Journal of Cultural Heritage xxx (2017) xxx–xxx

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Case study

# Frequency ratio and GIS-based evaluation of landslide susceptibility applied to cultural heritage assessment

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ARTICLE INFO

*Article history:*
Received 15 March 2017
Accepted 9 June 2017
Available online xxx

*Keywords:*
Landslide susceptibility
Frequency ratio
AUC
Cultural heritage
GIS

ABSTRACT

This study aims to produce landslide susceptibility maps using frequency ratio (FR) model with the help of GIS to be used in cultural heritage (CH) mitigation and assessment for a catchment from northeastern Romania. In total, seven conditioning factors were used to assess the landslide susceptibility index (LSI): elevation, slope angle, curvature, normalised difference vegetation index (NDVI), roughness, distance to rivers and landforms. The landslide susceptibility maps were prepared with the help of GIS software and classified into four susceptibility areas: low, medium, high, and very high. The more conditioning factors were added to the susceptibility, the better validation results were obtained (from an AUC = 0.51 corresponding for five factors, to an AUC = 0.75 for the seven factors). The model validation has shown that the maps made using FR model has a success rate of 75.24%. The landslide susceptibility maps have a high accuracy and will be helpful not only for CH protection and preservation, also for land-use planning, hazard mitigation, and risk reduction. Out of the 47 CH sites, more than a half are located in areas with high and very high susceptibility to landslides.



## 1. Research aims

The present work aims to report the results obtained with the help of statistical methods applied to landslide susceptibility in a catchment from northeastern Romania. This approach is useful and needed due to the increased intensity of natural hazards (e.g. landslides) throughout the world, in order to assess and mitigate the degradation of CH. There is a lack of studies that apply statistical modelling to assess landslide susceptibility on CH sites; this study comes to fill that gap. The results will be used to evaluate the present state of CH sites, disaster risk reduction, and as a powerful tool for local authorities and stakeholders to plan future mitigation measures.

## 2. Introduction

Natural hazards represent severe and extreme weather and climate event that occur naturally in all parts of the world; one of the main triggering factors is the global climatic changes that are exponentially increasing every year [1]. Besides the great economic damages, they are also affecting CH sites. At an international level, there are studies referring to certain natural hazards with direct effects on CH, including earthquakes [2], floods [3], gully erosion [4], and coastal erosion [5]. Landslides are one of the most critical environmental hazards of modern times. The last decades have demonstrated that the meteorological and hydrological risk processes have accentuated. The landslide susceptibility can be defined as the likelihood of a landslide to occur in a certain area, taking into account the local environmental factors [6], also known as conditioning factors. Over the last years, there has been an upward trend at the international level to apply statistical modelling to assess landslide susceptibility: bivariate and multivariate statistical approaches [7], binary logistic regression and stochastic gradient tree boost [8], GIS-based exposure analysis [9], CHAID and AHP [10], etc. The same methods were also applied in Romania [11–13], but none is applied in the field of cultural heritage. Tangential mentions are those regarding the monitoring [14], temporal analysis

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http://dx.doi.org/10.1016/j.culher.2017.06.002
1296-2074/

[15], and conservation strategies [16–18]. As a consequence of that, this study comes to fill the gap and be a starting point in studies regarding the landslide susceptibility models being applied in the field of CH. The protection and conservation of CH have become one of the most important desiderata of the modern world. CH is an expression of the way in which a community developed and lived, passed on to future generations, including customs, practices, places, objects, artistic expressions, and values [19]. Studies regarding the assessment of hazard and risks are a desideratum of the modern world, in order to provide stakeholders suitable tools to safeguard CH.

Valea Oii river basin (northeastern Romania, Iasi County, Fig. 1a) has been chosen as a study area, due to the availability of spatial data, repetitive field studies and field surveys. From a geological perspective, the Bassarabian deposits of Sarmatian age dominate the basin; Pleistocene terrace deposits are located in the lower half of the basin [20]. The area is highly susceptible to soil erosion processes [21,22] and vulnerable to the natural and anthropogenic pressure [23]. The method chosen to assess the landslide susceptibilities is frequency ratio (FR). The performance of the landslide susceptibility index is assessed using statistical modelling and validation dataset of known landslide locations – landslide

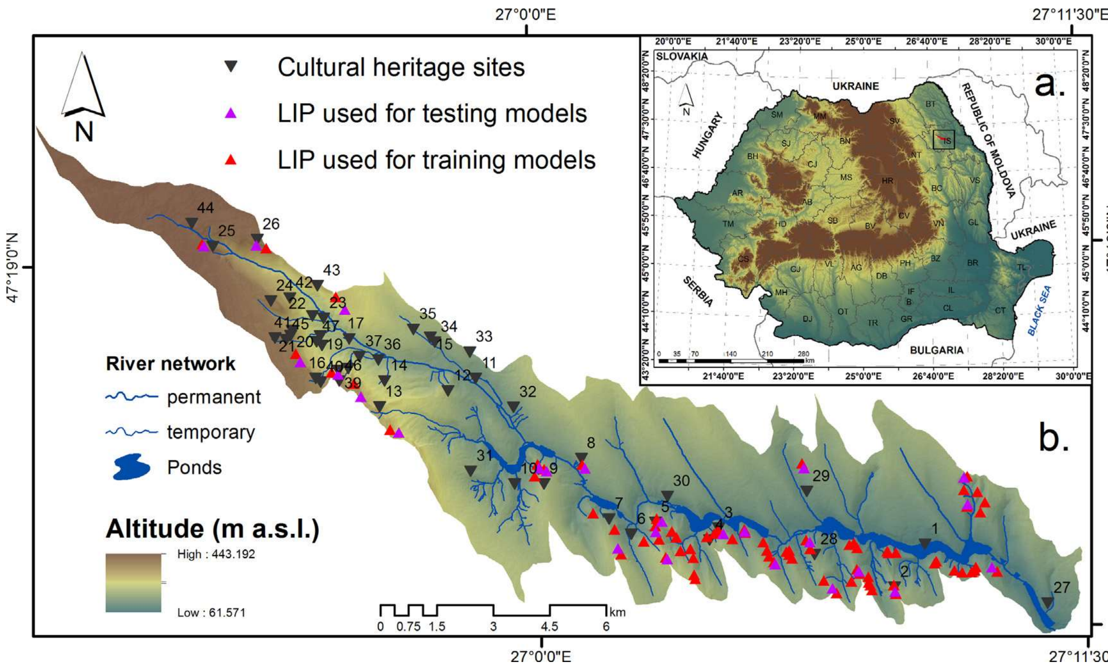


**Fig. 1.** a: geographical location of the study area in Romania; b: location of the cultural heritage (CH) sites and of the landslide identification point (LIP) used for testing and training.

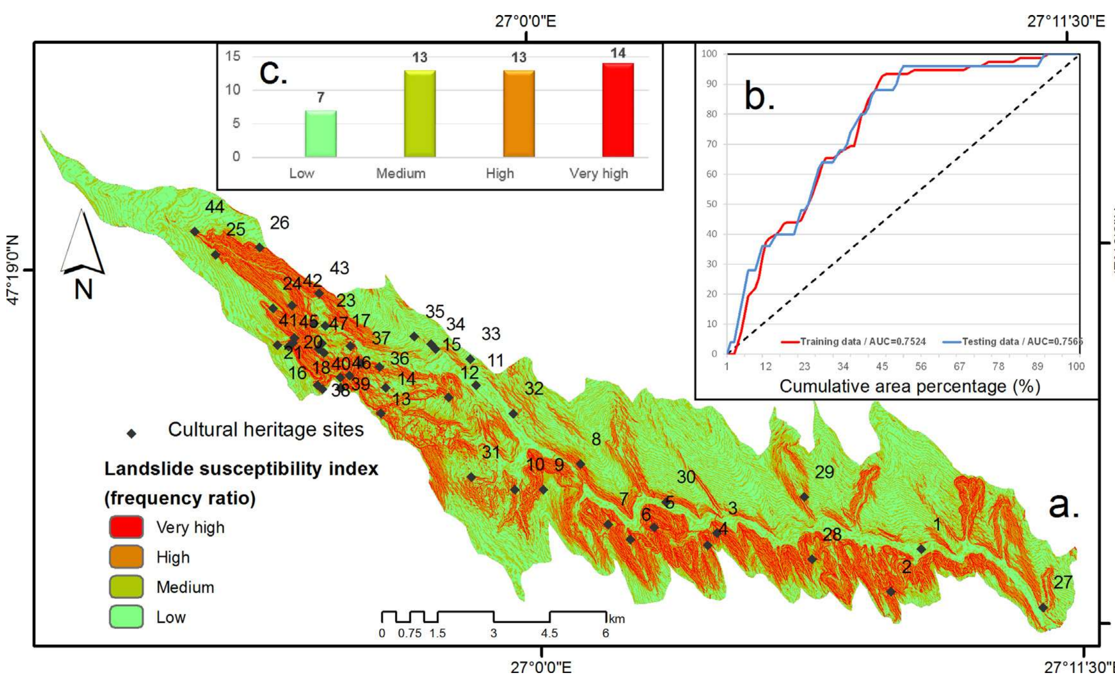


**Fig. 2.** a: landslide susceptibility map produced using frequency ratio (FR); b: plot of the prediction rate of FR landslide susceptibility map; c: distribution of cultural heritage (CH) sites on landslide susceptibility classes.

identification point (LIP) (Fig. 1b); LIPs were derived with the help of GIS for each landslide by extracting the highest point along the landslide polygon, also known as the depletion area.

Within the study area, there is a rich CH, consisting of a number of 47 sites, of which 11 are listed in the List of Historical Monuments (LMI) and nine are listed in the National Archaeological Registry (RAN) [23]. The most important one is the site from Cucuteni – *Cetătuie*, the eponymous site of the Cucuteni culture, the last great Eneolithic civilisation of Old Europe, part of Cucuteni-Trypillia Cultural Complex [24]. Out of 47 sites, 26 are of Eneolithic age, the rest belong to the following periods Geto-Dacian (4–2nd centuries, 3–2nd centuries and a necropolis), late Bronze Age (Noua culture), late Iron Age (la Tène culture), wooden vernacular architectural structures from 16th century, churches from 18th and 19th centuries, and one paleontological reservation.

## 3. Materials and methods

In order to proceed with the statistical modelling, a landslide inventory of the study area was prepared; this was made using orthophotos, topographic maps, and field surveys. A total of 48 landslides were identified, with a total surface of 9.7 $km^2$ representing 10% of the total area of 97 $km^2$. The base DEM has a pixel size of $5 \times 5$ m and it was derived from the topographic plans, scale 1:5000 digitising the contour lines.

In total, a number of seven conditioning factors were used to assess the landslide susceptibility index (LSI): elevation (reclassified into five classes), slope angle (reclassified into five classes $1^\circ$–$2^\circ$, $2^\circ$–$4^\circ$, $4^\circ$–$6^\circ$, $6^\circ$–$10^\circ$, and $> 10^\circ$), curvature (classified into three classes $< -0.8$, $-0.8$–$0.36$, and $> 0.36$), NDVI (divided into five classes ranging from $-1$ to 0.6), roughness (classified into five classes with values ranging from 0.05–0.86), distance to rivers (according to the small surface of the catchment it was reclassified into four classes after performing a buffer analysis $< 150$ m, 150–300 m, 300–450 m, and $> 450$ m) and landforms. The last factor was derived from the Topography Tools (ArcGIS) [25], comprising deeply incised streams, shallow valleys, U-shaped valleys, plains, open slopes, upper slopes and high ridges; out of these landforms, the plains and open slopes are dominating the latter. Lithology is a significant factor in landslide occurrence. The data available can only be extracted from the Romanian Geological Map (scale 1:200,000); taking into consideration the lack of a more detailed

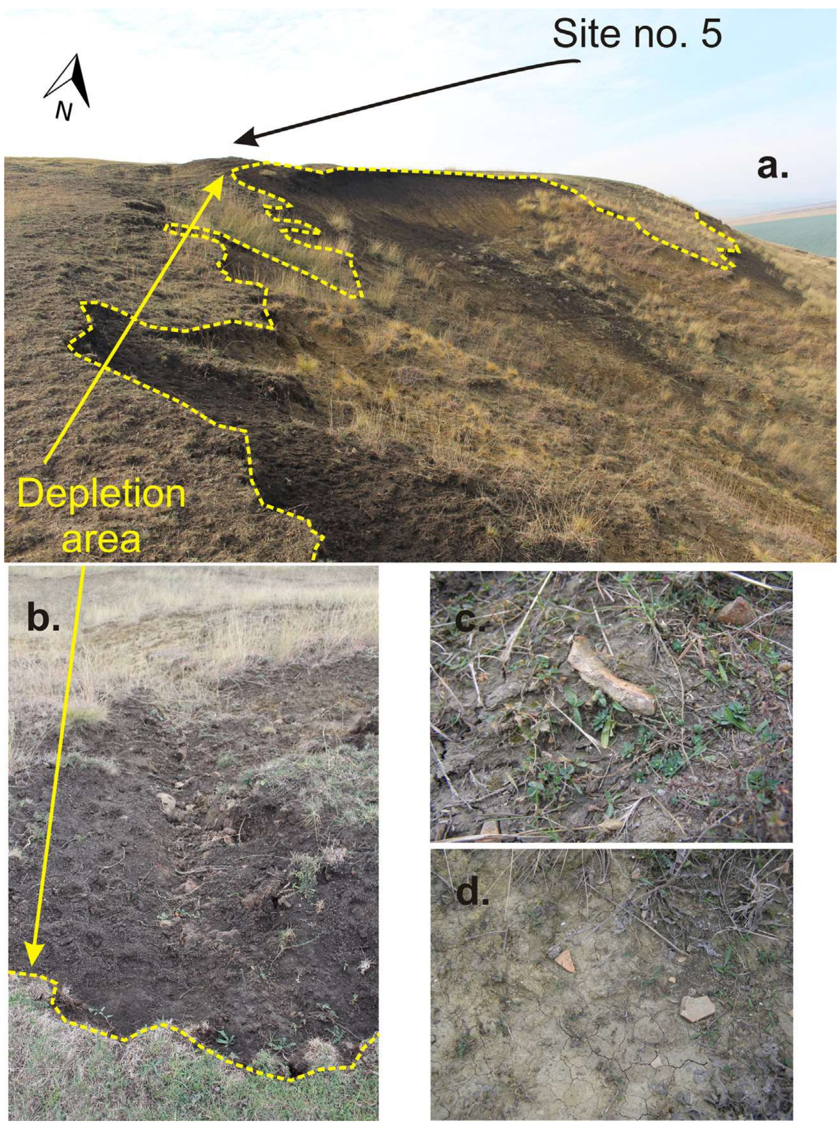


**Fig. 3.** a: the depletion area of the landslide affecting site No. 5; b: concentration of archaeological remains on the channels formed by water erosion; c, d: archaeological remains located at the toe of the landslide.

data regarding the outcrop lithology, we decided not to include this factor in the landslide susceptibility index calculation.

FR is a well-known reliable methods to produce high accuracy landslide susceptibility maps. FR model is based on the correlation between the known landslide locations (LIP) and the conditioning factors used in the study. The weight of each factor was calculated and then by summarising the weights we obtained the LSI using the following equation [26]:

$$LSI = \sum FR_i \quad (1)$$

where $FR_i$ is the FR of each factor type, and FR is the area where landslides occurred.

FR method selected the landforms, roughness, and curvature, as being the most important conditioning factors. The final susceptibility maps were reclassified into four susceptibility classes low, medium, high, and very high. The landslide inventory was overlapped in order to check if the model is viable.

## 4. Results and discussion

### 4.1. Validation and verification of results

The assessment of parameter correlations, characterising small catchment properties and processes, is one of the main objectives of modern geography; combining this approach with the effects that these processes might have on CH sites in the future, will help in a better preservation of the CH. Making correlations is a significant step to assess poor-studied territories; correlations made for specific areas could be extrapolated to characterise close by river basins situated in a similar landscape condition.

Predictive models are designed to predict future phenomena rather than recognise processes and objects that already happened. The output is a probability distribution of slope failure in a given area based on a set of environmental variables. Geomorphic processes like mass movements are intensely studied in the context of tectonic processes, but their role on catchment scale and the negative effects on CH sites need surely more attention.

In order to verify the predictive skills of the landslide susceptibility map produced with the help of FR model (Fig. 2a), receiver operation characteristics (ROC) and the area under curve (AUC) were computed (Fig. 2b). FR model produced an AUC = 0.7524. The location of the most susceptible areas is strongly related with the steep slopes from the right side of the catchment (which from a geomorphological point of view represents a cuesta) [22,23]. This also represents the side, which was preferred by the Neolithic populations in order to place their settlements, a number of 26 Neolithic settlements being encountered within the catchment [21].

### 4.2. CH sites affected by landslides

The Moldavian Plateau has a landslide density of 1.02 landslides per $km^2$. Regarding the age, landslides are classified in very old landslides (Upper Pleistocene – 6550 BP), old landslides (not earlier than 6550 BP), and more recent landslides (last centuries) [27]. There has been identified an increasing surface affected by landslides from 2.15 $km^2$ in 1894 to 9.7 $km^2$ in 2012. The increasing surface is due to the slide-earthflow slides from the right side of the basin; these started to have a higher frequency during the last decades due to the expansion of pastures and overgrazing. Within the study area, there is a number of 48 landslides; out of these, 17 landslides are active and 31 are stabilised; the active landslides are usually located on the north and northeastern oriented slopes. The stabilised slides represent the old and very old landslides and are located on both sides of the catchment (especially the slides from the upper part of the catchment, where Baiceni village is located).

The value of cultural heritage goes beyond conservation, monitoring and protection; it can offer significant data that cannot be recovered in the future and insights into human evolution, cultural evolution, the evolution of culture, people's behaviour, among other issues. Currently, within the study area, out of 47 CH sites, 20 sites are affected by landslides. More than a half of the CH sites are located in areas with high and very high susceptibility to landslides, an alarming number, which should raise the attention of local authorities in the future (Fig. 2c).

### 4.3. CH sites affected by different landslide types

The way landslides affect the integrity of the CH sites is different for archaeological sites and built monuments. Another factor that has a significant impact is the typology of the landslide, in the study area being identified translational, slide-earthflow, and rotational slides [28]. Taking into consideration this fact, there can be differentiated:

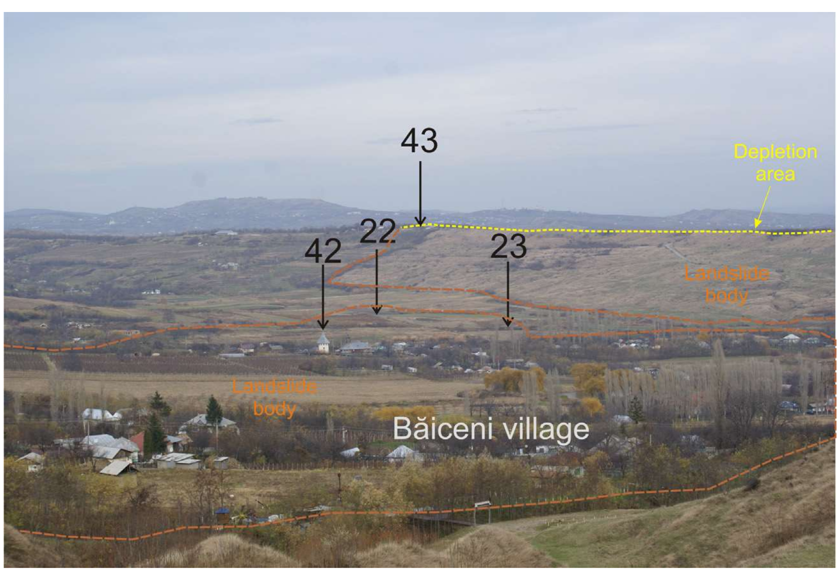


**Fig. 4.** Cultural heritage (CH) sites from the upper basin located on the landslide body.

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sites located upslope of active landslides (which may be retrogressive and erode the CH sites); in the case of archaeological sites, depletion areas represent zones with no vegetation (Fig. 3a), therefore an acceleration and concentration of water erosion are encountered (Fig. 3b); numerous quantities of pottery and flint pieces is washed down the landslide body (Fig. 3c and d).

In time, the value of the archaeological remains is dropping and by repetitive movements, they are more difficult to be dated to a specific period; this is the case of the site No. 5. In the case of churches or other monuments cracks appear on the walls, due to earth instability; if the cracks are not repaired, in combination with weathering processes, this can lead to the collapse of some parts of the monument or even to total collapse:

- sites located on landslides body; in the upper part of the catchment, in the Baiceni village area where the landslides with the highest surface are located, a significant number of CH sites are located on the landslide body (Fig. 4).

Translational and rotational slides have the highest surface and represent the most dangerous type of slides for CH sites. Out of 20 sites affected by landslides, 16 are located on or around rotational slides.

## 5. Conclusions

In this study, FR model and a GIS-based approach were employed for landslide susceptibility mapping. Seven conditioning factors were used, i.e. elevation, slope angle, curvature, normalised difference vegetation index (NDVI), roughness, distance to rivers and landforms, and integrated into GIS. The 48 landslides occupy a surface of 10% from the total surface of the catchment. The final landslide susceptibility maps were classified into four susceptibility classes low, medium, high, very high. The AUC plots have demonstrated a high accuracy of the LSI. The total number of the CH sites within the study area is 47; after overlaying the CH sites and landslide susceptibility maps it can be observed that more than a half sites are located in areas with a high and very high susceptibility to landslides. In present, 20 CH sites are affected by landslides. This should be a signal for the local authorities, which will have to implement mitigation measures in order to control the landslides triggering factors and to decrease the effects of the processes that are already happening.

## Acknowledgements

This work is performed according to the Russian Government Program of Competitive Growth of Kazan Federal University. Many thanks for the constructive comments of two anonymous reviewers and the editor for the manuscript handling.

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