OBJECT-ORIENTED METHODS FOR LANDSLIDES DETECTION USING HIGH RESOLUTION IMAGERY, MORPHOMETRIC PROPERTIES AND METEOROLOGICAL DATA

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ABSTRACT:

Mapping landslides and building landslides inventory have received a special attention from a wide range of specialist. In building a landslide inventory an important step is the spatial delineation of the landslides body, followed by the landslides classification according with an international used classification system and the identification of other landslides characteristics. The main methods for landslides mapping are based on field observation, image interpretation and stereo-restitution. Our paper discusses a semi-automated process based on objected-oriented analysis for landslides bodies' delineation. Several recent papers Moine et al. 2009, Tapas et al. 2010 had similar approaches for landslides bodies' delineation and classification using objected-oriented analysis combined with spectral and morphometric properties of the landslides. Our approach is similar with Tapas et al. 2010, but we take into account, besides the morphometric properties, the meteorological data for the periods when the landslides have occurred. The algorithm is using high resolution aerial images with a spatial resolution 0.5 meters, a DEM with a spatial resolution of 2.5 meters and daily meteorological data for the year 2005. The meteorological data was spatial interpolated and the images were used in the objected oriented analysis and this has led to a significant increase in the number of corrected indentified landslides. The algorithm was tested in the administrative area of Breaza Town from Romanian Curvature Sub- Carpathians, for which a detailed landslides inventory was available

1. INTRODUCTION

1.1 Aim of the paper

Landslides are frequent phenomenon for the Subcarpathians regions of Romania. Lithological features based mainly on clay and marl combined with permeable rocks, the torrential rainfall regime as well as a strong human impact has a key role for the landslide related hazards (Balteanu, 1986, 1997; Ielenicz et al., 1999, 2002).

The landslide-related hazards are a real environmental problem within the local and regional development of Subcarpathian areas, because the phenomenon occurs on almost all hill slopes, including the afforested ones. Superficial and shallow landslides superposes on large, old and deep landslide bodies (Ielenicz et.al., 1999; Armas et. al. 2004).

Landslide spatial occurrence in Romania was the subject of some recent papers. Most of the authors focuses on landslide susceptibility issues (Armas et al, 2004; Chitu et al., 2009; Mihai et al., 2010 etc.) and some of them focused also on hazard analysis (Sandric, 2008 unpublished) at different scale approaches, from local and regional analysis and to the whole Romanian territory (Balteanu et. al., 2010 in press). The GIS modeling (deterministic and probabilistic approaches) and mapping techniques are largely used within these papers

The aim of the paper is to develop a semi-automated algorithm for landslide body's identification and classification. The algorithm is based on object based image analysis (segmentation and classification) applied on high resolution air-photos in combination with lithology, morphometrical features and meteorological data

For the areas with complex morphodynamic features like the Subcarpathians, the image visual interpretation and field surveys are usually a time consuming step (Sandric, 2009, Moine, 2009, Tapas, 2010). It is usually very difficult to extract all the landslide bodies even on smaller areas (a catchment or a small administrative unit like a town or a community), because they have a complex typology (landslides, earthflows etc), they occurs on the whole slope area, the landslide bodies of different generation are superposed

1.2 Main contributions in the international literature

International contributions on landform automatic classification are quite recent approaches (Dragut, Blaschke, 2006). Landslide analysis on satellite imagery is an older research field (Mantovani et al., 1996, McDermid, Franklin, 1994, Brardinoni et al., 2003; van Westen, 2003; etc.). Since 2006, there is an increasing interest in developing algorithms for landslide classification, based on spectral data (Borghuis et al., 2007) as well as on digital elevation data (van van Asselen, Seijmonsbergen, 2006). Landslide mapping based on remote sensing imagery object based image analysis and classification (Nichol et al., 2005; Moine et al., 2009), remote sensing

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imagery in combination with morphometrical features (Tapas et al., 2010) were developed and tested within different areas with encouraging results

These latest studies focuses on the integration of data with different spatial resolutions together with data derived from elevation models, as well as other segmentation rules within landslide algorithms. These are relevant contributions but they are limited in terms of the data variety. Our study considers that besides the favorable factors for landslides landslide, the triggering factors like the amount of precipitation that reaches the terrain surface can complete the segmentation rules for landslide bodies. Testing the proposed algorithm on a representative case study from the Prahova Valley in the Subcarpathians can help the improvement of the existing methods for landslide mapping and classification

1.3 Study area

The study area we focuses our analysis is the Breaza town administrative area, which is situated along the Prahova River Valley within the Prahova Subcarpathians (SE Romania, Curvature Subcarpathians). This area has an interesting situation because of the great density of landslide bodies (156 bodies were mapped by Sandric, 2008, on a surface of about 70km^2). They are covering almost all the slopes in a complex lithological and structural-tectonical background. Breaza town is located along the main transcarpathian railroad and European road between Bucharest and Brasov.

From the geological point of view, the study area superposes on a nappe system, thrusting each other from the North to the South. These nappes belong to the Cretaceous and the Palaeogene flysch areas, as well as to the Upper Cretaceous and Lower Miocene posttectonic sedimentary covers. The folds configuration, as an effect of the tectonical transformations, shows a system of parallel synclines and anticlines, oriented from the East to the West.

The most affected lithostratigraphic units are: Gura Beliei marls (Upper Cretaceous posttectonic sedimentary covers) which produce rotational and translational slides, earthflow; molasse deposits of Doftana (marls, clays, sandstones of Lower Miocene posttectonic sedimentary cover) affected by rotational and translational slides, Pucioasa Strata (marls, clays of Paleogene Flysch) affected by earthflow, rotational and translational slides.

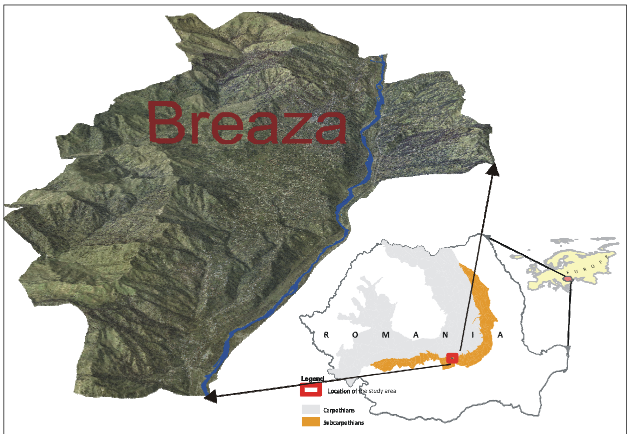

Figure 1. Location of the study area

The area is characterized by high slopes gradients with values between 15-30˚, specific to most of the hillslopes within the area, medium drainage density, with values between 0.3-1 km/km^2

The natural vegetation of the area was replaced during the last two centuries by the secondary vegetation, with a high deforestation degree (50-60%) The human activity has relevant impact for this area, with a population density of about 50-75 inhabitants/km^2 (higher values in the Breaza town built-up area). There are 10 built-up areas, mostly rural areas attached since 1968 to the Breaza town (mainly scattered farms).The local economy is dominated by agricultural activities, based mainly on grazing and orchards. These are favorable conditions for landslides

2. MATERIALS AND METHODS

2.1 Materials

The analysis is based on image segmentation techniques for an object-oriented classification. These datasets were integrated in digital format in order to define the landslide body's configuration according to their spectral and morphometric features (McDermid, Franklin, 1994, Tapas et al., 2010). Our main interest was to extend the analysis with other relevant datasets like lithology and the amount of precipitation that reaches the terrain surface

The high resolution imagery consists in digital orthophotos acquired from the National Agency for Cadastre and Real Estate Advertisement (ANCPI Bucuresti). The acquisition date of the air-photos is July 2005. Images are in natural colors and have a spatial resolution 0.5 m. They are co-registered with 1:5000 scale topographic maps. These images were integrated within a digital mosaic covering the whole administrative area of Breaza town. Some problems are featuring these images: the orthorectification errors (limited) and their temporal resolution. They are summertime imagery limiting the identification of a lot of the slope morphodynamics features (including landslide bodies). Forests and meadow vegetation occurs in green signatures while eroded areas are in shades of light brown.

Visual interpretation opportunities of this imagery were limited by the uncertainty of the limits of the superficial and shallow landslide bodies. Field mapping and observation was usually applied for the validation of the landslide inventory based on aerial imagery.

Since the year 2008, new imagery was obtained for the Subcarpathian sector of the Prahova Valley by Ionut Sandric, in order to validate and to improve the landslide inventory for the Breaza town administrative area. The high resolution digital imagery obtained with a Canon 400D camera from a Cessna aircraft is frequently oblique which are usually better for landslide bodies' interpretation. Some of the nearly vertical images were geometrically corrected and used for landslide body extraction in digital format The DEM was obtained using the ANUDEM interpolation method implemented in ArcGIS Desktop 9.3.1 – ArcINFO version. The layers used in the ANUDEM method are: contours with intervals from 5 to 5 meters, point elevation and rivers, all collected from the topographical maps at a scale of 1:5000. The spatial resolution of the DEM was 2.5 meters and it was calculate by dividing the contour intervals by 2. The accuracy of the DEM was tested by comparing random selected point elevation with the values of the generated surface. The standard deviation was 3.6 meters (Sandric, 2008). From the DEM we derived the slope gradient, plan curvature and profile curvature, which we assumed that

plays an important role in landslide body delineation. These morphometrical parameters were used also by Tapas et al., 2010 to create rules for objects classification
Weather data and mainly the rainfall data is a feature we proposed for this analysis. As landslidings depends on the rainfall thresholds we used the opportunity to collect data with the help of an automatic weather station. This was installed eastern from Breaza town, in Cornu village since 2007 in a characteristic position in order to obtain reliable data for rainfall every 15 minutes. From the total amount of data we selected only the records corresponding to the most relevant landslidings episodes around the area of the station. They feature mainly the torrential rainfall periods during the months of June and July.
Another data set was that from Cimpina weather station data, which is situated southernwards from Breaza town. This rainfall data (since 2005) was selected according to the above mentioned principle (for the torrential rainfall episodes with landslidings re-activation). This digital data was the subject of interpolation in order to generate a special layer for image segmentation. The main target is to extend the analysis to other spatial data in order to improve the landslide inventory.
Other data is represented by geological features in digital format. This layer was derived from 1:50000 scale geological maps on paper (edited by the Geological Institute). The role of this data within the analysis is quite limited because landslide inventory made between 2004-2009 in the Breaza town administrative area showed that landslide bodies occurs on almost every geological formations. Even sandstones and conglomerates alternating with clay and marls are featured by landslides in combinations with rockfalls. The lithological data was used only as ancillary data in the image segmentation and classification steps

Materials	Spatial resolution/Acquisition time	
Orthophotos	0.5m	2005
Oblique air-photos	0.1m	2008
DEM	2.5m	1980
Lithology	30m	1980
Precipitation	10m	2000-2009

Table 1. Materials

2.2 Methods

For OBIA analysis we used ENVI EX product, developed by ITT (ENVI EX). The steps necessary to complete the feature extraction module from ENVI EX are: choosing the scale parameter; merging the object primitives; refine the objects using a threshold value for just one band of the image and it is an optional step; extraction of the attributes; object classification based on rules or examples. The segmentation algorithm used by ENVI EX is developed by ITT and is a patented product (Xiaoying, 2009). Chossing the right scale for the segmentation process is an important step in the OBIA analysis, which can lead to important errors in the final result. The scale parameter is related with the size of the objects that have to be identified and in ENVI EX the scale can take values from 0 to 100. Choosing a low scale value leads to small size objects and sometimes to over-segmentation on the other hand, choosing high scale can lead to under segmentation and large objects. It is always recommended that the scale parameter should be choosing after several trials should be combined with the merge objects step from the segmentation process. In ENVI EX the merge option presented in the second step is developed based on Robison et al 2002
For the morphometrical analysis it was used ArcGIS Desktop 9.3.1 – ArcINFO version with Spatial Analyst extension. The spatial analyst extension provides advanced tools for generation of DEM (the ANUDEM, Hutchinson, 1989) and for terrain analysis. From the DEM the slope, plan curvature and profile curvature were generated. An image with the amount of precipitation fallen in one week was generated for the entire area. The image was generated based on the measurements from the automatic meteo stations located in Cornu and on a linear relation between altitude and the amount of precipitation. This linear relation allowed us to spatialize the precipitation, even though the area has only ~350m difference in altitude
In order to use the orthophotos and the morphometrical parameters for the segmentation and classification process, it is first required that all the data should be fusion. The fusion process was carried out in the ENVI 4.7 image analysis software and the file was saved and ENVI standard format. The schema of the analysis is presented in figure 2.

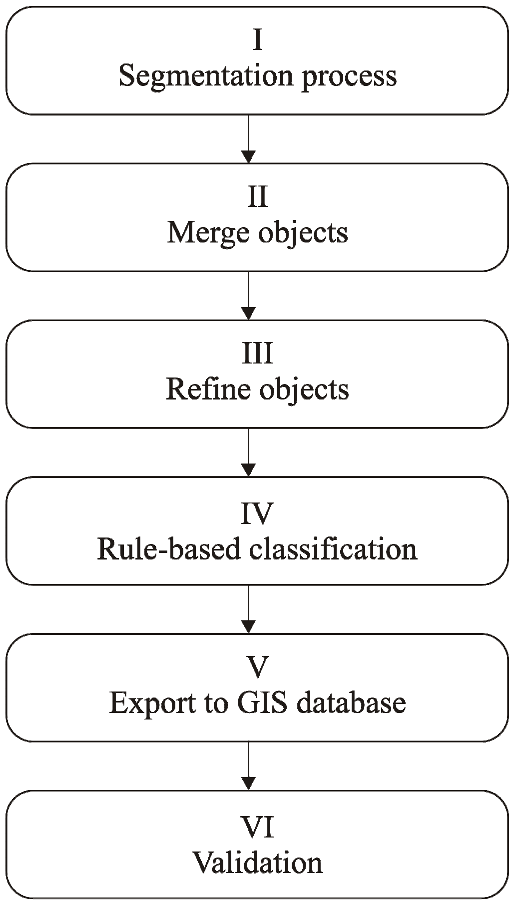

Figure 2. Schematic representation of the analysis process

3. RESULTS AND DISCUSSION

The first step of the process was to choose the appropriate scale for the segmentation process. Several trials were performed with different scale values ranging from 20 to 65 and the best segmentation was obtained with a scale value of 35
The second step was the objects merge and like for the first step, several trials were made. The best merge values for a scale parameter of 35 for our study area was 95

The third step of the segmentation process is the option of refining the objects based on an interval values for just one band. For the Breaza area it wasn't necessary to refine the objects and no thredsholding was applied for either band (Table 2)

Scale	Merge	Refine
35	95	-

Table 2. Segmentation parameters

In the classification process the aim was to identify only the deep seated rotational slides according with the Cruden and Varnes 1996, landslide classification system. The deep seated rotational slides are characterized by a longitudinal profile in which the convex and concave curvature is alternating due to the landslide morphological features created by the curved sliding surface. Because we decided to identify the deep seated slides the land-use and land-cover doesn't play a very important role and this was the reason for which it hasn't been used an ancillary data in the segmentation process. The amount of precipitation that it should be considered in order for a deep seated landslide to occur is approximate 100mm (Sandric, 2008). The slope gradient usually is ranging from 5 degree in the accumulation zone up to 35 degree on the landslide scarp. Taken into consideration all this we have developed the following classification rules presented in the table bellow (Table 3)

Band	Value
Slope gradient	4 - 40
Plan curvature	< 0
Profile curvature	-5 – 5
Elongation	< 5
Area	1500 - 4000
Effective precipitation	80mm

Table 3. Classification rules

The slope gradient interval was choose between 4 degrees in order to indentify the accumulation zone, where the values are lower and the value of 40 degree was chosen in order to identify the landslide scarp. The values were extended over the natural limits observed during the field works due to the uncertainties presented in the DEM and also propagated from the slope algorithm.
The size of the landslides in the Breaza administrative unit is ranging from 1500 sqm up to 3500 sqm. There are some exceptions where the size of the mapped landslides is bigger than 3500sqm. This situation is presented only in areas where due to the complexity of the spatial relations between landslides it wasn't possible to delineate them and they were mapped as areal landslides.
An important parameter in the classification rules was considered the elongation of the objects. Usually the shape of a landslide is elongated along the slope and the relation between length and width is more or less from 3 to 5 sizes bigger the length than the width. Taken into consideration this relation length to width for this area we established that a value of 5 for the elongation, from the shape attributes, would be suitable to separate objects that are not landslides from objects that are landslides

The longitudinal profile of a rotational landslide has zone with convex curvature in alternation width zone with concave curvature. Because of this morphological feature, the profile curvature of the slopes was taken into consideration for the classification rules. The profile curvature derived from the DEM had values from -12 to +10. By overlapping the field mapped landslides onto the profile curvature we managed to identify the average interval specific to rotational slides, being between -5 to +5 and it was introduced as rule in the classification process
The plan curvature plays an important role in the identification of the landslide boundaries, because the landslides occur mainly on areas with concave plan curvature. This is an important aspect and it was used as a rule in the classification process. For the plan curvature the concave curvature was considered as favorable for landslides appearances
The precipitation data was introduced also as a classification rule, by the amount of water that arrives at the terrain surface. The map algebra method was used to calculate the amount of water intercepted by the vegetation and then to eliminate it from the total amount of precipitation. The effective precipitations higher than 80mm were retained as a rule in the classification process. This rule also helped to take into account the role of the forest in the landsliding process
For the area of Breaza a detailed landslide inventory was created, based on field surveys and image interpretation. The landslides inventory includes 177 landslides, mostly deep-seated rotational slides (ca. 92%) and several translational slides (3%), complex landslides (3%) and earth flows (2%).
The rotational slides are spread over the entire area with no particular pattern. The slope gradient intervals are between 5 and 25 with a maximum of 40 on the landslide scarps of the hillslopes of the Provita River in the area of the Irimesti village and on the terrace scarp over Breaza town. Over 70% of the rotational slides are present on marls, marls with clay and marls with sandstone and over 85% are present in areas with grass and low density tree cover, the remainder being old landslides, present in areas with deciduous forest and in a dormant state of activity.
The lithological units affected by the translational slides are almost entirely marls with sandstone (over 95% from the translational slides). The complex landslides are present on marls with clay and marls (over 85%) and the earth-flows on clay and marls (over 95%).
The most affected land-use/land-cover classes are the areas with grass and low density tree cover, where during the heavy rain from spring and autumn the shallow and deep landslides are reactivated (Sandric, I., Chitu, Z., 2008).
The OBIA has identified 615 features as being rotation slides. From the 615 features a number of 259 (approximate 42%) are located inside the mapped landslides or are intersecting the existing landslides. In terms of spatial location the feature are well distributed and are covering areas where it could be landslides or in areas that are landslides, but they have not been mapped due to errors or misinterpretation. The size of the classified features is from 1400sqm up to 65000sqm, but most of the features are from 1400sqm up to 10000sqm. None of the features identified as rotational slide is fully overlapping a mapped landslide. Most of the features are outside of the mapped landslide in areas where there is a potential for sliding, but so far there hasn't been seen any landslides. The best overlap between the features identified as slides and the actual slides is presented in figure 3 and is located on the terrace scarp from the eastern part of Breaza de Jos town.

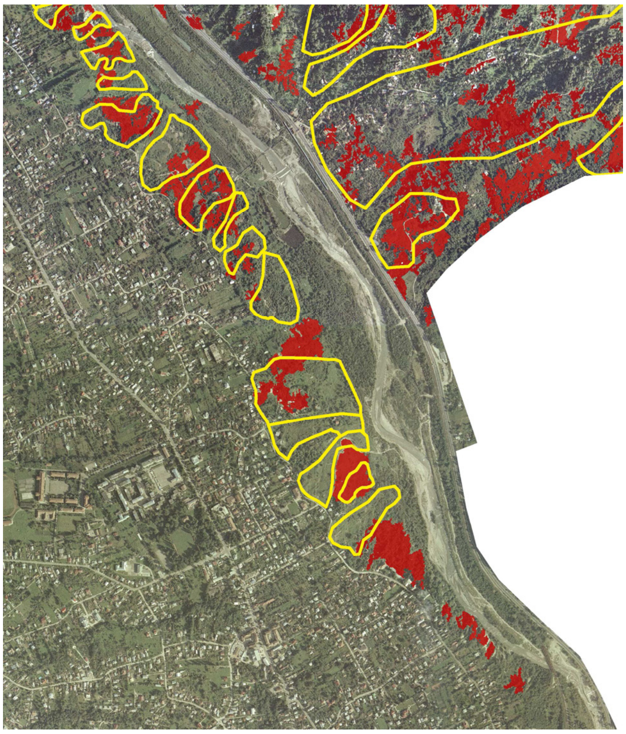

Figure 3. Identified features versus mapped landslides (in red classified objects and in yellow mapped landslides); terrace scarp from eastern part of Breaza de Jos town

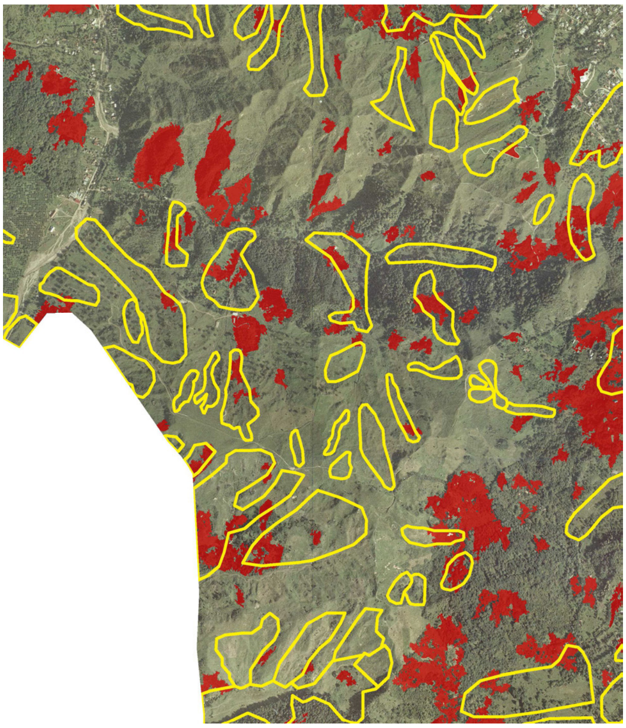

Figure 4. Identified features versus mapped landslides (in red classified objects and in yellow mapped landslides); hillslopes from the south-western part of the study area

In the center of the image (Figure 3) can be seen the almost full overlap between the classified objects and the mapped landslides, although the classified objects is extending outside of the mapped landslides. The outside part is corresponding to a particular lithology in that area, that couldn't be taken into account in the classification process. On the other sites of the image it can be seen the overlapping areas between the mapped landslides and the classified objects and the degree in which they are overlapping. On the right side on the Prahova River, presented in the middle of the image, they are big rotational slide which cover the entire slope and the identification of these big landslides were only partially. There is because of the slope gradient values, that here were below the minimum threshold value. The slope gradient is the effect of the uncertainties propagated from the DEM resolution and the slope algorithm.
Figure 4 presents the south-eastern part of the study area, where the overlap between the classified objects as being landslide and the mapped landslides is almost inexistent. Most the features classified as being landslides are presented on the upper part of the hillslopes where the slope gradient and the profile curvature have met the criteria, but not on the grass lands with high texture ranges from the center of the image

4. CONCLUSION

The use of OBIA for landslides identification and classification has been proven as a promising method, but the results obtained are still far from obtaining a good and scientifically reliable landslide inventory. More attention should be given to the classification rules and to the data in the analysis. The lack of the DEM with a spatial resolution equal with the orthophotos and the lack of a more detailed lithological and pedological map have brought to many uncertainties in the classification process. Future approaches should take into consideration the quality of the data, but also the possibility of using more parameters in the segmentation process

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