COMPARISON OF STANDARDIZED METHODS (OBJECT-ORIENTED VS. PER PIXEL) TO EXTRACT THE URBAN BUILT-UP AREA: EXAMPLE OF LUBUMBASHI (DRC)

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ABSTRACT:

The delimitation of urban areas, and in Africa in particular, remains a challenging issue and is an important one for city management in a context of rapid urban growth. The objective of this study is to delineate the morphological limits of the urbanized city which is different from administrative boundaries. Two methods have been developed: the first one is using object-oriented classification (using eCognition software) while the second is based on a automated and customizable spectral threshold (by generating a large number of thresholding which are then combined to determine a probability of belonging to urban area) using GRASS (free GIS software). The main goal is to test if the classification procedure could be avoided (training and validation are time-consuming processes). Both methods are applied to 4 different dates, using SPOT-1 (1986), SPOT-2 (1995), ASTER (2001) and SPOT-5 (2006) images to test the reproducibility and robustness at different dates, and by using different sensors. The results show that on one hand the two methods produce fairly similar results for a given date, both from a standpoint of quantity and quality. On the other hand, for all dates, the results are consistent and very good (overall accuracy between 88% and 95%).

1. INTRODUCTION

The last decades have seen unprecedented global population growth, especially located in urban areas (Weber, 2000). Today, over 50% of the population live in a city. Estimates suggest that by 2030, over 60% of the population will be urban (Tatem et al., 2004). In Africa, urbanisation has also expanded rapidly in recent year, suggesting ominous consequences on the structure and functioning of the urban system if the problem is not taking into account (Kombé, 1999).

Without adequate mapping tools, policy-makers are struggling to determine the morphological limits of their city (Mouafo, 2000). Moreover, the morphological limits differ from the administrative boundaries. The ignorance of the morphological city may cause many difficulties, particularly with regard to urban planning. This can induce a lack of infrastructure and equipment in fast growing areas, especially informal settlements, exacerbating the precarious living conditions of resident people (Kombé, 1999). In consequence, urban area delimitation is one of the main concern for urban management (Assako-Assako, 2000). The lack of archives coupled with the rapid growth of African cities does not facilitate the future management of cities. The satellite data archive can fill this gap. The development of a methodology for multiple dates and sensors is essential.

Since decolonization and in the African context, it is common that archives, and up-to-date data, are lacking (Mban, 2007). In this context, the use of satellite imagery can be seen as a solution which allows the mapping of the city that can be seen as a valuable tool for city managing (Pouyllau, 1989). In addition, satellite images through their archives provide an opportunity to reconstruct the evolution of the city growth, allowing a better understanding of city dynamics. The distinction between urban and non-urban areas is particularly difficult in African cities, because for example of the natural materials used in construction (Sietchiping, 2003).

The aim of the study is to develop generic and reproducible methods that allow delineation of the urban area using satellite images.

In this study, two methods will be tested to delimit the urban area. The first one is a object-oriented classification method, performing a segmentation followed by classification of these segments using their spectral characteristics, textural, morphological and context (Benz et al., 2004).

The second method, based on GRASS (free GIS software), uses a threshold (Terretaz and Collet, 1997) on the first component of a principal component analysis (PCA). The aim of this method is also to test if the classification process can be simplified as much as possible (training and validation are time-consuming and tedious processes) and make it as automatic as possible.

2. STUDY AREA AND MATERIAL

The selected study area is the city of Lubumbashi (Democratic Republic of Congo). Three multi spectral SPOT images will be used to test the two methods (Table 1). In addition, an ASTER image will be used to verify the reproducibility of the method using another sensor.

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Date	Sensor	Bands used	Spatial resolution (m)
04/06/86	SPOT-1	R-G-NIR	20
05/08/95	SPOT-2	R-G-NIR	20
10/10/06	SPOT-5	R-G-B-NIR	10
27/08/01	ASTER	R-G-NIR	15

Table 1. Characteristics of images used

The panchromatic band of the 2006 SPOT image was georeferenced (UTM 35S–WGS84) using a scanned and georeferenced topographical map (1: 200 000) of the region. Then, the multispectral bands for each year have been coregistred using this georeferenced band. The geometric correction was made using a first order transformation. The global RMS error range from 0,68 to 1,26 (pixels).

The original satellite images cover a much wider area than the area of interest. Consequently, they were centred on Lubumbashi and clipped to an area of approximatively 550km² (22km x 25km).

3. METHODOLOGY

3.1 Introduction

Two types of methods will be tested. The first one is an object-oriented classification. The second one is based on an automated and customizable spectral threshold classification per pixel. Each method represents a main type of classification technique using satellite images.

The two methods will be applied to a time series of SPOT images from 1986, 1995, and 2007 to verify the reproducibility of the methods at different times. The reproducibility will also be tested on a different type of data, an ASTER image of 2001.

3.2 Object-oriented method

The object-oriented classification relies on a segmentation followed by classification of these segments using their spectral, textural and morphological characteristics (Benz et al., 2004). eCognition software (version 6) is used for the segmentation and classification steps.

The relative importance of each spectral band has to be specified for the segmentation step. Several segmentation test have been made and the best result includes the green, red and near infra-red bands with respective weights equals to 1, 1 and 2 (Almeida, 2007).

Three parameters need to be defined for the segmentation step: the **scale parameter** allows the user to define the average size of resulting segments (Lewinski, 2004), that is to say, the fineness of the segmentation. This parameter is determined by the size of characterized objects. When this parameter is high, the resulting objects will be larger. It was chosen by trial and error (value between 7 and 25) and the best result was chosen by visual interpretation (value of 20). The **shape parameter** defines the weight of the shape criterion when segmenting the image. The higher its value, the lower the influence of colour on the segmentation process (Lewinski, 2004). The **compactness parameter** defines the weight of compactness criterion. The higher the value, the more compact image objects may be. As for the scale parameter, their value was chosen after trial and error and visual interpretation. For shape and compactness, default settings given in eCognition yielded the best results (0,1 for shape and 0,5 for compactness).

The Nearest Neighbour algorithm for supervised classification was used. The attributes used in classification were chosen based on visual interpretation. The regions are described in terms of spectral averages of the blue, the green and the near infra-red bands and a vegetation index (NDVI). Haralick's textural attributes are also used : homogeneity of the blue band (Ackermann, 2004).

Training and validation areas were selected based on visual interpretation of satellite images supported by consultation of very high resolution images.

3.3 Thresholding and pixel based method

The simple thresholding of images is a well-known method, associated with other simple tools and well documented (mathematical morphology, PCA, buffers, simple query, generalisation, ...), that lead to the delimitation of the urban area (Kombé et al., 2007). The aim of this method is also to be fully automatic: to achieve this objective, a script has been written which contains all the steps that will be described below.

To synthesize the information contained in the SPOT multi spectral bands, which are highly correlated (Boucherit, 1997), a principal component analysis is performed and the first component is used (Deng et al., 2009; Jollife, 2002). GRASS rescales the results of the component between 0 and 255.

Then, the next step is to threshold the first component at each value (i.e. between 0 and 255). The result is a binary image containing built-up and non built-up pixels. Each output from the thresholding is smoothed using a closure (mathematical morphology operation). It consists in achieving a dilation followed by an erosion using a 3x3 moving window (Kombe, 2007; Assako-Assako, 2008). The objective is to eliminate, or reduce, the impact of artifacts. In other words, with a closure, thin and heterogeneous forms, and small areas (less than the size of the window used) are eliminated (Weber et al., 1997).

Then, a continuity criterion is achieved by generating a 200 meters buffer around the urban core. All built-up pixels located within the 200m buffer will be integrated to the urban perimeter. This step is repeated as a loop until no more area is added to the previous result.

Once these steps are done for each threshold between minimum and maximum, the resulting binary maps are summed up to obtain a urban frequency map. Then, an analysis of the discontinuities present in the cumulative frequency curve of this map is performed, using DISCONT algorithm. This algorithm is based on the work of Jenks (Jenks, 1963) and is based on a cartographic generalisation algorithm (Douglas, 1973). The objective is to obtain different thresholds that will define four classes relative to the belonging to the urban area: certainly non-urban, probably non-urban, probably urban and certainly urban. Two transitional classes between the original classes of interest are integrated to compensate the difficulty to fix a strict distinction between urban and non-urban (Assako-Assako, 2000). The introduction of thresholds in the urban frequency

map also makes a validation possible and allows a mapping of the urban growth evolution.

Classification by thresholding is a well documented method (Terretaz, 1997). The originality of this method, beyond the fact that it is fully automatic, is the non-arbitrary choice of the thresholds, the addition of transitional classes and the possibility of customizing the different parameters used (size of the moving window, size of the inclusions to delete, length of the buffer for the continuity criterion).

3.4 Generalisation

Both methods use in common the following methodological elements. Once the first classification (built-up vs. non built-up) step is made, a first generalisation is conducted: non built-up inclusions of less than 1 km² within built-up areas are eliminated. This reduces the impact of artefacts: for example, vegetation, water or bare soil small patches are correctly identified as non built-up but are part of the urban area. Their integration in the urban area provides a more consistent result (Weber et al., 1997). Then, only the largest built-up patch is extracted and is considered as the urban core from which a continuity criterion will be applied. That is to say that any area considered as built-up and located within 200 meters from the urban core (Weber et al. 1997; Donnay, 1997; Weber, 2000) will be integrated into the urban perimeter.

3.5 Validation

Regarding the validation process, 200 points were randomly generated for each image and visually interpreted. An overall accuracy (ratio between points that are correctly classified and the total number of points) is calculated for the whole map, and for each class for the threshold method. Besides, a visual delimitation of the city was conducted to measure the surface of the real urban area and to compare to the results obtained. These two sets of validation were used to assess the results of both methods.

4. RESULTS AND DISCUSSION

4.1 Quantitative assessment

The results are quantitatively assessed in two ways: overall accuracy and urban area surface.

The two methods present very similar overall accuracy results, with a difference of +-3% at each date. The overall accuracy for all dates lies between 88% and 93% for the object-oriented method and between 88% and 95% for the threshold method (Table 2), which is quite consistent and high for both methods. When comparing the detected urban area to the visual delimitation, both methods tends to overestimate the urban area: differences lies between -1,7% (SPOT5 2006) to +2% (SPOT1 1986) for the object-oriented method, and between -0,2% (ASTER 2001) to +6% (SPOT1 1986) for the threshold method (Table 2).

Year	Overall accuracy (%)*	Overall accuracy (%)**	Urban area (km²)*	Urban area (km²)**	Urban area (km²) validation
1986 (SPOT-1)	91	88	71,9	74,1	69,9
1995 (SPOT-2)	88	91	88,3	88,1	87,1
2001 (ASTER)	92	95	117	114,9	115,1
2006 (SPOT-5)	93	90	144,3	151,1	146,8

Table 2. Accuracy assessment for the object-oriented method (*) and the threshold method (**) and the urban area surface

The SPOT-1 1986 image yielded the poorest results for both methods (overestimation in the two cases). Looking at the results of the PCA, it was the 1986 image that yielded the lowest importance for its first component. This could suggest a lower quality of the original data. By cons, the ASTER of 2001 presents very good results. The spectral bands (red, green, near-infrared) used are similar to SPOT. The better results are probably due to the better spatial resolution. But, the quality of this image must also be very good, since the 2006 SPOT image, with its better spatial and spectral resolution, yield similar result for the object-oriented method and poorer result for the threshold method.

It is possible to have a finer reading of the overall accuracy results by analysing each class result of the threshold method. One date will be analysed here, but the others are very similar to the SPOT 1986 example (Table 3). The classes accuracies illustrates that there is a clear delimitation between urban and non-urban : the probably non-urban class results lies between 88,8% (SPOT 86) and 95,5% (ASTER 2001) and the probably urban class results lies between 81% (SPOT 86) and 94% (ASTER 2001). In addition, the extreme classes, presents very consistent results of 100% for non-urban class and over 93% for urban class. Here again, the SPOT-1 of 1986 yield the poorest results, while the ASTER of 2001 has the best results.

Class	% Urban	% Non-urban
Non-urban	0	100
Probably non-urban	11,2	88,8
Probably urban	81	19
Urban	93,8	6,2
Total	**84,5**	**90,2**

Table 3. Accuracy assessment for SPOT 1986 (threshold method)

Given these results, the object-oriented method seems a bit more consistent, but the absolute best result comes from the threshold method. At first sight, the two methods provide comparable results and both methods are replicable at different date and using different sensors.
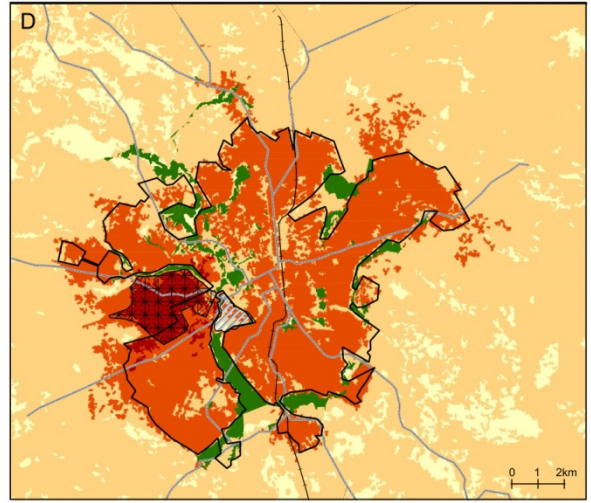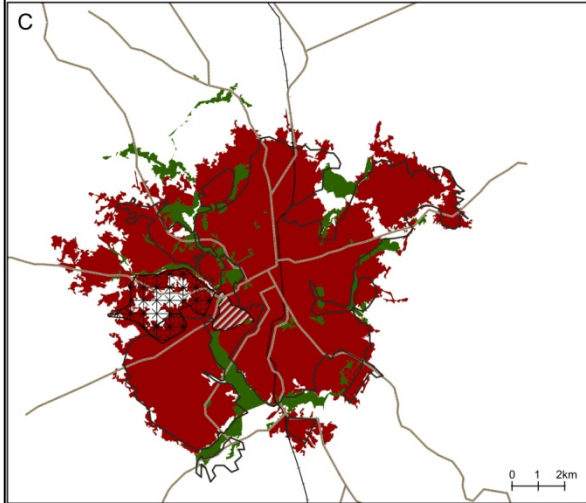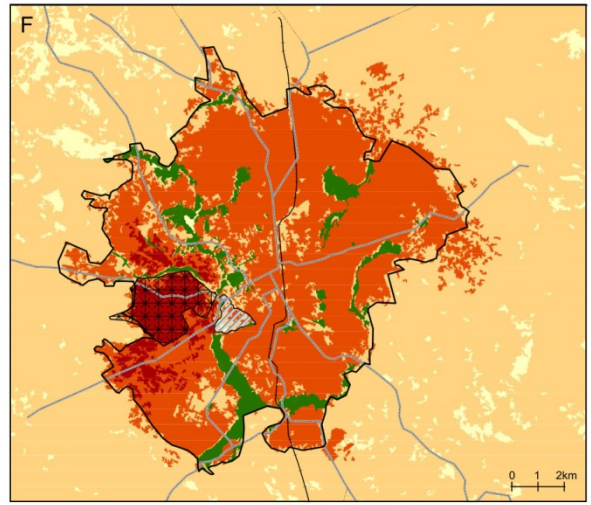
Threshold method
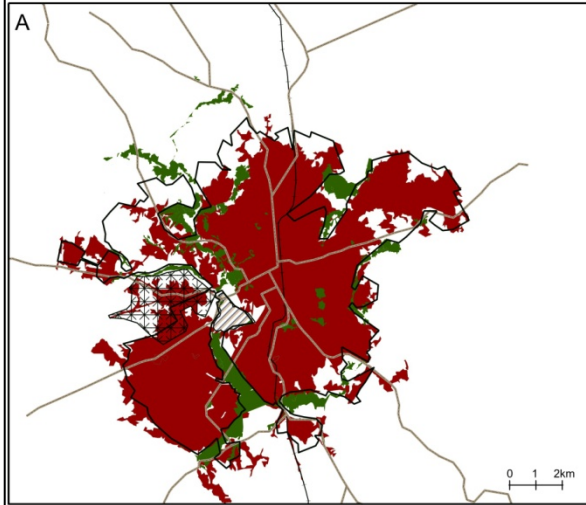
Object-oriented method

1986
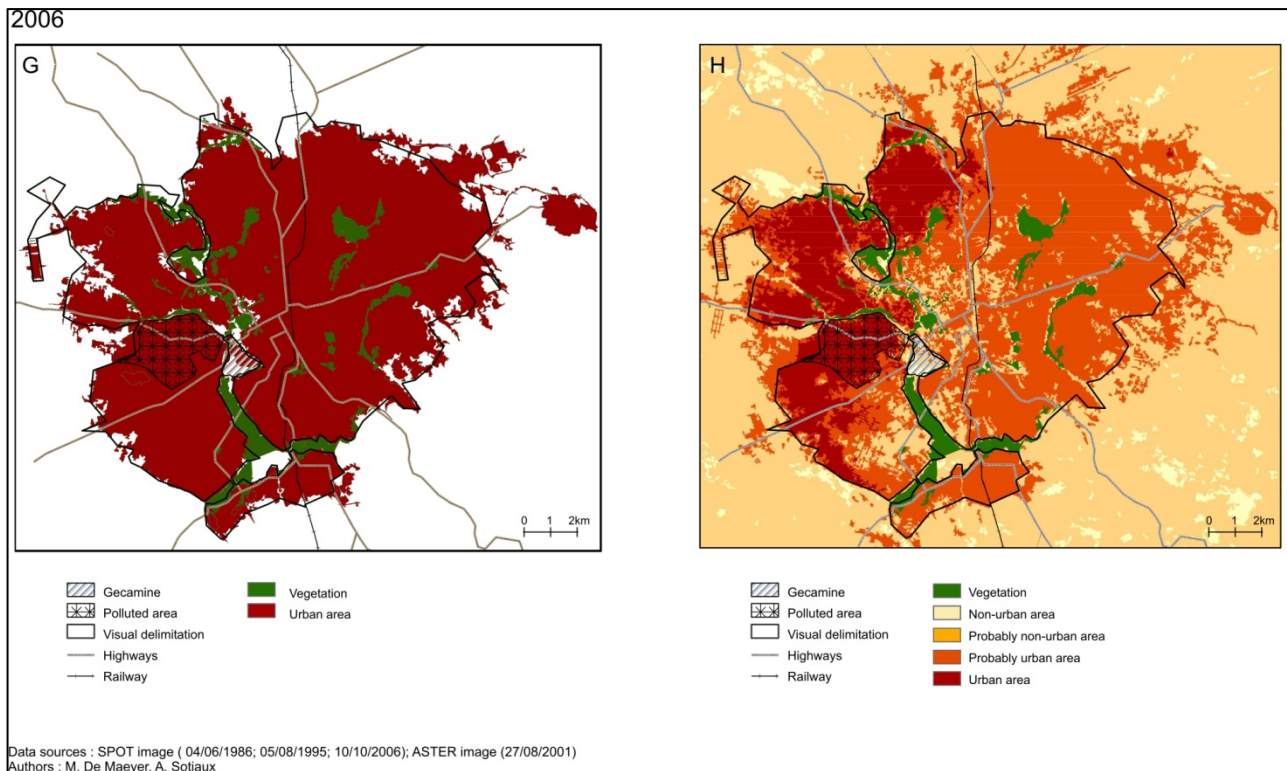
A

B

1995

C

D

2002

E

F
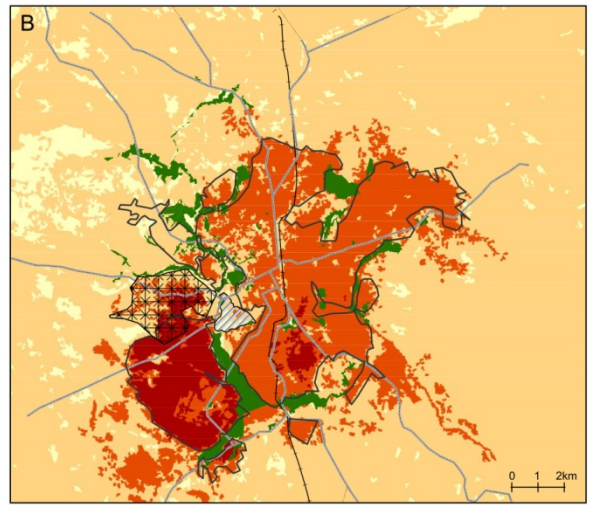
Figure 1. Urban area delimitation for both methods

4.2   Qualitative assessment

The methods will now be visually compared and assessed. In 1986, the errors are mainly overestimation of the urban area and are located west of the city, in a polluted area under the influence of the Gecamines chimney (Fig. 1A and 1B). Indeed, the prevailing winds blow from the South-East to the North-West which expose this area to pollution. In consequences, the environment is heavily damaged and appears as a desert, very bright on satellite images and is thus detected as built-up. In the threshold method, overestimation errors are also located South-West and South-East of the city (Fig. 1B), in bright areas on the image that probably are large bare soils areas located near to the city.

The results of SPOT-2 of 1995 (Fig. 1C and 1D) show similar errors as those observed in 1986, i.e. overestimation of the urban area located west of the city in the polluted area.

For the ASTER image of 2001 (Fig. 1E and 1F), the polluted area is still considered as a part of the urban area, but now it is correctly classified. Indeed, in 2001 this area is built-up and part of the city. The errors are now located North-East of the city: underestimation in the object-oriented method and overestimation in the threshold method. This error is due to the fact that this region presents a different geological substratum that the rest of the city. This geological difference is visible on the satellite images and creates confusion in the detection of the urban area (over- or underestimation). This error was not present at the previous dates because this area was too far from the urban area, and not yet built.

The results of the SPOT-5 of 2006 (Fig. 1G and 1H) shows similar errors as those observed in 2001. They are mainly located in the North-East of the city, on a different geological substratum. The object-oriented method shows an underestimation in this area while the threshold method shows an overestimation. This difference between methods is also reflected in Table 3.

The visual assessment of the results allows the same conclusions as the quantitative assessment: the best result is yielded using the ASTER of 2001, the poorest result is obtained using the SPOT-1 of 1986. Besides, the errors are almost similarly located for both methods and are due to two characteristics of the city of Lubumbashi: the presence of the polluted area, West of the city, very bright on the images and misclassified in 1986 and 1995. From 2001, the polluted area is actually built-up and part of the urban area. The second characteristic is due to the different geological substrata in the North-East. Its influence in 1986 and 1995 is minor because it was too far from the urban area, and probably not yet built. But from 2001, it is the major source of confusion for both methods.

This second assessment strengthens the fact that both methods provides good and similar results and are reproducible at different dates and using different captor.

5.   CONCLUSIONS

The delimitation of urban areas in Africa remains a challenging issue and is an important one for city management in a context of rapid urban growth. This study has developed two different methods (object-oriented classification vs. threshold per pixel classification) of urban area delimitation. The different results obtained are very similar (+/- 3% at each date) for the two methods and have especially proven their reproducibility, not only across time but also by using different sensors. However, best results are obtained using an ASTER image for the threshold method, despite the better spatial resolution of SPOT-

5 in 2006. The object oriented approach provides results slightly more consistent, but also slightly lower regarding the absolute best result. The development of a simple method, based on concepts used for a long time and well known, yields very good results and its automation also enables to avoid the training and validation processes (tedious and time consuming) of the object-oriented classification. For a deeper exploration of these methods, it would be appropriate to test their reproducibility in other cities, possibly using other sensors.

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