Pedosphere **26**(3): 335–350, 2016
doi:10.1016/S1002-0160(15)60047-9
ISSN 1002-0160/CN 32-1315/P
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Published by Elsevier B.V. and Science Press

PEDOSPHERE

www.elsevier.com/locate/pedosphere

A Comparative Analysis of Binary Logistic Regression and Analytical Hierarchy Process for Landslide Susceptibility Assessment in the Dobrovăţ River Basin, Romania

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(Received March 19, 2015; revised November 13, 2015)

ABSTRACT

A correct assessment of the landslide susceptibility component is extremely useful for the diminution of associated potential risks to local economic development, particularly in regard to land use planning and soil conservation. The purpose of the present study was to compare the usefulness of two methods, *i.e.*, binary logistic regression (BLR) and analytical hierarchy process (AHP), for the assessment of landslide susceptibility over a 130-km^2 area in the Moldavian Plateau (eastern Romania) region, where landslides affect large areas and render them unsuitable for agriculture. A large scale inventory mapping of all types of landslides (covering 13.7% of the total area) was performed using orthophoto images, topographical maps, and field surveys. A geographic information system database was created, comprising the nine potential factors considered as most relevant for the landsliding process. Five factors (altitude, slope angle, slope aspect, surface lithology, and land use) were further selected for analysis through the application of a tolerance test and the stepwise filtering procedure of BLR. For each predictor, a corresponding raster layer was built and a dense grid of equally spaced points was generated, with an approximately equal number of points inside and outside the landslide area, in order to extract the values of the predictors from raster layers. Approximately half of the total number of points was used for model computation, while the other half was used for validation. Analytical hierarchy process was employed to derive factor weights, with several pair-wise comparison matrices being tested for this purpose. The class weights, on a scale of 0 to 1, were taken as normalized landslide densities. A comparison of results achieved through these two approaches showed that BLR was better suited for mapping landslide susceptibility, with 82.8% of the landslide area falling into the high and very high susceptibility classes. The susceptibility class separation using standard deviation was superior to either the equal interval or the natural break method. Results from the study area suggest that the statistical model achieved by BLR could be successfully extrapolated to the entire area of the Moldavian Plateau.

Key Words: Moldavian Plateau, multivariate statistical method, predictor weights, receiver operating characteristic curve, semi-qualitative method

Citation: Patriche C V, Pirnau R, Grozavu A, Rosca B. 2016. A comparative analysis of binary logistic regression and analytical hierarchy process for landslide susceptibility assessment in the Dobrovăţ River Basin, Romania. *Pedosphere*. **26**(3): 335–350.

INTRODUCTION

Landslides constitute impulsive risk phenomena with potentially severe consequences for the environment and human activities. They manifest as displacements of rock masses on slopes that are unstable and are favored by a combination of factors including geological, geomorphometric, climatic, and hydrological ones, and, in addition, human activities. An assessment of landslide risk assumes the analysis and the coupling of landslide probability (hazard) and the degree of vulnerability entailed. The former includes landslide susceptibility and temporal frequency, while the latter quantifies the potential damage consequent upon actual or potential landslides.

Landslide susceptibility is defined as the occurrence probability of landslides in an area. Evaluation of this seeks to assess the surface (or volume) and the spatial distribution of landslides which may potentially occur in a given area (Fell *et al.*, 2008). Therefore, landslide susceptibility constitutes the first stage in a landslide risk assessment. Studies devoted to landslide susceptibility assessment are becoming more and more numerous (Gokceoglu and Sezer, 2009) and seek to identify and apply the most suitable analysis methods and to provide solutions for the mitigation or elimination of the negative consequences of these phenomena (Soeters and van Westen, 1996; Aleotti and Chowdhury, 1999).

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The development of geographic information system (GIS) techniques and statistical tools has significantly improved landslide analysis, facilitating fast and accurate computations and giving more insight into the landsliding process, including its mapping (Guzzetti *et al.*, 1999; Chacón *et al.*, 2006; van Westen *et al.*, 2006; Chen *et al.*, 2011; Prasannakumar *et al.*, 2011). Such maps, as part of an environmental risk assessment, are very useful in urban and regional planning (Bathrellos *et al.*, 2012, 2013; Papadopoulou-Vrynioti *et al.*, 2013; Youssef and Maerz, 2013).

Landslide susceptibility mapping methods can be classified into three major groups: semi-qualitative, quantitative, and hybrid (Ayalew *et al.*, 2005). The analytical hierarchy process (AHP), developed by Saaty (1980) for solving decision-making problems, belongs to the semi-qualitative group, or to the hybrid group when applied in combination with bivariate statistical analysis, and provides good results for landslide susceptibility assessment (Ayalew *et al.*, 2005; Komac, 2006; Yoshimatsu and Abe, 2006; Bai *et al.*, 2008; Yalcin, 2008; Hasekioğulları and Ercanoglu, 2012). A good online description of how the AHP works is provided by Teknomo (2006).

The quantitative group, with numerous applications in landslide susceptibility mapping, comprises bivariate methods (Pachauri and Pant, 1992; Van Westen, 1993; Uromeihy and Mahdavifar, 2000; Süzen and Doyuran, 2004a, 2004b; Magliulo *et al.*, 2008; Magliulo 2010, 2012; Oh *et al.*, 2010; Regmi *et al.*, 2010; Sterlacchini *et al.*, 2011; Shahabi *et al.*, 2013; Chalkias *et al.*, 2014; Saadatkhah *et al.*, 2014) and multivariate statistical methods, with the latter including binary logistic regression (BLR) (Dai *et al.*, 2001; Ayalew *et al.*, 2005; Zhu and Huang, 2006; Mathew *et al.*, 2009; Bai *et al.*, 2010, 2011; Chauhan *et al.*, 2010; Das *et al.*, 2010; Nandi and Shakoor, 2010; Pradhan, 2010; Rossi *et al.*, 2010; Van Den Eeckhaut *et al.*, 2010; Atkinson and Massari, 2011; Ercanoglu and Temiz, 2011; Akgun, 2012; Althuwaynee *et al.*, 2014; Sabokbar *et al.*, 2014; Youssef *et al.*, 2015). Other quantitative methods include more complex approaches based on neural networks or fuzzy techniques (Lee *et al.*, 2004; Champati Ray *et al.*, 2007; Borgogno Mondino *et al.*, 2009; Yilmaz, 2010; Farrokhzad *et al.*, 2011; Pradhan, 2011).

The complexity of landslide susceptibility assessment is in relation to the different analysis scales employed, the accuracy of input data, and the influence of susceptibility on risk evaluation (Castellanos Abella and van Westen, 2008). The existence of a wide variety of methods is beneficial, as it enables deeper exploration from various viewpoints (Sassa *et al.*, 2009), but, on the other hand, requires special attention to the harmonization of mapping approaches and models, input data, and the levels and scales used for representing landslide susceptibility, hazard, and risk (Hervás and Montanarella, 2007; Cascini, 2008; Fell *et al.*, 2008).

In Romania, several recent studies have sought to apply both quantitative and qualitative methods to develop landslide susceptibility assessment and appropriate mapping, on various scales (Micu and Bălteanu, 2009; Bălteanu *et al.*, 2010; Armaş, 2011, 2012; Constantin *et al.*, 2011; Grozavu *et al.*, 2012; Nicorici *et al.*, 2012; Mărgărint *et al.*, 2013). In addition, efforts are being made to elaborate a general legal framework for the treatment of risk phenomena, including landslides, through the application of methodological standards to their analysis and mapping.

A correct evaluation of landslide susceptibility is extremely useful for the diminution of associated potential risks to local economic development, especially in connection with land use planning and soil conservation (Liu *et al.*, 2006; Bai *et al.*, 2009). The topic is of great interest, because landslides may cause the exclusion of valuable agricultural land from economic exploitation. The purpose of the present study was to compare two methods for assessing landslide susceptibility, BLR and AHP, as applied to part of a relatively small hydrographic basin situated in a plateau affected, over large areas, by a variety of geomorphological processes including landslides.

MATERIALS AND METHODS

Study area

The study area forms part of the Dobrovăţ River Basin, located in eastern Romania in the Central Moldavian Plateau, which belongs to the major geostructural unit of the East European Platform (Fig. 1). Our attention focused on the southern half of the basin, with an area of 130 km^2, while its northern part was disregarded in our study as it is covered with compact forested areas, which make landslide mapping a difficult task.

The surface geological strata present a monocline structure (northwest-southeast gradient of 5–7 m km^{-1}) and the lithology is relatively simple and homogeneous, with a prevalence of Sarmatian (upper Miocene) clays and marls and some intercalations of sands, sandstones, and limestones (Ionesi, 1994). Morphologically, the study area is characterized by the presence of two large, consequent valleys (Dobrovăţ and its major tributary, Rediu) and a larger number of small subsequent tributary valleys. This configura-

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