

MAPPING POST-OLYMPICS URBAN USE CHANGE IN THE PERIPHERY OF ATHENS USING MULTI-TEMPORAL PIXEL-BASED AND SEGMENTATION TECHNIQUES

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ABSTRACT:

The city of Athens, Greece, was given the go-ahead to host the 2004 Olympic Games in 1996. Considerable land cover/use changes (LUCC), principally conversions to urban land use from other types, associated with the preparation for the Games, have since taken place (e.g. sports and transport infrastructure, a new international airport, etc). The measurement of such LUCC is cost-effectively done over large geographic regions using Earth observation remote sensing (EO/RS) technologies. In the present study, two land use/cover classification methods are applied to map urban change in the area of Messogia in the East periphery of Athens: a pixel-based methodology based on a supervised maximum likelihood classification, and an object-based segmentation approach. We use a combination of five Landsat TM and ETM+ images spanning 12 years (1994-2005) and compare the results with a rule-based multi-temporal technique. For validation we use black and white aerial ortho-photos of 1995 and Google Earth. Preliminary results show best performance for the object-based classification. It is also concluded that both classification schemes are improved by the rule-based multi-temporal approach.

1. INTRODUCTION

Athens, the capital city of Greece, is an urbanistic case that has attracted a lot of scientific attention. It is quite densely populated while its location and topography have kept it rather limited in size. Over the last century, due to several historic and political factors that have led to a perpetual urbanisation of the main Greek cities, Athens was literally transformed from a collection of townships of a total population of 700,000 people in 1921 to a metropolitan area (often referred to as a 'cement-city') inhabited by roughly 5,000,000 people. This process evolved fast and without any specific organised urban planning. This in turn resulted in numerous problems that seem increasingly difficult to solve: lack of open and green space, near-constant traffic jams, an 'endemic' air pollution problem called nefos (similar to that of Los Angeles), etc.

In 1996, when the city of Athens was given the go-ahead to host the 2004 Olympic Games, there was a widespread feeling that this was the long-anticipated chance to improve the situation and with it the living conditions of ordinary Athenians. The Olympic Games have indeed brought several urban land use changes in Athens and its periphery, such as the construction of numerous sporting facilities, motor highways, a surface light railway, a new international airport, etc. At the same time, the continuing absence of a national cadastre, a forestry inventory and a spatial planning framework, coupled with a rather permissive fiscal policy that is blamed for favouring capital gains for unauthorised construction violators, has led to an increase of the urban sprawl around the newly constructed Olympic works.

There is therefore a pressing need for a long-term urban planning framework that will also incorporate the environmental obligations that Greece has signed to, such as the

Kyoto Protocol's reduction of carbon dioxide emissions by 8% from 1990 levels between 2008 and 2012. So far, Greece has failed to comply with its commitments and faces a bill of at least 225 million euros by 2010 (Kathimerini, 2006). Previous work (Symeonakis et al., 2007a) has stressed the importance of the development of a reliable land use change mapping and monitoring system. An efficient way to map and monitor such changes is via the use of Earth observation remote sensing (EO/RS) technologies.

In the last decade, the advent of the very high resolution (VHR) satellites (IKONOS and Quickbird) has given an additional boost in this direction. Unfortunately, the increased detail that comes with the higher spatial resolution and the decreased spectral information can sometimes act as a drawback and impede the successful delineation of the desired urban land cover types. Moreover, their limited archives do not usually cover periods long enough to capture the evolution of urban use change. Medium resolution satellites, such as Landsat, can therefore still provide useful imagery for urban studies, mainly due to their spectral depth and their archives which go back to the early 1970s.

The classification of RS data to produce meaningful land use maps has traditionally been carried out over the last 30 years using pixel-based techniques. Lately, object-oriented methods based on image segmentation algorithms are gaining momentum (Beaulieu and Goldberg, 1989; Benz et al., 2004; Devereux et al., 2004; Hay et al., 2001, 2003). Hay et al. (2005) and Schiewe et al. (2001) present the benefits of using such techniques as well as the potential problems. For a thorough review of the different object-based methods the reader is referred to Blaschke et al. (2004).

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Another issue mentioned in the LUCC literature that warrants attention is that changes cannot be accurately mapped using RS data only from the two ends of the period in question (Gamba et al., 2005). A larger set of imagery and the use of multi-temporal techniques is seen as more fit for the monitoring of change processes as it allows for the correction of individual-year classification errors that are otherwise labelled as change.

In the present study the objective is to map urban land use change between 1994 and 2005 in an area on the eastern outskirts of Athens. Five Landsat images and a rule-based multi-temporal approach are utilised to better capture the process of change. A pixel-based as well as an object-oriented approach is tested. The classifications before and after the multi-temporal processing is applied, are also compared. The methodological framework suggested is assessed and suggestions are made for its successful application.

2. METHODOLOGY

2.1 The study area

The Messogia Plain in the prefecture of Attica, lies in the East of the city of Athens. It occupies an area of about 400km². It is bounded by Mt. Ymittos (1026m) from the West and the Evoikos Gulf from the East. In terms of agricultural use, the area is covered mainly by olive groves, vineyards, and various types of orchards. It is also characterised by diverse microclimatic conditions with irregular and intense rainfall in spring and autumn, harsh winters and dry and hot summers. Over the last decade, the construction of a new highway (Attiki Odos) and the new international airport of Athens along with its vicinity to the city has made the area's townships increasingly popular for suburban living.

Ancillary data included a 20m-pixel DEM for the ortho-rectification and terrain correction processes. For training purposes and the accuracy assessment of the classifications, black-and-white 1:25000 aerial orthophotos of 1995 and Google Earth (Google 2007) were utilised. The area of study is covered by Quickbird fused multi-spectral and panchromatic data which results to 61 to 72cm pixels (at nadir).



Figure 1. The study area of Messogia in the eastern periphery of Athens

2.2 The data

Five Landsat TM and ETM+ images were used in the study (Table 1):

| DATES | SENSOR & SOURCE |
|----------------|---|
| 13/6/94 | Landsat 5, TM, Global Land Cover Facility (GLCF) |
| 6/8/99 | Landsat 5, TM, GLCF |
| 7/7/00 | Landsat 7, ETM+, Joint Research Centre (JRC) |
| 1/10/02 | Landsat 7, ETM+, Eurimage |
| 27/06/05 | Landsat 5, TM, Eurimage |

Table 1: Landsat data (path: 183; row: 34) used and their source. Free data are depicted in bold.

2.3 Image pre-processing

The pre-processing applied in this research was based on the joint Commonwealth Scientific and Industrial Research Organisation (CSIRO) and Australian Greenhouse Office (AGO) approach used for the National Carbon Accounting System (NCAS, Furby 2002).

Initially orthorectification of the available images was performed using a viewing-geometry approach. Specifically the viewing-geometry and block adjustment model implementing Toutin's approach (Toutin, 1994) for ortho-rectifying images was employed.

The image data was then calibrated to produce radiometrically consistent images that can be compared to each other. The images were normalised to a reference image, as a reliable correction to absolute reflection units is not possible. Four calibration steps were applied in the radiometric correction procedure: 1) Top-Of-Atmosphere (TOA) reflectance calibration (also called sun angle and distance correction); 2) Bi-directional Reflectance Distribution Function (BRDF) calibration; 3) terrain illumination correction (Wu et al. 2004) and 4) calibration to 'like-values' (Furby and Campbell 2001, Wu et al. 2001).

2.4 Single-year classifications

2.4.1 Pixel-based classification

Ground-truth data showing the location and extent of representative urban and non-urban land cover classes to train the land cover mapping process were derived from the aerial photographs, and Google Earth.

Maximum Likelihood (ML, Rao 1966), perhaps the most popular classifier for optical data, was then applied to the five dates individually to produce the desired urban land use maps using Erdas Imagine 8.7.

Per-pixel-based classifiers, which only use spectral information, can produce a large amount of "salt and pepper" noise pixels both inside and outside the objects in the classified image, which decreases the classification accuracy. One method for removing such noise is to apply a majority filter that preserves edges and line features better than a low pass or averaging filter (Jensen 1996). In this study, a commonly used 3 · 3 majority filter (Bauer et al. 2003, Symeonakis et al. 2007b, Weber and Puissant 2003) was applied to the ML classification output to reduce its spatial heterogeneity (i.e., salt-and-pepper). This filtering both enhanced the map's interpretability and eased the task of comparison with the other dates.

2.4.2 Object-oriented classification

The object-based classification of the imagery was carried out using eCognition 4.0 (Definiens Imaging, 2004). eCognition provides two main types of classifiers: nearest neighbour and membership functions. In this study we used the first and divided the analysis in three steps: multiresolution segmentation, creation of classes, and creation of classification rules. During the first stage, the image segments were created. The parameters were defined for the scale, the spectral and the shape properties of the objects. The segments were then calculated on three hierarchical levels through a trial-and-error process to result in the final segments that best represented the urban and non-urban land cover types. Initially, four main land cover classes were created: impervious, agricultural, rural and water. Training sites of known areas were collected for each class and the classifier was run in an iterative improvement process to achieve a differentiation of the borders of the class distributions in the multidimensional feature space. Using ecognition's classification statistics and stability tools, the most reliable and stable results were chosen for each year. Finally, the four cover types were separated in the required urban (impervious cover type) and non-urban (agricultural, rural and water cover types) land use types.

2.5 Multiple-year processing

The multi-temporal processing was performed using a rule-based approach with a view to reducing the amount of false change detected when comparing two urban land use maps of any two dates. The approach exploits the observation that many commission errors vary differently compared with real life processes. In our study case, for example, it is rather unlikely that a given pixel or object would change from 'urban' to 'non-urban' and back or vice versa.

2.6 Accuracy assessment

Accuracy assessment involved image pre-processing accuracy and urban use classification accuracy. The last stage, that of urban use change accuracy, will also be undertaken in the immediate future.

With regards to pre-processing, the accuracy of the ortho-rectification of the 2000 base image to the DEM was assessed using 20 independent 'check' GCPs that were not used in the model fit. The registration of the rest of the images to the 2000 base image was also assessed using another 20 independent check GCPs.

Regarding the urban use classification accuracy, when undertaking change detection using multi-temporal images, it is often difficult to make the accuracy assessment which involves simultaneous collection of reference data for all dates. In our case, none of the image dates coincided exactly with the validation data. The imagery that were validated so far are the ones closest to the validation data i.e. the 1994 and 2005 images. Future work will explore the possibility of using the method proposed by Liu and Zhou (2004) which uses a rule-based rationality evaluation with post-classification comparison in tandem with the existing reference data.

100 reference polygons with a varying area of 10 to 20 Landsat pixels each, were developed using a stratified random sampling frame across the two land use types. The samples were located in areas where the majority of the pixels were of the same land

use type. This eliminated the potential of a sample being chosen along a boundary edge which might introduce errors as it is difficult to accurately label from the reference data.

Error matrices, percentage correct, omission and commission errors for the urban and non-urban land use classes were estimated.

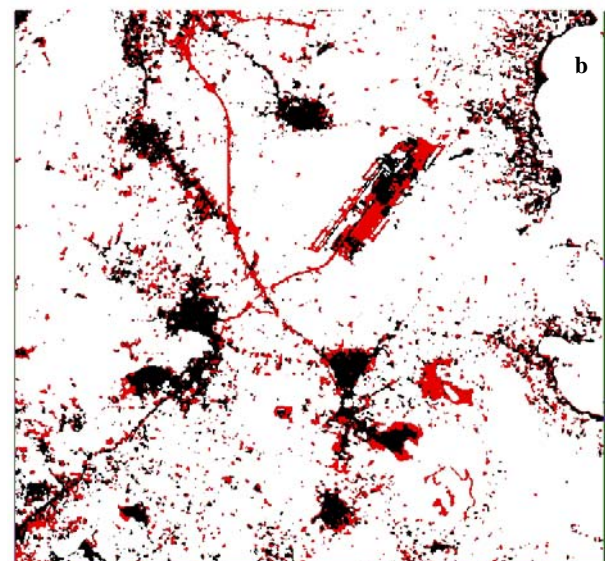
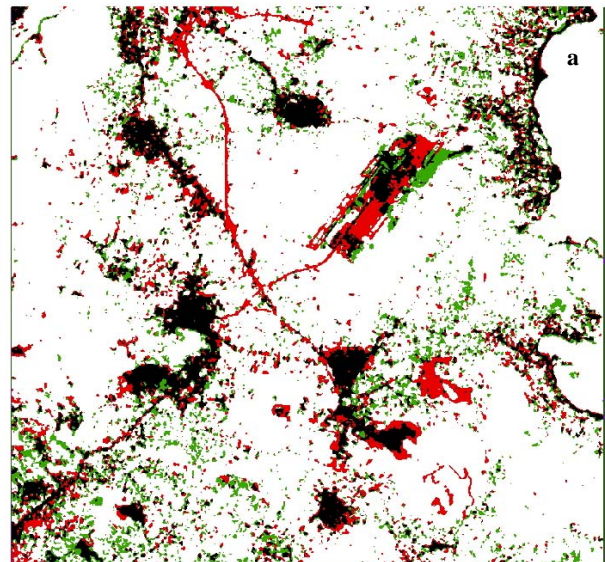
3. RESULTS

3.1 Rectification and calibration

The free Landsat data (GLCF and JRC) are available as ortho-rectified images. The 2000 image was chosen as the ortho-rectification reference. Around one hundred GCPs were collected from it for rectifying the purchased scenes and to check the ortho-rectification of the 1994, 1999 and 2005 images.

3.2 Classification results

The urban change results from both pixel-based and object-based approaches are shown Figure 2 with and without the multiple-year processing.



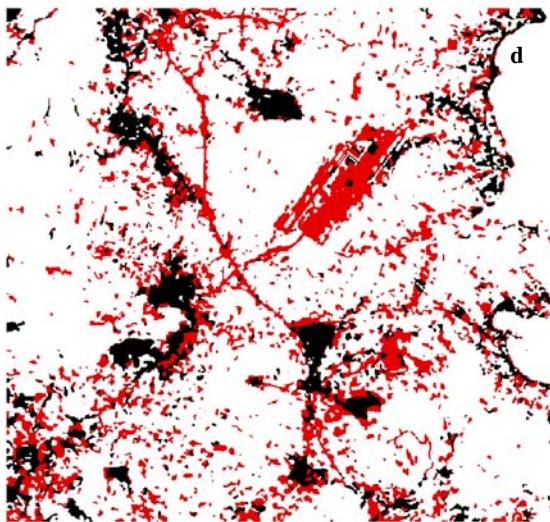
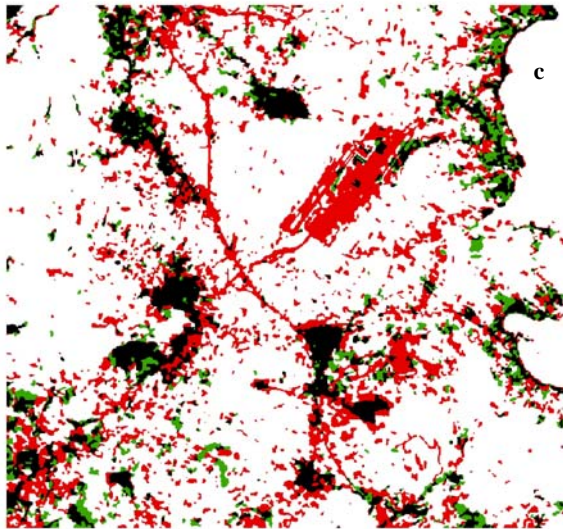


Figure 2. Change from non-urban land use to urban (in red) between 1994 and 2005 derived from maximum-likelihood classification without (a) and with (b) the multiple-year processing. (c) and (d) are the respective results from the object-based classification approach. Areas in green: change from urban to non-urban identified by the single-year processing; areas in black: unchanged urban use; areas in white: unchanged non-urban use.

3.3 Accuracy assessment

Image pre-processing accuracy was high with an over-all size of the mean errors (RMSE) around 10m in both directions for all images.

The classification accuracy results are summarised in Tables 2 and 3 below.

| | | | Urban (%) | Non-Urb. (%) |
|------|-----|-------------|-----------|--------------|
| 2005 | SYP | Correct (%) | 86 | 95 |
| | | Commis. (%) | 14 | 20 |
| | | Omis. (%) | 14 | 5 |
| | MYP | Correct (%) | 95 | 100 |
| | | Commis. (%) | 10 | 11 |
| | | Omis. (%) | 5 | 0 |
| 1994 | SYP | Correct (%) | 70 | 86 |
| | | Commis. (%) | 35 | 24 |
| | | Omis. (%) | 30 | 14 |
| | MYP | Correct (%) | 79 | 100 |
| | | Commis. (%) | 10 | 25 |
| | | Omis. (%) | 21 | 0 |

Table 2. Single-year processing (SYP) and multiple-year processing (MYP) maximum likelihood classification assessment results for 1994 and 2005.

| | | | Urban (%) | Non-Urb. (%) |
|------|-----|-------------|-----------|--------------|
| 2005 | SYP | Correct (%) | 90 | 95 |
| | | Commis. (%) | 28 | 2 |
| | | Omis. (%) | 10 | 5 |
| | MYP | Correct (%) | 96 | 95 |
| | | Commis. (%) | 37 | 3 |
| | | Omis. (%) | 4 | 5 |
| 1994 | SYP | Correct (%) | 86 | 93 |
| | | Commis. (%) | 29 | 3 |
| | | Omis. (%) | 14 | 7 |
| | MYP | Correct (%) | 99 | 96 |
| | | Commis. (%) | 39 | 1 |
| | | Omis. (%) | 1 | 4 |

Table 3. Single-year processing (SYP) and multiple-year processing (MYP) object-oriented classification assessment results for 1994 and 2005.

4. DISCUSSION

Here we attempted to produce urban land use change maps for the area of Messogia, in the East of Athens, Greece at the Landsat scale using both pixel and object-based classification techniques. A multi-temporal rule-based methodological framework was also compared with results obtained from single-year classifications: a practice commonly applied using the freely available GLCF Landsat archive for mapping land use/cover change (Kilic et al., 2006; Tatem et al., 2005; Tatem et al., 2006; Symeonakis et al., 2007b).

According to the preliminary results of this study, the object-based approach produces better results than ML. The rule-based multiple-year processing seems to improve the classifications for all years and both urban and non-urban land use types. The results show that if only two dates are used to map land use change, as in the case of the land use change studies that employ the data from the free GLCF archive then, consequently, a multi-temporal approach cannot be applied, and the change results are susceptible to false labelling of change, due to the high commission and omission errors. It is therefore recommended that a fuller set of Landsat data, optimally on a

yearly basis, is employed for accurately mapping urban land use and urban land use change. Moreover both techniques would probably improve significantly if more advanced multi-temporal methods were employed such as the Conditional Probability Network (CPN) proposed by Kiiverii and Caccetta (1998).

5. CONCLUSIONS

The general euphoria related with the 2004 Olympic Games of Athens was exacerbated by the incessant idealising of what the Olympic Games and the anticipated urban changes would bring. The lack of an organised planning framework that includes the mapping and monitoring of such changes impedes any attempt for a real and lasting improvement in the lives of the citizens of the greater Athens area. This pilot study has shown that the multi-temporal object-oriented classification approach with the capacity to take context and semantic information into account and thanks to the robust fuzzy classification with its accuracy and reliability assessment, can provide a useful operational tool for mapping and monitoring urban change at the meso (30m) scale.

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