Detection of landslides from aerial and satellite images with a semi-automatic method. Application to the Barcelonnette basin (Alpes-de-Hautes-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 new very high spatial resolution images and by the development of object-oriented image analysis. In this context, the aim 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 expert knowledge on landslides. This approach is based on (1) a calibration step which consists to translate qualitative indicators derived from expert knowledge (by a photo-interpretation technique) in quantitative indicators and (2) a validation step which allows testing the relevance of these indicators to detect landslides by using an object-oriented method and by only using (aerial or satellite) images with different spatial, spectral and temporal resolutions. Results are (1) a formal and generic grid characterizing 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 precursor signs, characteristic forms and predisposition factors for landslides at 1:10,000. It is also used to locate and map past events, declared movements and instable zones (MATE & LCPC 1999). But this traditional technique is complex to apply to large area 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 landslides studies due to the inadequacy of the spatial resolution. Indeed, the pixel size (30 m) doesn't allow to detect objects of the size of a landslide (30 m on average). Moreover, per-pixel classification methods don't fit for landslide detection because the spectral response of a landslide isn't unique and can correspond to the aggregation of pixels with different spectral properties. The difficulty is also that landslides have often the same landuse 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 VHSR images and their inherent complementarities between spatial and spectral informations, 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 (cf. above).

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 as to their importance in 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).

Since recently, some studies used this new method to detect geomorphological units like alluvial materials, sedimentary deposits, alluvial fans, fluvial terraces, rock cliffs (Van Asselen & Seijmonsbergen 2006), potential sites of landslides or landslides (Molenaar 2005). In the segmentation process, several images, i.e. optical images (e.g. ASTER image - Argialas & Tzotsos 2006 - ortho photos - Molenaar 2005) or radar/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) about 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 originality of the proposed approach is there is (1) a calibration step which consists to translate qualitative indicators derived from expert knowledge (by a photo-interpretation technique) in quantitative indicators and (2) a validation step which allows testing the relevance of these indicators to detect landslides with an object-oriented method and by only using optical images of different spatial, spectral and temporal resolutions.

The study area and the data source are firstly introduced. Then the methodology is explained and, finally, preliminary results are presented and discussed, before conclusions and perspectives.

2 STUDY AREA AND DATA SOURCE

The study area is situated 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 different kinds. 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 (78.8%; Thiery 2007).

The calibration site is based on 156 active landslides of different types (i.e. translational slides, rotational slides, earthflows and rock-block slides) and of different sizes (i.e. from 1000 to 20000 m²) located on the north-facing slope. A test zone of 25 km² containing 73 landslides is used for the validation and the evaluation steps.

Two types of data source are used: aerial and satellite images and vector data. Three ortho photos (1974 –infrared colour and 2000, 2004 – natural colour) of the basin (spatial resolution of 50 cm) are used to calibrate the method. The both ortho photos and a panchromatic SPOT 5 image (2.5 m spatial resolution) are tested to validate the proposed method. The vector data is a mapping of the 'expert' inventory 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 step where qualitative landslides indicators are defined based on bibliographic researches and on a visual photo-interpretation technique, (2) a calibration step based on the identification of quantitative indicators and their calculation by using the huge toolbox available in the object-oriented image analysis software (Definiens Professionnal[1]), (3) a validation step applying rule-based classifications guided by the indicators calculated in step 2 (features), and (4) an evaluation step based on the expert mapping of landslides.

4 RESULTS AND DISCUSSION

Step 1 - Relevant indicators mentioned in the literature allowing to detect the presence of landslides are identified e.g. landuse, vegetation density, texture, presence of cracks, surface disturbance or scarp visibility (tab. 1). They are observed for the 156 landslides on the three ortho photos. It enables to propose a formal and replicable grid for detecting

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

and describing landslides in four categories (corresponding to landslides' landuse types).

Figure 1. Schematic representation of the methodology.
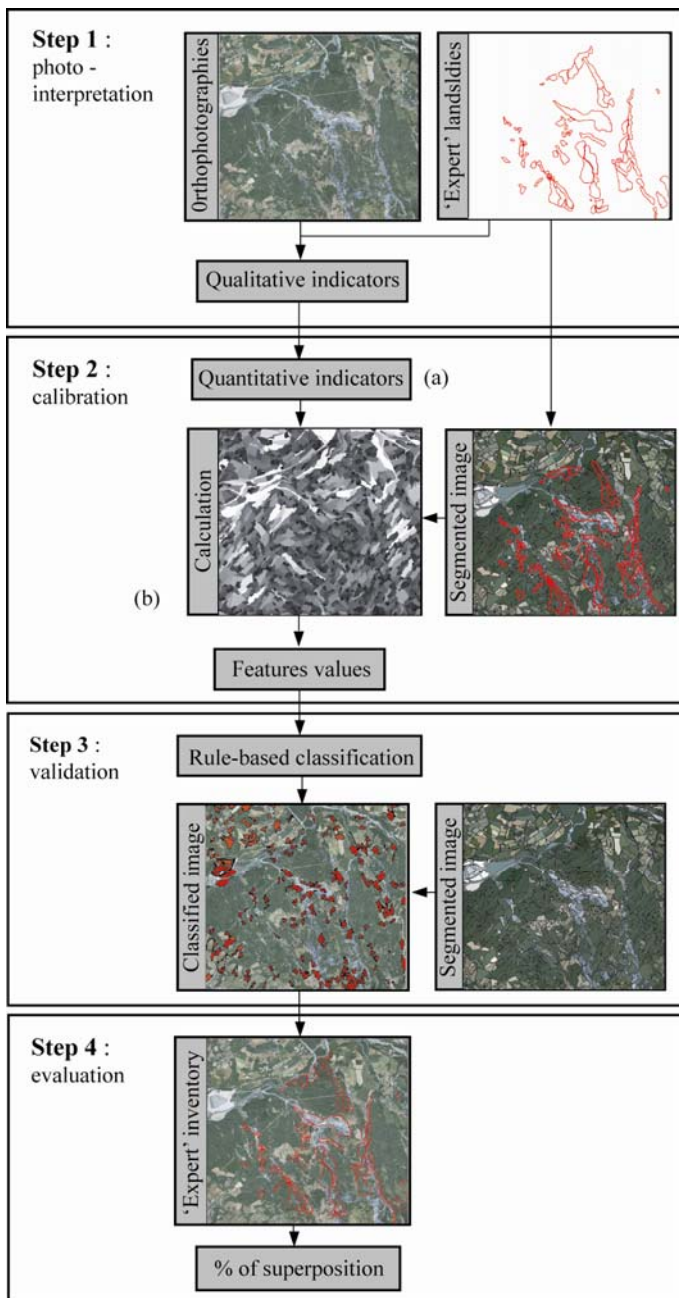
Step 2 - The more recent ortho photo (2004) is chosen to calibrate the indicators. The image is firstly segmented into homogeneous regions by taking into account the outlined landslides. The scale, color and shape parameters are adjusted in order to be adapted to define 'regions' of the size and of the shape of the landslides indicated on the 'expert' map (tab. 2).

Table 2. Segmentation parameters.

Scale	Color	Shape	Smoothness	Compactness
160	0.1	0.9	0.9	0.1

Four main indicators are chosen, i.e. spectral, shape, texture and neighborhood characteristics in-

dicators, to translate qualitative criteria. A correspondence between these quantitative indicators and features proposed by the toolbox of the eCognition software is found (tab. 1). Main shape features are chosen to characterize the morphometric indicators (the compactness index is described by the shape index, compactness and roundness features). Landuse and vegetation density description is given by the color of the observed object. Therefore, the main spectral features of the eCogntion 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. So, four main texture features are chosen to characterize these indicators. Finally, 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).

These features are then calculated for 50 representative 'regions' corresponding to 50 'expert' landslides selected among the 156 observed landslides. Following a statistical analysis, relevant intervals of values are defined for each criterion. A knowledge base is then developed in an attempt to separate landslides from other landscape units.

Step 3 – A test zone on the 2004 ortho photo is used to validate the method. The same segmentation parameters as those used for the calibration step (step 2) are applied (tab. 1). The first classification hierarchy is based on spectral criteria and differenciates four types of landcover classes i.e. bare soil-black marl, grassland, bare soil-grassland-forest mixed and forest. For each class, a second classification hierarchy is developped by separating 'landslide area' from '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 base 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 features values and the membership functions used in the rule-based classifications.

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

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	*Different 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]	
Neighbourhood	Mean difference to neighbour – layer 1 Mean difference to neighbour – layer 2 Mean difference to neighbour – layer 3	[-60 − 70] [-60 − 70] [-60 − 70]	

Step 4 – The evaluation step consists in comparing the number and the area of landslides extracted by the semi-automatic method to the 'expert' landslides. A first evaluation is made on the 2004 ortho photo 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 don't 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. Whatever the test, no less than 96% of the 'objects' detected as landslides by the automatic classification do not correspond to 'expert' landslides. But when the landslides are extracted, most of them are underestimated in terms of area (tab. 5).

No specific pattern in the spatial distribution of the wrongly classified landslides was observed that can help to explain the errors.

Table 5. Results of the landslides detection on the 2004 orthophoto.

	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 consists in applying the best combinations of features (test 1 and 4) on (a) an infrared colour orthophotography (1974) and (b) on a VHRS image (2.5m Pan Spot), after finding a suitable segmentation for the both images.

On the 1974 orthophotography, the number of landslides detected by the rule-based classifications is nearly the same as for the 2004 orthophotography 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. 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.
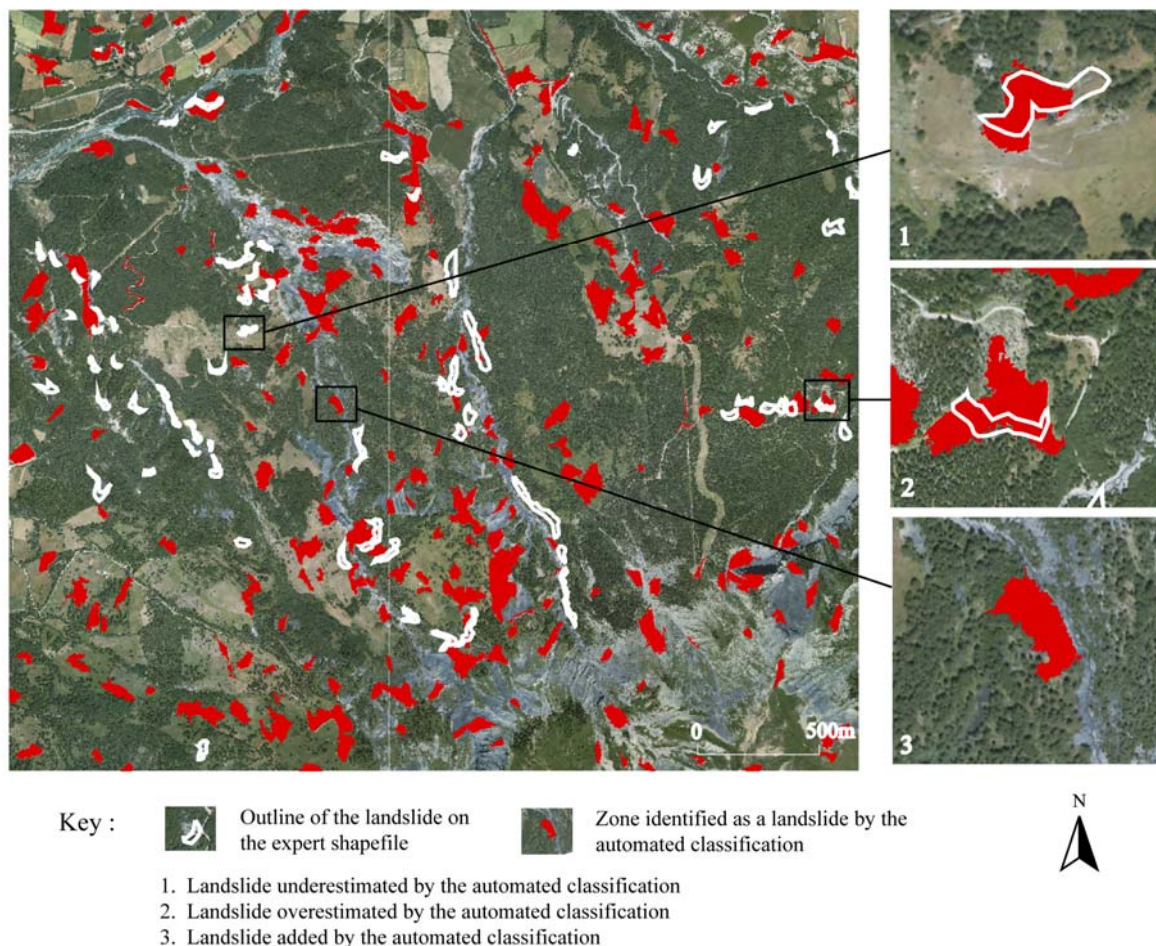
5 CONCLUSION AND PERSPECTIVES

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 'ablation' and 'accumulation' zones. The perspectives for the future are to apply the same method to the characterization of very large landslides (i.e. area > 100000m²) using a DTM lidar (e.g. automatic characterization of the 'La Valette' earthflow of the Barcelonnette basin).

Figure 2. Example of results for test 1 of the evaluation step (step 5).

Key : Outline of the landslide on the expert shapefile   Zone identified as a landslide by the automated classification

1. Landslide underestimated by the automated classification
2. Landslide overestimated by the automated classification
3. Landslide added by the automated classification

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