MAPPING URBAN SPRAWL USING VHR DATA AND OBJECT ORIENTED CLASSIFICATION

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ABSTRACT

Changes in land cover and land use composition and status are important characteristics that affect landscape organization and function. In the context of water management in a suburban watershed of a metropolitan city, agriculture intensification, changes in parcel plan and expansion of urbanization contributed to transform runoff, to move the localization of the areas concerned by flood risk and to expose a most important part of the population to this risk. These phenomena increased the vulnerability of the landscape. The study area is the Touch River watershed (Haute-Garonne, France) as it has a representative landscape cover of the Toulouse city surroundings. On the contrary of most of studies on context that focussed on small data sets, we worked on a large metropolitan and agricultural area (507 km^2) with the typical pattern of intricately mixed land use ranging from pure urban to rural. With the availability of the very high spatial resolution images, the past few years in remote sensing work have seen rapid progress in development work object- and knowledge-based techniques aimed at automatic image interpretation. This trend has been driven in part by the awareness that traditional approaches (pixel-based maximum likelihood classification) fail to deliver the kind of information requested by the user: elementary objects which characterize urban area. The aim of this work is to develop and test a methodology to map urban objects with an object-oriented classification method using a 5m Spot-5 merged satellite image on the Touch watershed. We present an image analysis flowchart, based on the use of the eCognition object-oriented software. The cartography which is obtained identifies the urban objects at different scale levels and different organization levels (dense, discontinued and spread urbanization). Using specific segmentation parameters, we define a fine-scale level and a coarse-scale level that allow to characterize respectively single houses and residential areas. Classification was realized using fuzzy membership function and training samples. A particular effort has been made to evaluate the quality of the results (confusion matrix, Kappa coefficient), in relation with field data. The comparison of the urban objects obtained from eCognition and from a Computer Assisted Photo-Interpretation classification showed that the object-based classification method produces urban objects with a higher level of accuracy (identification and localization) for the three types of urbanization (spread, discontinued and dense). So, in the context of our study, this work demonstrates that it makes possible, in a semi-automatic approach, to map, on a large area (several hundred square kilometres) extensive data of the landscape description, having significant consequences on the watershed hydrologic behaviour. In our case, the urban objects will be combined to the agricultural land cover map (obtained with a per pixel classification method) in order to produce the best land use map.

Key words: urban area – object oriented classification – eCognition – landscape – very high spatial resolution

INTRODUCTION

The urban expansion increases the vulnerability of the landscape in the case of the flood risk. The watershed approach seems to be essential in comparison to the regional or departmental analysis. In this context, simulation and precaution tools are necessary, especially to evaluate urbanization and land use change. The APIBAR project is a research project financed by CNES (French Space Agency) with support of BRGM (French Geological Survey) and ESAP. The main objective is to demonstrate the advantage of use of remotely sensed data in hydrologic models to evaluate flood risk at the scale of the watershed. We chose the Touch River watershed as it has a representative landscape cover of the Toulouse surroundings.

The aim of this paper is extraction of the urban area from the SPOT-5 image by the use of object oriented software eCognition. This information will be then integrated into the simulation model of flood area of the watershed. The last studies demonstrated that a supervised per-pixel classification method is adapted to map successfully agriculture area, but not for the urban elements, especially if these are discontinued or spread in the landscape matrix.

Many categories of land use have a characteristic spatial expression which may be identified in fine spatial resolution remotely sensed images. For instance, residential districts in many towns and cities are often characterized by a complex spatial assemblage of tile-roof and slate-roof buildings, as well as tarmac and concrete roads, interspersed with gardens comprising grass lawns, bare soil and trees (1). Using high resolution sensing data makes it possible in principle to detect man-made features such as buildings and roads. Very high resolution satellite data contains significant more detailed information than previous satellites (e.g. Landsat TM) but problems arise from their high spectral variance. The so called salt and pepper effect is a handicap for the recognition of semantic classes (2) when using traditional per pixel classification. Because of this reason the object oriented software eCognition of Definiens Imaging was chosen to complete the aim of this project. Another argument for use of object oriented classification is that traditional pixel-based approaches are based exclusively on the grey value of pixel itself. Thereby only the spectral information is used for the classification (3). Especially in urban areas we often find objects which can be separated into different classes only by their orientation and relations to neighbouring objects. Here the object-oriented method of eCognition has a clear advantage over a pixel-based spectral method (4).

METHODS

Study area and data

For the purpose of future hydrological modelling we needed integrated study area. The watershed of the Touch River, southwest of Toulouse, France, was chosen as a suitable area of interest. The watershed covers 507 km^2 and measures from east to west 73 km. The agricultural area is very important as it represents 476 km^2 (94% of the total area). The population is localized mainly in the area of Toulouse city and the number of inhabitants is around 160 thousands. With the distance from the city centre (impervious urban cover) the percentage of urban surface decreases on behalf of agriculture land. The isolated farms are characteristic in the country side area. The objective of this paper was the recognition of especially these elements of only few buildings together in the matrix of the cultivated fields. The watershed of the Touch River was divided into 8 strata according to the landscape characteristics (combination of land use, water availability and pedology). For the purpose of this paper only three strata were chosen, which each represents one characteristic type of urbanization within the watershed (Figure 1). The total area of the three strata covers 36 561 ha.

Classification was based on orthorectified images of the SPOT 5 satellite (commercial product of Spot Image). We had a panchromatic band (spatial resolution 5m) and 4 spectral bands (G, R, NIR, MIR; spatial resolution 10m). The date of acquisition is 29. September 2002.

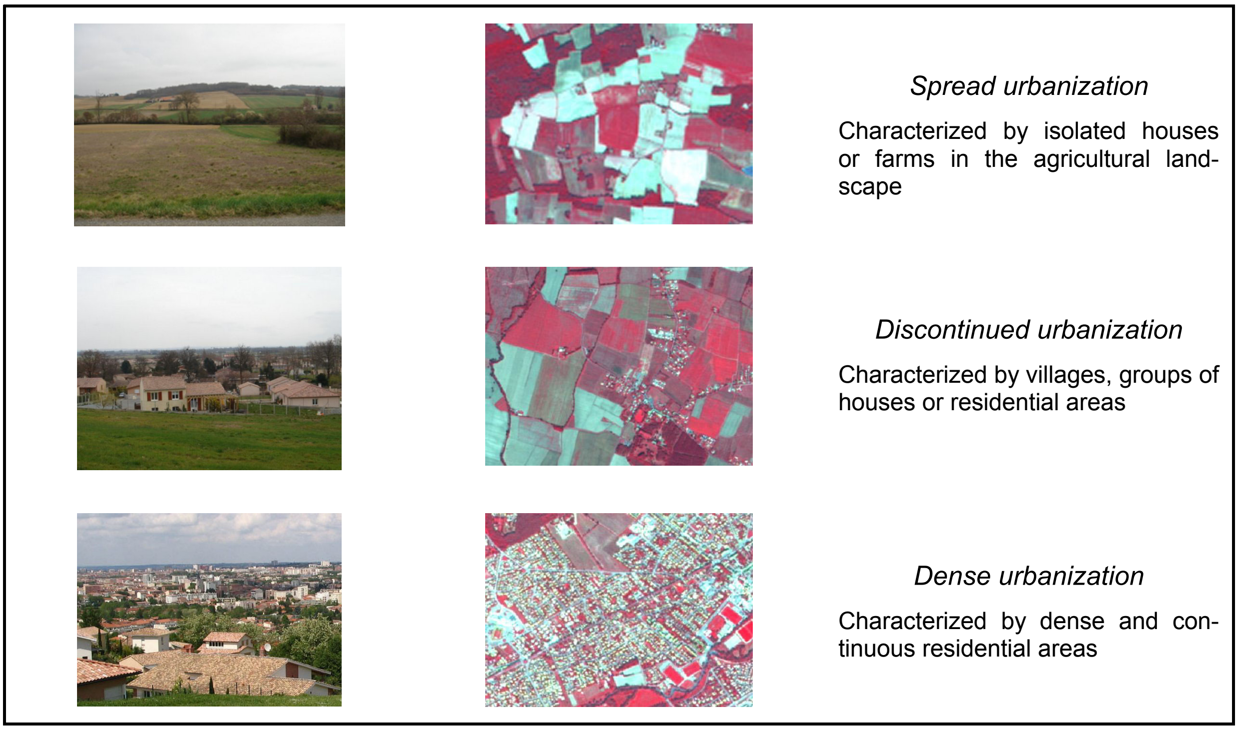


Figure 1: Types of landscape of the Touch River watershed.

Pre-processing

The classification in eCognition was performed on the non-merged data at first, but the results of this approach weren't successful, so the image fusion was used as a pre-processing of the data (3, 4, 5). The objective is to obtain a high-resolution multispectral image that combines the spectral characteristic of the low-resolution data with the spatial resolution of the panchromatic image (6). In this paper, the ENVI Gram-Schmidt Spectral Sharpening was used. The main advantage of this pan-sharpening method compared with other tradionnals (e.g. Hue Intensity Saturation and Principal Component), is that it increases the spatial resolution of the multispectral data while preserving its spectral integrity (7).

Classification

Software eCognition is based on an object oriented approach to image analysis. In contrast to traditional image processing methods, the basic processing units are image objects or segments, and not single pixels. Segmentation means the grouping of neighbouring pixels into regions (or segments) based on similarity criteria (digital number, texture) (8). The segmentation technique used in eCognition is a region-growing procedure that groups pixels or subregions into larger regions based on some predefined criterion. The merging procedure is based on three concepts: colour, smoothness and compactness (9). The size of the image object depends also on the scale parameter, which is a measure for the maximum change in heterogeneity that may occur when merging two image objects (10). A knowledge-based approach is used to classify objects into information categories, using fuzzy logic based on attributes of image objects and/or nearest neighbour classifier. The classification actively utilizes different levels of segmentation and different classification hierarchy levels (class depths) (11). The multitude of additional information can be derived based on image objects (e.g. shape, texture). Besides its neighbours, each object also knows its sub- and super-objects in such a strict hierarchical structure.

The classification of the pan-sharpened image was made on three levels. The classification process is shown on the diagram (Figure 2).

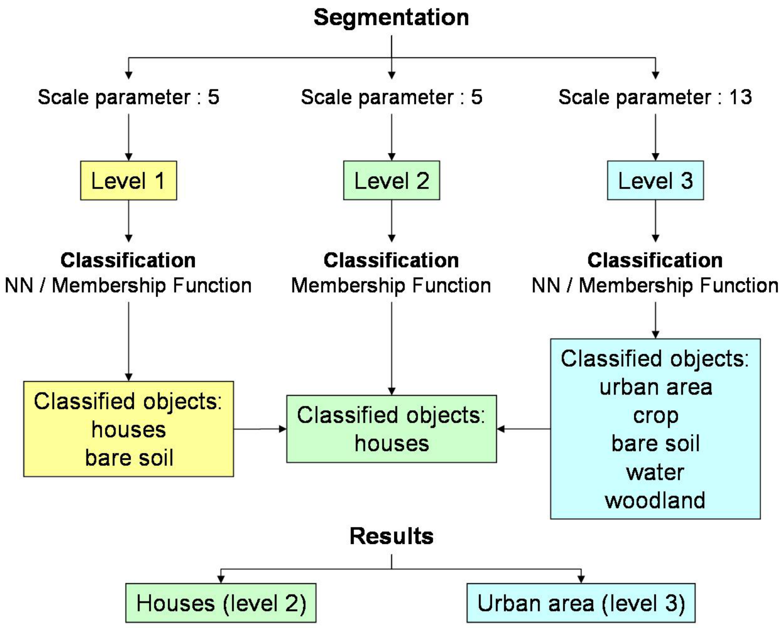


Figure 2: Work-flow diagramm of the classification.

There are no clear suggestions for the usage of segmentation parameters, as they should be determined on an "ad hoc" basis (12) and in the same time the quality of classification is directly affected by the segmentation quality (Neubert and Meinel 2003). The first level has the finest scale parameter for the purpose to detect every single house within the image to extract the buildings, only two classes were created. Both classification methods were used to describe the classes. The Nearest Neighbour (NN) classifier is able to evaluate the correlation between object features and handles much easier the presence of overlaps in the feature space (2). The description of the class *bare soil* was made because of the easy confusion of the roofs of buildings and bare soil. Without creation of this class, all objects of bare soil could be assigned to the class *houses*. Next level was created with coarser scale parameter to have more general view of the scene and to be able to extract whole residential area. In this case, all classes which could be seen within the image were created. The last level (this one is labeled level 2 in the classification hierarchy) was created to improve the classification result of the level 1 and so were used the same segmentation parameters as on the level 1. Just one class was then created and described with membership functions: an object will be assigned to the class *houses* (level 2) if an object of class *houses* (level 1) exists in the sub-level and in the same time, in the super-level exists an object of the class *urban area* (level 3).

The method was first made up on a subset of the whole watershed, which contains the three types of urban cover. Then, the classification process with the same segmentation parameters and class hierarchy was run on the whole watershed, but in this paper we presented only the results of the three typical strata.

Validation method

We used the eCognition accuracy assessment tools and ground truth data for the validation of the classification. eCognition provides tests of Classification Stability, Best Classification Result and Error matrix based on samples. The field survey mapping was made to obtain ground truth data. The validation segments, each of 49 ha, were dislocated all over the whole watershed and were distributed on base of random stratification (13, 14) to well involve the variability of the land cover. The three strata of interest were covered by number of 28 validation segments. The classification results were exported from eCognition to vector shapefile format. Then the comparison of the classification result with segments based on the ground truth data were performed in ArcView software and so we obtained the confusion matrix and the associated indicators: overall accuracy, user's accuracy, Kappa coefficient.

RESULTS

Classification in eCognition

The scale parameter of the multiresolution segmentation is an important factor. With the coarser scale parameter, there is possibility to detect some isolated farms whose spectral response is very different to the surrounding surface, but at the same time the small houses of dense urban area do not form separated segments. And if the extraction of the houses is the main purpose it is necessary to use a fine scale parameter.

In the level 1, the aim was to extract every single house of the scene. The result shows that there is a problem of confusion between the classes of *houses* and *bare soil*, some bare soil objects were classified as houses, which both have very high reflectance values. This is because we used only one image of September. The problem was partly resolved using membership functions of the shape object features. The buildings represent the most compact objects within the scene and also the length/width ratio of these objects is usually low. But all wrongly classified objects weren't eliminated. These are mainly objects which are on the border of the bare soil fields with high value of reflectance.

The object of level 3 is the extraction of whole residential area (houses and gardens). Confusion in the classification can be seen between classes *urban area* and *crop*. The confusion is evocated by the close spectral response of the cultivated fields (summer crops) and some lawns and gardens of the residential area, as we used only one image of September. Results of classification of the urban objects are shown in Figure 3.

Spot-5 image sample (Pan image - 2,5m spatial resolution) | Urban objects resulting from the fine-scale level of segmentation | Urban objects resulting from the coarse-scale level of segmentation

Figure 3: Results of the classification.

In both cases, the objects of *houses* or *urban area* were all assigned to the right class, but to these classes were assigned also some objects of bare soil or crop (over-estimation of the *urban area* and *houses* classes). In the context of our study of flood simulation, it is only a small problem as this urban mapping will be combined with a land use map of the agricultural area made with a supervised per-pixel classification method (maximum likelihood algorithm). But, as the land use is not available at this time, the classification result was improved by manual on-screen purifying.

From the classification results, we derived two types of products: conversion of classified objects into vector shape file format for the statistical accuracy assessment of the classification and two maps based on the levels 2 and 3.

Validation

eCognition tools confirm the fact mentioned above, that the descriptions of classes *houses* and *bare soil* are very close to each other, but instead of this fact, best classification result shows high degrees of membership for the objects classified as *houses / urban area*. The eCognition error matrix based on samples results with the average overall accuracy of 0,8826 for the fine segmentation level and 0,9389 for the coarse segmentation level. The average Kappa index is 0,7226 and 0,9178 respectively.

For the validation based on ground truth data we used shapefiles which contained only the class *urban area* (level 3 – coarse level) or *houses* (level 2 – fine level), then the Table 1 shows the percentage of objects assigned to the classes of validation segments.

Table 1: Error matrix (in percentage) calculated for the urban area class on the three strata and at two different scales depending of the level of segmentation (before cleaning).

	Classified objects					
	Dense urban strata		*Discontinued urban strata*		*Spread urban strata*	
Validation fields	*Houses*	*Urban area*	*Houses*	*Urban area*	*Houses*	*Urban area*
Urban area	93	84	87	72	25	16
Crop	1	4	7	18	36	53
Bare soil	0	1	4	4	26	22
Woodland	6	11	2	4	10	7
Undefined	0	1	0	2	3	1

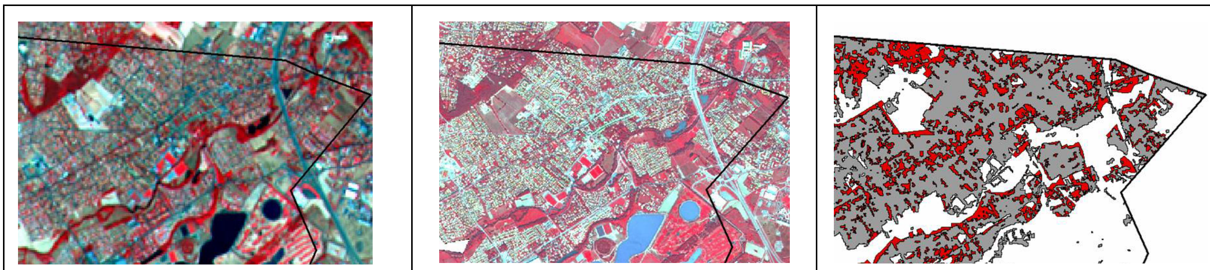
The average accuracy of the detection of residential objects was for the fine level 68% and for the coarse level 57%. The user's accuracy for *houses* and *urban area* was very good for the dense urban and discontinued strata (between 72% and 93%). But it decreases dramatically in the spread urban strata with respectively 16% and 25% for the user's accuracy of the urban area and houses. These poor degrees of accuracy in this stratum are explained by confusion with bare soil (mainly caused by the use of the image of only one date for the classification).

After cleaning the first results, the user's accuracy for houses and urban area is still very good for the dense urban and discontinued strata respectively 84% and 88%. Cleaning process really improved the spread urban strata, now with user's accuracy of 65%. The average accuracy of the detection of residential objects after cleaning process for the coarse level was 79%.

Comparison with the SPOT Thema product

SPOT Thema is an urban land use management database product covering mainly France. It is a vector database generated from SPOT imagery, compatible with a broad spectrum of standard land planning and management applications. It is based on SPOT 1 to 4 data (15). We compared the SPOT Thema layer with the result of eCognition to evaluate a computed assisted photo-interpretation classification method versus semi-automatic object classification method. In our analysis we consider the SPOT Thema layer as the reference in the error matrix. The urban area class coming from eCognition and SPOT Thema contains houses with gardens, industrial and commercial infrastructure, roads and airport.

In the dense urban strata, 85% of the urban objects were correctly classified according to the SPOT Thema urban classes and for the urban discontinued strata the percentage of correctly assigned urban objects is 70%. The misclassification with the agricultural area is caused by the different level of detail. The SPOT Thema layer is produced on base of the 20m spatial resolution images, whereas the eCognition classification was realised on the fusioned 5m spatial resolution image. With the 5m image we were able to distinguish the buildings and the green areas which is not possible with the 20m image as we had mixed pixels (pixels which contain building and green areas) (Figure 4).



Spot-4 image (20m)	Spot-5 fusioned image (5m)	Superposition of the urban classes from SPOT Thema (in red) and eCognition (in grey)

Figure 4: Comparison of the SPOT Thema product and eCognition classification.

CONCLUSIONS

Our project deals with a methodology for classifying urban area of different density (spread, discontinued and dense) from VH spatial resolution image using an object oriented approach. Each type of strata has been classified using the same eCognition parameters, then the methodology results as reproducible. eCognition software is a useful tool to extract small objects of certain significance from the whole scene. In this paper the aim was to extract the urban surface in general so the image resolution of 5m was sufficient.

The analysis of the error matrix shows that results of dense urban and discontinued urban strata could be used without next step of purifying the confusions, mainly of the borders of the fields. The confusion between classes *bare soil* and *urban area* only in the case of spread urban strata could be resolved by using an additional image layer of digital elevation mode (DEM) (Houses can easily be identified by their relative height to neighbouring objects (16)) or using another remotely sensed image of different date (we should be able to avoid the misclassification between *bare soil* and *urban area*).

The comparison with the SPOT Thema layer shows that the urban map produced by eCognition gives similar or even more accurate results of detecting the urban objects. It means that semi-automatic object-oriented approach could be an alternative to the CAPI method: it is less time consuming, homogeneous all over the classified area and maybe cheaper. A further work should be to compare our results with the SPOT Thema layer based on SPOT 5 images in order to validate our conclusions.

If we come back to the general context of our study, the final result of the classification gives the required information in order to evaluate the effects of the land use change (especially urban expansion) on the flood risk assessment. The next step would be to combine this object oriented classification of the urban elements with the supervised per-pixel classification of the agricultural area to have an exhaustive land use map.

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