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Systematic Evaluation of Fuzzy Operators for Object-Based Landslide Mapping

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Abstract: This research presents a semi-automated object-based image analysis (OBIA) methodology for landslide delineation and change detection analysis from multi-temporal satellite images for a study area in North-West Iran. The approach applies fuzzy set theory for rule based classification while systematically utilizing advantages of membership functionalities in OBIA, both for the spatial and spectral information dimensions of landslides. Several fuzzy logic membership functions are employed to combine spectral analysis, shape analysis and textural measurements using gray-level co-occurrence matrix (GLCM). Objects are generated by applying multi-resolution segmentation in a sequence of feature selection and object classification steps applied to different satellite imagery (IRS-1D, SPOT-5 and ALOS PalSar) together with slope and flow direction derivatives from a digital elevation model and topographically-oriented gray level co-occurrence matrices. After the generation and optimization of the multi-resolution image segmentation a fuzzy rule object based classification is performed and 42 spatial and spectral parameters for detecting landslides in the study area are identified. Fuzzy membership values for 11 membership functions are calculated by using 20 landslide objects as training data which are taken from a landslide inventory database. We employ six different operators for the object based classifications and compare the accuracies of the resulting landslide maps based on a Fuzzy Synthetic Evaluation (FSE) approach and by using the landslide inventory database. Results of this research demonstrate that that the accuracy of fuzzy rule based classification is significantly affected by the choice of the fuzzy operators. In this respect, FSE turns out to be particularly appropriate to assess the accuracy of fuzzy based classifications.

Keywords: Object-based image analysis, Fuzzy rule based classification, landslide delineation, change detection, North-West Iran

1. Introduction

In the context of landslides monitoring multi-temporal satellite images have proven to be a highly suitable dataset for generating landslide inventories and detaching the occurred changes (Chen et al., 2007; Martha, 2011). Obviously, the wide range of nowadays available Earth observation data implies the need for accurate and fast methods for investigating landslides and to facilitate the generation of landslide inventory maps and databases (Hölbling et al., 2012). According to this demand Object-Based Image Analysis (OBIA) has gained prominence in the field of remote sensing during the last decade, being credited with the potential of overcoming weaknesses associated with the per pixel analysis, as for instance neglecting geometric and usually also contextual information (Blaschke, 2010; Drăguţ and Eisank, 2012). In the context of image processing methods to detect and delineate landslides, OBIA has a high potential to monitor the evolution of landslide-prone areas over time, as spectral, spatial, contextual as well as morphological parameters can be considered (Hölbling et al., 2012). OBIA provides a potentially semi-automated approach for landslide mapping based on the spectral, morphological, and contextual landslide objects (Lu et al., 2011). In the context of object-based image classification methods a fuzzy rule-based classification systems have become an important research area in the recent years. Several studies have used a fuzzy rule-based classification in OBIA approach (Sebari and He, 2013). Within this research fuzzy rule sets and its membership functions and operators for detecting and assessing landslides changes were occurred in the northern part of Iran form 2005 to 2011. We used multi-scale and temporal satellite images and GIS datasets for applying an object-based fuzzy rule classification in order to improve the accuracy of the results and to identify the most effective fuzzy membership functions and operators.

2. Study area and datasets

The study area formed part of the Urmia Lake basin in north-western Iran. A landslide inventory database for this area was available from the Ministry of Natural Resources, East Azerbaijan Province, Iran. This database includes records of the occurrence of 109 landslide events, whose GPS coordinates were recorded during field surveys. Based on the field observations and the landslide inventory dataset most of the landslides can be categorized as rational slides that occurred in the elevation higher than 1600 m with slopes >7 % within the agricultural and pasture lands (Feizizadeh and Blaschke 2013). We use these physical characteristics for the detection of landslides through OBIA techniques. In order to delineate landslides and to perform change detection analyses, a semi-automated fuzzy rule-based classification approach was applied. The analysis was based on multispectral SPOT-5 satellite image from 05 May 2005 with 10 m spatial resolution, an IRS-1D P6 panchromatic satellite image from 21 May 2005, which had 5.8 m spatial resolution as well as multispectral ALOS satellite imagery from 12 May 2011 with 10 m spatial resolution. A DEM derived from a 1:25,000 scale topographic map with 10 m spatial resolution was used to extract morphometric features characteristic of landslides, e.g. slope and flow direction. A combination of suitable diagnostic features of each data layer was used in an object-based environment with a knowledge-based approach to detect and monitor the landslides in parts of the Urmia lake basin with highly rugged terrain.

3. Fuzzy rule based classification

As basis for the fuzzy logic membership approach we generated a set of 20 training objects based on landslide inventory database. The selection of proper training samples for calculation membership values is on the key step in fuzzy rule based classification. Within each of these 20 locations we generated multiple objects aggregating the total of 2135 pixels as training data for calculating membership value of 42 features. The membership values were calculated according to 11 membership functions including: larger than, smaller than, larger than (Boolean, crisp), smaller than (Boolean, crisp), larger than (linear), smaller than (linear), linear range (triangle), linear range (triangle inverted), singleton (exactly one value), approximate Gaussian and about range. This approach is based on the knowledge collected during the modeling step. Thus, the shapes of membership functions are defined with relation to information related to attribute's mathematic formulations and threshold's values. The shape of the membership function is specific for each property (Sebari and He, 2013). Our fuzzy membership functions were applied through the use of six operators including 'and $_{(min)}$', (abb.AND), 'or $_{(max)}$' (abb.OR), 'mean $_{(geometric)}$' (abb. MGE), 'mean $_{(arithmetic)}$' (abb.MAR), 'mean $_{(geom.weighted)}$' (abb.MGWE) and 'and $_{(*)}$' (abb. ALP). 'AND' and 'ALP' refer to logical intersection and returns the minimum of the fuzzy values, while 'OR' corresponds to logical union and returns the maximum of the fuzzy values. 'MAR' and 'MGE' return the arithmetic respectively geometric means of the fuzzy values and '(Aksoy and Ercanoglu, 2012). The fuzzy based classification separated the objects into two classes as "possible landslide" and "no-landslide" areas.

4. Accuracy assessment and change detection procedure

We adapted the Fuzzy Synthetic Evaluation (FSE) error matrix approach for computing the accuracy of multi-operator fuzzy rule-based classifications. Within this research, the known landslide locations in the study area were used as reference data to assess the accuracy of the 12 maps derived from the different fuzzy operators. After producing landslides maps based on fuzzy operators and applying the accuracy assessment, the object based change detection analysis between 2005 and 2011 was performed. Landslide objects from images in 2005 were extracted and compared to the 2011 image data. Actual landslide changes were determined to have occurred if corresponding objects had different identity at 2011. Figure 1 depicts the results of object based landslide change detection between 2005 and 2011.

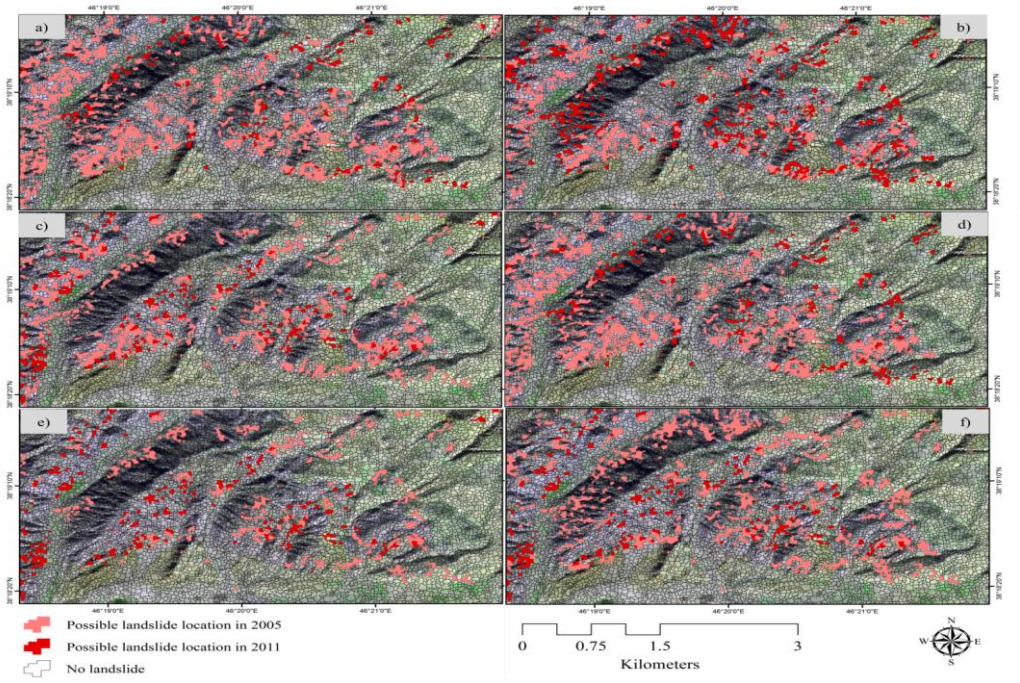

Figure 1. The results of object based landslide change detection from 2005 to 2011 based on fuzzy operators including: a) AND, b) OR, c) MAR, d) MGE, e) MGWE and f) ALP.

5. Results and conclusions

Based on the results of accuracy assessment the 'AND' operator with 93.87% accuracy performed best. The second best performance was obtained from the classification map carried out by the fuzzy 'MEG' operator (FSE = 93.32 %) which is closely followed by 'MAR' attaining 93.67%. We perceived that the 'OR' operator provides an FSE value of about 91.98% and the 'ALP' operator about 89.45 %. While the 'MEGW' operator with 86.18% accuracy in comparison to the other five porters delivered significantly poorer results. Based on the results of the current research, our future work will include the combination of fuzzy operators for the task of landslide delineation. Furthermore this study demonstrates the possibility of the FSE approach to assessing the accuracy of (fuzzy) object-based classification. So far this approach is not used in OBIA for fuzzy rule-based classifications. The authors believe that OBIA will benefit from further research integrating this technique in fuzzy OBIA-based classification. Considering the level of classifications accuracy calculated from FSE, we conclude that such an integration may provide a powerful framework which could lead to more accurate results.

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