Detection of landslides from aerial and satellite images with a semi-automatic method. Application to the Barcelonnette basin (Alpes-de-Haute-Provence, France)

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ABSTRACT: Until now, visual photo-interpretation techniques combined to ground survey remains the most used method to locate and characterize landslides. New perspectives in using remote sensing for landslides location are now offered by the availability of very high spatial resolution images and by the development of object-oriented image analysis tools. The objective of this paper is to propose a semi-automatic method to locate landslides with very high spatial resolution (aerial and satellite) images and by using expert knowledge on landslides. The approach is based on (1) the definition of quantitative indicators derived from expert knowledge (by a photo-interpretation technique) and (2) the introduction of these indicators in an object-oriented method using multi-resolution and multi-source images (aerial or satellite). The results are (1) a formal and generic grid characterizing the landslides and (2) the identification of relevant criteria to extract landslides.

1 INTRODUCTION

Landslides are a major problem in mountainous regions (Alexander, 2008). From earth observation data, landslides study can be summarized in three application domains: (1) mapping (inventory), (2) characterization and (3) spatial and temporal monitoring (Metternicht et al. 2005). These applications require fine (1:5000 to 1:10,000) and up-to-date spatial information which can be integrated easily in a GIS platform.

Until now, visual photo-interpretation techniques combined to ground survey remains the most used method to locate and characterize landslides (MATE & LCPC 1999; Mantovani *et al.* 1996). It allows identifying geomorphologic features and predisposition factors of landslides at 1:10,000 scale. It is also used to locate and map past dormant and and active landslides (MATE & LCPC, 1999). But this traditional technique is complex to apply to large areas and is time-consuming. Moreover, it requires an expert knowledge on the hazard and remains very subjective (Mc Kean & Roering, 2004).

In the optical domain, High Spatial Resolution images (HR - 30 to 5 m) with classical per-pixel methods are not used in detection and characterization in landslides studies due to the inadequacy of the spatial resolution. The coarse pixel size does not allow to detect small landslides of a characteristic length of less than 60 m. Moreover, per-pixel classification methods do not fit for landslide detection because the spectral response of a landslide is not unique and can correspond to the aggregation of pixels with different spectral properties. The difficulty is also that landslides have often the same landcover as their direct environment and have consequently the same spectral response.

The new generation of Very High Spatial Resolution images (VHSR – 4 to 1 m) offers new possibilities with its finer spatial resolution. It can be exploited to provide detailed information on landslides. But in order to benefit from the complementarity of spatial and spectral information, new method considering object-oriented image analysis instead of only spectral analysis (based on pixel values) have been developed (Geneletti *et al.* 2003; Harayama *et al.* 2004). These new methods could help avoiding the problem of the heterogeneous spectral response of landslides.

In the object-oriented image analysis, the first step is the segmentation of the image into 'regions'. It consists in grouping together pixels with similar properties by taking into account spectral information, but also texture, shape and size of object primitives. The influence the described parameters have on the segmentation is flexible and can be specified by the user through the manipulation of different parameters based on color and shape (compactness and smoothness) factors (Flanders et al., 2003). Different layers of the data can also be weighted with regard to their weight in the segmentation operations (Tansey et al., 2008).

The second step is the classification process of these regions based on examples (by a nearest neighbourhood algorithm) or on membership functions allowing users to develop an expert knowledge base (based on fuzzy logic) and to assign regions to certain classes. This fuzzy classification approach allows detecting classes that may contain membership ambiguities (Flanders et al., 2003).

Some studies used object-oriented methods to detect geomorphological units like sedimentary deposits, alluvial fans, fluvial terraces, rock cliffs (van Asselen & Seijmonsbergen 2006) and potential sites of landslides (Molenaar, 2005). In the segmentation process, several optical images (Argialas & Tzotsos, 2006; Molenaar, 2005) or radar and lidar images (van Asselen & Seijmonsbergen, 2006) are combined with vector or cartographic data in order to extract indicators (slope, elevation, distance to a river, roughness, presence of surface drainage, presence of cracks) on the 'regions'. These indicators are directly extracted from regions and are used to set up rule-based classifications.

In this context, the objective of this paper is to propose a semi-automatic method to locate landslides based on very high spatial resolution (aerial and satellite) images and by using an object-oriented image analysis method. The method is based on: (1) the definition of quantitative indicators derived from expert knowledge (by a photo-interpretation technique), (2) the intreoduction of these indicators in an object-oriented method by using optical images of different spatial, spectral and temporal resolutions.

In the following, first the study area and the data source are presented. Second, the methodology is explained and, third, preliminary results are presented and discussed.

2 STUDY AREA AND DATA SOURCE

The study area is located in the Barcelonnette basin (South French Alps). This basin extends over 200 km² and is drained from East to West by the Ubaye river.

Various factors including lithology, tectonics, climate and the evolving landuse have given rise to numerous slope movements of several types. The North-facing slope appears as the most sensitive slope of the basin: 10% of its surface is affected by landslides of different types, mainly translational and rotational superficial slides (Thiery, 2007).

The experimental site comprises 156 active landslides (eg. translational slides, rotational slides, mudslides and rock-block slides) of different sizes (eg. from 1000 to 20,000 m²). A test zone of 25 km² containing 73 landslides is used for the validation step.

Aerial images, satellite images and thematic vector data are the source of information. Three ortho photographs (1974 –infrared colour and 2000, 2004 – natural colour; © IGN) of the basin (spatial resolution of 50 cm) are used. The ortho-photographs and a panchromatic SPOT 5 image (© CNES 2004; 2.5 m spatial resolution) are tested to test the proposed method. The vector data is an expert map of all landslides of the north-facing slope from 2007 (Thiery, 2007). It is related to a database containing morphometric characteristics of the inventoried landslides.

3 METHODOLOGY

The proposed method is organized in four steps (Fig. 1): (1) a photo-interpretation analysis where qualitative landslides indicators are defined based on bibliographic researches and on a visual photo-interpretation technique, (2) the definition of quantitative indicators and their calculation by using the toolbox available in the object-oriented image analysis software (Definiens Professionnal[1]), (3) the application of rule-based classifications guided by the indicators calculated in step 2 (features), and (4) the evaluation of the method.

4 RESULTS AND DISCUSSION

1) Step 1

Relevant indicators mentioned in the literature allowing to detect the presence of landslides are identified (eg. landuse, vegetation density, texture, presence of cracks, surface disturbance or scarp visibility; Tab. 1).

These indicators are observed for the 156 landslides on the three orthophotographs. It enables to propose a formal and replicable grid for detecting and describing landslides in four categories.

2) Step 2

The more recent orthophotograph (2004) is chosen to calibrate the indicators. The image is first segmented into homogeneous regions by taking into account the observed landslides. The scale, color and shape parameters are adjusted in order to define 'regions' of same size and shape as the landslides of the 'expert' map (Tab. 2).

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[1] Formerly known as eCognition, developed by Definiens Imaging GmB, Germany.

Table 1. Qualitative indicators used in the photo-interpretation grids and their correspondence in terms of quantitative indicators and features in the Definiens Professionnal software.

Qualitative indicators	Quantitative indicators	Definiens Professionnal features
Area Length Compactness index	Shape	Area Length/width ratio Shape index Compactness Roundness
Landuse Vegetation density	Spectral	Brightness Spectral layers means Pixel ratios Maximum difference index
Texture Cracks Ridges Disturbance of the surface	Texture	GLCM* contrast GLCM entropy GLCM mean GLCM correlation
Scarp visibility Accumulation zone visibility	Neighbourhood	Mean difference to neighbour
Watercourse proximity Road proximity	Topology	Distance to

* Grey Level Co-occurrence Matrix

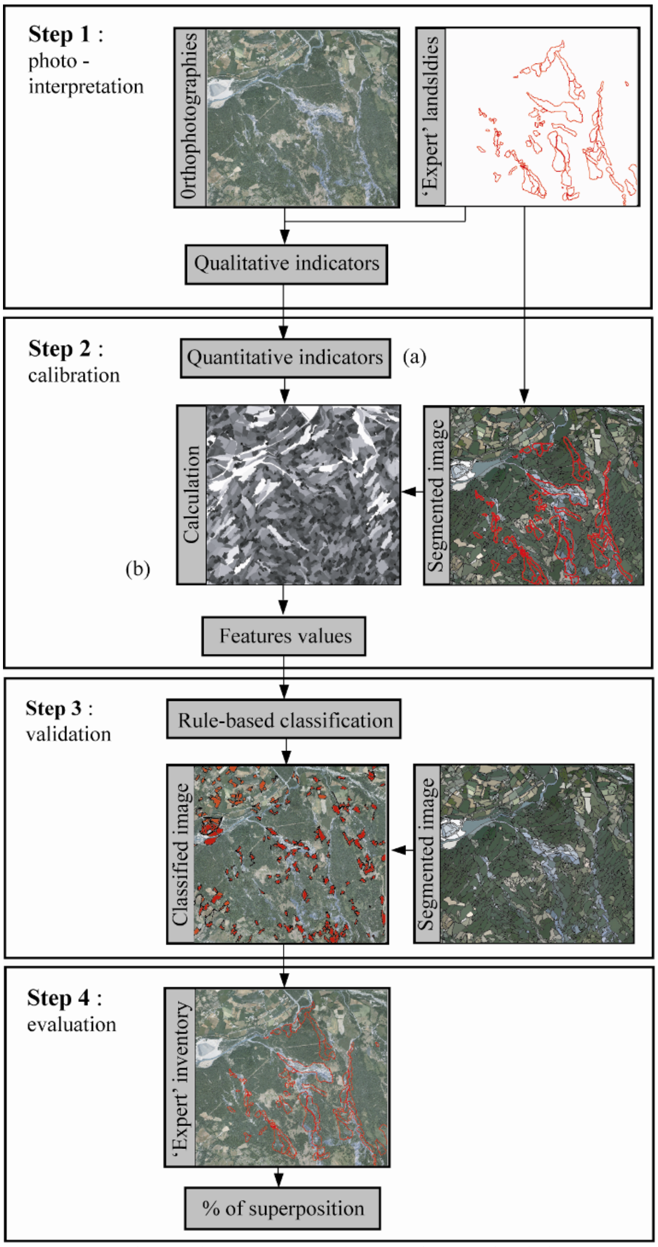

Figure 1. Schematic representation of the methodology.

Four main indicators are chosen (eg. spectral, shape, texture and neighborhood characteristics indicators) to translate the qualitative criteria of Step 1. A correspondence between the quantitative indicators and features proposed by the toolbox of the eCognition software is proposed (Tab. 1). The main shape features are chosen to characterize the morphometric indicators (for instance, the compactness index is described by the shape index, compactness and roundness features). Landcover and vegetation density description are given by the color of the observed object. The main spectral features of the Definiens Professionnal software are retained to characterize these two indicators. The texture of a landslide is related to the presence of cracks and/or ridges and to the surface disturbance. Four main texture features are chosen to characterize these indicators. The main neighbourhood feature (mean difference to neighbour) is retained to represent the scarp and accumulation visibility because it shows the degree of contrast between an object (the scarp or the accumulation zone) and its contiguous objects (the environment around the scarp or around the accumulation zone).

Table 2. Segmentation parameters.

Scale	Color	Shape	Smoothness	Compactness
160	0.1	0.9	0.9	0.1

These features are then calculated for 50 representative 'regions' corresponding to 50 'expert' landslides selected among the 156 observed landslides. Relevant intervals of values are defined for each criterion fro a statistical analysis. A knowledge base is then developed in order to distinguish the landslides from other landscape units.

3) Step 3

A test zone on the 2004 orthophotograph is used to test the method. The same segmentation parameters as those used at Step 2 are applied (Tab. 1). The first classification hierarchy is based on spectral criteria and differenciates four types of landcover classes (eg. bare soil-black marl, grassland, bare soil-grassland-forest mixed, forest).

For each class, a second classification hierarchy is developped by separating the 'landslide area' from the 'non-landslide area' according to their membership to other features (shape, texture and neighborhood).

The significance of these three features is tested by several combinations (Tab. 3) giving seven knowledge bases introduced in the fuzzy classification approach.

Table 3. Test protocol.

Criteria:	Spectral	Shape	Texture	Neighborhood
Test 1	yes	yes	no	no
Test 2	yes	no	yes	no
Test 3	yes	yes	yes	no
Test 4	yes	no	no	yes
Test 5	yes	no	yes	yes
Test 6	yes	yes	no	yes
Test 7	yes	yes	yes	yes

Table 4 presents the feature values and the membership functions used in the rule-based classifications process.

Table 4. Range of values used in the rule-based classifications.

Type of criteria	Criteria	Range of values	Membership function
Spectral	Brightness Layers means Pixel ratios Max. difference	*Ranges of values and membership functions for each type of landuse*	
Shape	Area Length/width Shape index Compactness Roundness	[1000-20000] [0.5 – 5] [0.5 – 5] [0.5 – 3] [0 – 2.5]	
Texture	GLCM contrast GLCM entropy GLCM mean GLCM correlation	[20 – 380] [1 – 10] [40 – 180] [0.8 – 1]	
Neighbo-urhood	Mean difference to neighbour – layer 1 Mean difference to neighbour – layer 2 Mean difference to neighbour – layer 3	[-60 – 70] [-60 – 70] [-60 – 70]	

4) Step 4

The last step consists in comparing the number and the area of landslides extracted by the semi-automatic method to the 'expert' landslide map. A first evaluation is made on the 2004 orthophotograph to define the most adapted features combinations (tests) for landslide detection. The best results are obtained by 'test 1' based on shape criteria (15% of the 'expert' landslides identified) and 'test 4' based on neighborhood criteria (26% of the expert landslides identified). A maximum of 8% and a mean of 3% are found for the other tests.

When the extracted landslides are overlaid to the 'expert' map, three cases are observed (Fig. 2): (1) an underestimation of extracted surfaces, (2) an overestimation of extracted surfaces and (3) a creation of surfaces which do not correspond to any landslides.

For the landuse classification, classes with bare soil and black marls areas have a classification accuracy of 3 to 7% versus 0 to 3% for the other classes.

For the landslide extraction, object-oriented classifications largely overestimate the number of 'expert' landslides. At the opposite, when landslides are identified, the extracted area corresponds mainly to the landslide 'source' area and the accumulation zone is not extracted (Tab. 5).

Table 5. Results of the landslide detection on the 2004 ortho photograph.

	Under-estimated landslides	Over-estimated landslides	Non identified landslides	Added landslides
Test 1	10	1	62	407
Test 2	5	1	67	1153
Test 3	1	0	72	31
Test 4	18	1	54	2065
Test 5	2	0	71	1052
Test 6	2	1	70	67
Test 7	1	0	72	31

The second evaluation consisted in applying the best combination of features (test 1 and 4) on (a) an infrared colour ortho photo (1974) and (b) on a VHRS image (2.5m Pan Spot), after a suitable segmentation of both images.

On the 1974 orthophotograph, the number of landslides detected by the rule-based classifications is nearly the same as for the 2004 orthophotograph with the test 4. It is more overestimated with the test 1. This can be related to landuse changes between 1974 and 2004 or to the spectral differences between the natural colored photography and the infrared photography of 1974.

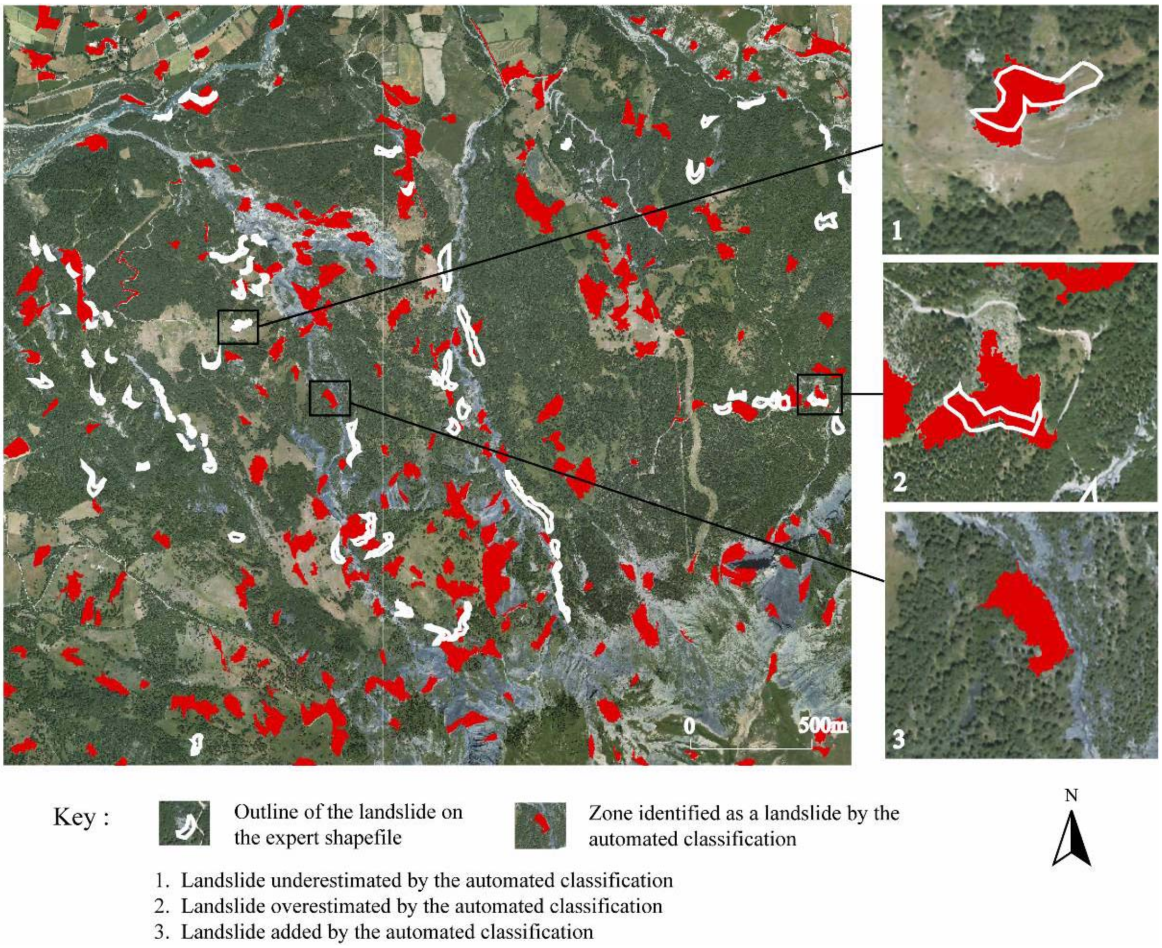

Figure 2. Example of results for test 1 of the evaluation step (step 5) on the 2004 ortho photo (© IGN).

On the panchromatic SPOT image, landslide extraction appears as unsuitable despite of the adjustment of segmentation parameters. This is partly due to the too low spatial resolution of this image and to the too restrictive spectral resolution.

These tests show that the segmentation of the data into 'regions' is of a great importance because if the initial segmentation does not respect the boundaries of the real-world objects of interest (landslides), the classification cannot provide meaningful results. Moreover, the spatial and spectral resolutions of the images have to be fine (around 1 m) to allow this extraction.

5 CONCLUSION AND PERSPECTIVES

This study has allowed to propose a formal and generic grid with qualitative indicators characterizing landslides. The aim of this paper was to translate these indicators into quantitative criteria (features) and to integrate them in an object-oriented image classification. The proposed method is then a semi-automatic method based on expert knowledge. The analysis of a variety of parameters has allowed to define the best indicators (shape and neighbourhood) to be used to extract landslides from very high spatial resolution aerial images. Tests have also showed that the spatial and spectral resolutions are very relevant to detect this specific object.

To improve the proposed method, other quantitative criteria could be integrated as the topological relation to other objects (e.g. distance to a watercourse). Other data (DTMs or lidar) could also be integrated in the object-oriented analysis to characterize the roughness of landslides.

Some tests are occurring in order to apply this method separating the source area (ablation zone) and the runout area (accumulation zone).

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