established in the World Wide Web. Those do provide satellite images for the last 30 years. Though this data is available only on a medium scale level mostly acquired by sensors from the Landsat platforms, it is a reliable source of information in terms of LULC change detection monitoring on a mid scale level of approximately 1:75.000.

Table 2: Satellite Image Data for the analysis of the Phoenix metropolitan area

sensor	spatial res.	spectral res.	path/row	acquired
Landsat MSS	80 m	4 bands	39/37	05.05.1973
Landsat MSS			39/37	01.04.1979
Landsat MSS			40/37	24.03.1979
Landsat TM	30 m, 120 m thm.	6 ms, 1 thermal	37/37	04.05.1985
Landsat TM			37/37	18.03.1991
Landsat TM			37/37	13.03.1995
Landsat ETM+	15 m pan, 30 m ms, 120 m thm.	6 ms, 2 thermal, 1 pan	37/37	19.04.2000
ASTER	15 m vis, ir, 30 m ms, 60 m thm.	8 ms, 6 thermal		20.03.2003

At least seven satellite scenes from different sensors have been used for this investigation (**table 2**). For a LULC change detection analysis imagery recorded nearly at the same date for each year investigated is strictly recommended. That guarantees nearly identical phonological appearance in all the images. In this investigation we used seven images all acquired during a six week period in late spring, representing a healthy vegetation.
All image data have been preprocessed first; e.g. properly georeferenced to a unique reference system guaranteeing reliable spatial accuracy. An atmospheric correction has not been applied to the images, because the atmospheric conditions for all dates indicate no disturbances from clouds, fog or water vapor in the atmosphere.

Fig. 1: Satellite Imagery of the Phoenix metrolitan area recorded in 1973



sensor: Landsat MSS, 03/73, bands: 4 (red), 2 (green, 1 (blue)

In a next step the images have been cut to fit to the chosen area of interest (aoi). The PHX aoi is about 72 km x 112 km in y and x, representing the metropolitan area and the surrounding farmland and natural lands (**figure 1**). Not only the multispectral and panchromatic (if available) bands have been used in this investigation, but in addition a normalized vegetation index (NDVI) has been calculated Moeller (2004).

3. Object Oriented Image Analysis

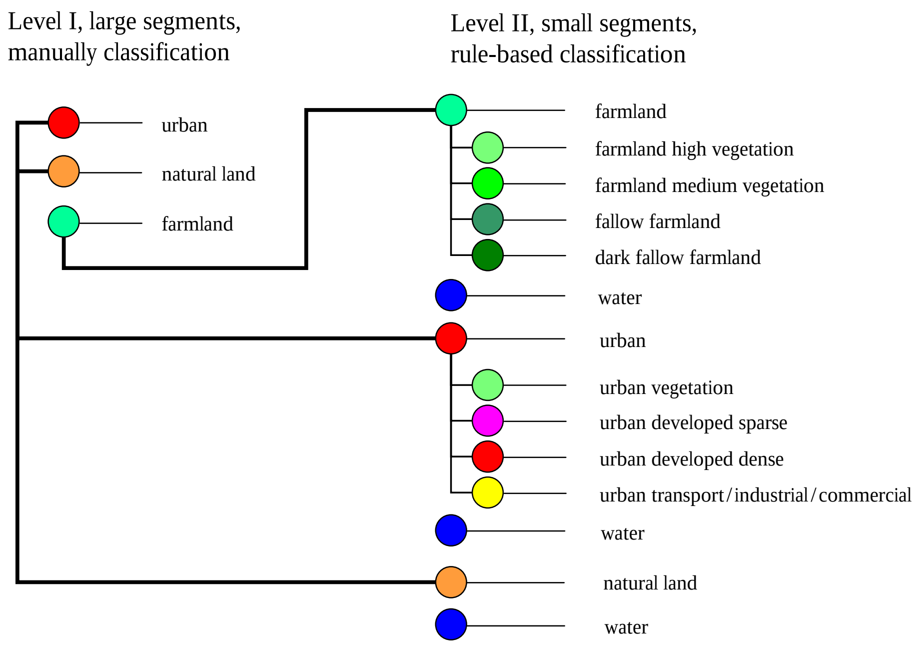
A change detection analysis is mainly carried out on a pixel by pixel spectral reflectance change base and has been performed for the PHX area Stefanov et al. (2001). That means pixels with the same geographical location are computed on to each other and differences are calculated. This method is proofed for images of several dates of acquisition recorded by the same sensor Howarth and Boasson (1983). In our investigation imagery from different sensor types have been analyzed and the common pixel by pixel approach could not be applied. We decided to classify the images first and in a next step we wanted to compare the changes on a grid cell basis.
Usually images are analyzed based only on their spectral properties by the statistical analysis of the image pixels values. A pixel with its specific spectral signature will be classified in one spectral category. Those categories represent the defined object classes, which are related to

LULC classes. However the lack of this approach is the limitation to the spectral reflectance as the one and only criteria. Other object information like shape size, textural information, and topological relations like neighborhood or bordering objects could also be an important criteria and should be considered for a classification with a higher degree of accuracy. This additional classification knowledge will definitely led to an increased of analysis results in terms of classification accuracy.
The sophisticated image object - oriented classification approach we used consists of a two step method. In a first step image segments have to be calculated and in the second step the classification of these segments has to be performed.
Image segmentation is not a recent development Kettig and Landgrebe (1976), Haralick and Shapiro (1985), but only a few number of image analysis software makes use of this approach and lead to qualitatively convincing results while being robust as well as operational. The segmentation of an image into an appropriate number of regions or segments representing the desired objects is a problem with a huge number of possible solutions and it is strictly opposed to the so called Modifiable Area Unit Problem (MAUP) Hay et al. (2001). The high degrees of freedom must be reduced to a few which are satisfying the given requirements. Additionally, segmentation needs to address a certain scale: does the application require information about single bushes or trees or about land cover units such as orchards or mires? Most segmentation approaches do not allow the specification of several scale levels for image segments and those do not consider the scale of and a level of detail or generalization as well.
Newly developed segmentation and classification software enables the calculation of image segments on several scale levels. Those segmentation levels represent large segments on a high level (for example classes like: ‘urban body’; ‘farmland’; ‘desert’; etc.) and smaller, finer segments on lower levels like: ‘residential’, ‘commercial’, ‘transportation’, ‘urban parks’, etc. for the higher level class ‘urban body’. The segments sizes and shapes on several levels have to be defined by the user more or less iteratively. Once a reliable segmentation scheme has been established representing objects of the desired classes on different levels (see above), the object oriented classification may be performed.
The first step in the classification process is the definition of desired classes for each segmentation level. Once the classes have been named, their specific characteristics have to be defined. Those characteristics are not only the spectral reflectance values used for the statistical evaluation but also parameters like: size, shape, and perimeter, texture, neighboring relations as well as relations to sub or super objects. A huge toolbox can be utilized for the explicit definition of classes in the object-oriented classification software. Borders between neighboring classes with only slight differences can be described with a soft transition from one class to another class using fuzzy rules.

4. Object oriented analysis of the Phoenix satellite imagery series

For the seven images segments have been calculated on two levels, one consisting of large segments (level I) and the other with smaller, more detailed segments on level II. The segments belonging to level I have been classified manually first into the three major LULC classes: ‘urban area’, ‘farmland’, and ‘natural land’.
This first level classification results have been used as an input source for the definition of rules to the classification of the level II segments. Those have been reclassified by the introduction of decided rules depending on spectral properties, shape properties and inheritance relationship. The complete class scheme is outlined in **figure 2**.

Figure 2: Classes on two Segmentation Levels



For the reclassification of the rough level I segments on level II special sophisticated rules have been introduced like these examples:

- belongs to super object level I ‘urban’, spectral properties ‘urban residential’ - must be level II ‘urban residential’
- belongs to super object level I ‘urban’, spectral properties ‘farmland vegetation’, borders GE 75% to neighboring vegetated objects on level II - must be ‘vegetated farmland’
- belongs to super object level I ‘urban’, spectral properties ‘farmland vegetation’, borders GE 75% to neighboring ‘urban features on level II’ - must be ‘urban park’

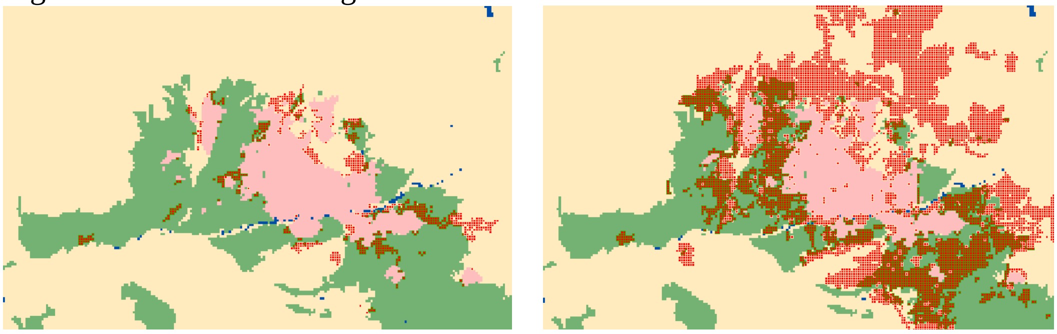
A classification scheme with class definitions consisting of appropriate class borders is a long lasting process and for some classes it needs a huge number of improvement cycles until the results of the classification lead to reliable results. However the class water with ist unique spectral reflectance can be defined comparable fast.

The level II classification has been tested for its accuracy with the average misclassification error for each of the seven years investigated. Unfortunately a reliable source for an intense ground truth compare (e.g. aerial images for the several years) was is not available for the PHX area. Instead we had to use the original satellite imagery and selected randomly 50 points in the aoi for each image analysed. These image points have been compared manually with the classification results and lead to an overall classification accuracy of 83% for all satellite images.

5. Mesh Overlay and Analysis of the Urban Growth

For the change detection analysis, e.g. the growth of the PHX area into the urban fringe, a method for generalizing the classes has been chosen, because a change analysis based on individual object shapes is still not existent. We used a mesh overlay in this study, each grid

Figure 3: Visualized Changes



for the first period 1973 – 1979 | for all time periods 1973 – 2003

underlying: major LULC classes of 1973

Legend:

natural land | farmland | farmland to urban

urban | water | natural to urban

cell with a 0.25 km^2 size, covering the whole aoi. The underlying level II fine classification has then been up sampled to its major LULC classes (urban, farmland, natural land). After the mesh overlay, the changes could be visualized and also calculated in the exact amount of area which has been converted for each period. **Figure 3** outlines the changes for one period (1973 - 1979) as well as all changes during the 30 year period 1973 - 2003.

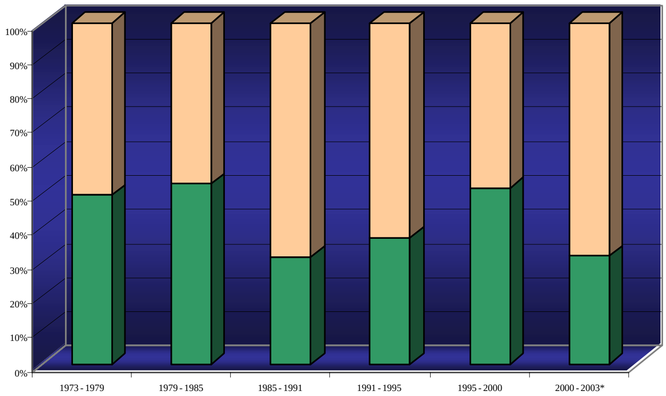
Figure 4 illustrates the conversion of farmland and natural land to an urban usage. For three of the six change periods a ratio of about 50% to 50% for both LULC classes can be detected, but for three observed periods the conversion from natural land towards an urban use has been increased. This leads to the conclusion that farmland usage with the connected water rights for irrigation has become a bigger value during the growth period. Farmers nowadays try to keep their land for agricultural purposes. The spatial trend of growth for the PHX is directed towards an occupation of the natural land which is for the PHX region the Sonoran desert.

Table 3: LULC Changes of the Phoenix Metropolitan Area (in km^2)

period	farmland to urban	natural land to urban	overall LULC chg.
1973 - 1979	106.25	108.25	214.5
1979 - 1985	259.75	231.5	491.25
1985 - 1991	132.25	289.25	421.5
1991 - 1995	198.25	335	533.25
1995 - 2000	216.75	202.75	419.5
2000 - 2003*	149.75	323	472.75
overall	1063	1489.75	2552.75

* ASTER satellite scene does not cover the whole metropolitan area

Figure 4: Conversion from Farmland & Natural Land to an Urban Use



green: farmland to urban, beige: natural land to urban

6. Discussion

The use of object oriented image analysis in combination with an overlaid mesh led to impressive results in terms of multiple image data analysis. The segmentation first and later classification is an improvement compared to common statistical classification approaches. Mainly the manual pre-classification on a rough segmentation level has been very helpful for the definition of major LULC classes (**table 4**).

However a method based on change detection for the individual shapes would end up with the most reliable results. Future research could focus mainly on the question: how do human understand LULC changes and how can we utilize this knowledge in terms of computer based change detection monitoring? Object oriented image analysis is a first step; a following second step could include an object-oriented change detection tool as a logical consequence.

Table 4: Advantages/Disadvantages of the Segmentation based Object Oriented Classification versus Pixel based Multi Spectral Classification

method	evaluation
segmentation process as a technical process (on different scales)	challenging, no standards
building relations to neighbors sub-, super objects	easy using GIS functionality, intrinsic process in o-o software environment
building relations to sub and super objects with coarser and finer resolution	only for multi-scale segmentation
data fusion (different sensor, resolution, raster, vector data)	high potential
re-usable semantic models (classes)	high potential
feature analysis (spectral, shape, neighborhood relation features)	one of the main strengths
usability, initial learning curve	similar
defining scale parameter for segmentation	difficult, most problematic issue
automation, repeatability, transferability	high potential, first empirical tests, e.g. Flanders (2003)
performance	depends on the image size
accuracy assessment	unsolved so far in the o o environment

source: modified from Blaschke (2003)

7. Acknowledgements

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