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Landslide inventory for Moldavian Plateau, Romania

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Extended Abstract

INTRODUCTION

Landslides, as mass movement geomorphologic processes, are characteristic for any climatic zone, and occur at any spatial and temporal slice (past, present, future). The causes of landslides triggering are various, and usually, predisposing and preconditioning factors are needed. The variety of mechanisms (Varnes, 1978, Cruden and Varnes, 1996, Hungr et al., 2014) and magnitudes is a characteristic of these processes and shape. Clear clustering properties are seen at temporal (Witt et al., 2010) and spatial level.
The cartographic representations of the extant slope failures, the landslide inventories, are the most basic elements in analysis of controls on the spatial and temporal patterns of mass movements and the environmental, human or geomorphic consequences of slides (McKean and Roering, 2004, Van Westen et al., 2008, Guzzetti et al., 2012). Due to permanent development of new remote sensing data and techniques, nowadays there is a general increase of accuracy of landslides inventories, with more and more theoretical and applied outcomes in landslide management and mitigation. The high quality of these images allow a better understanding of local conditions for each landslide, and consequently a better typological classification, through deciphering and interpretation of a large range of morphological features (Tarolli et al., 2012).
In this context, we have created a polygon based landslide inventory containing 24,263 landslides for the entire area of Moldavian Plateau, NE Romania which cover 24,803 km^2. The landslide inventory can be used to study and analyse the spatial patterns of the landslides, both as processes and as morphologies created. The present approach can constitute a baseline for the regional assessment of landslide susceptibility, and further for hazard and risk evaluation (Guzzetti et al., 1999).

STUDY AREA

The Moldavian Plateau is one of the most representative unit plateau of Romanian territory Despite many limits of the Moldavian Plateau cited in geographical literature (Băcăuanu et al., 1980), this approach will relate to the area comprised between Prut Valley (to the east), Siret-Moldova valleys (to the west) and the northern border of the country (Figure 1). The border between plateau unit and Carpathian Mountains, in north-western part of the study region was drawn according the geological map of Romania at scale 1:200,000. The south-west extreme part, dominated by fluvial terraces and holocene alluvial deposits, known as Tecuci Plain, was not included in the studied area, being considered a part of Romanian

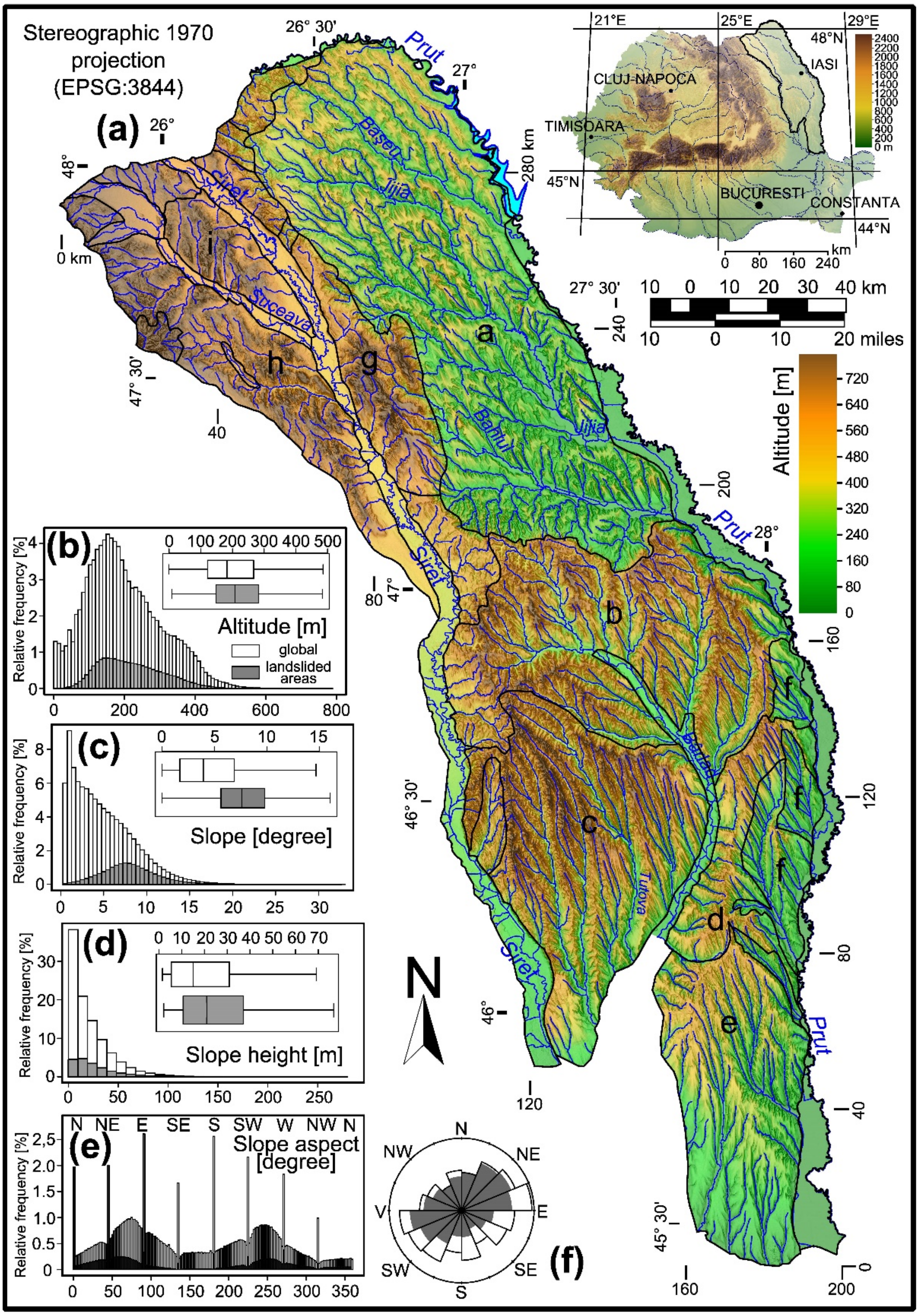

Figure 1 Geographical position, physiographic subdivisions, elevation distribution and descriptive statistics graphics of the Moldavian Plateau, based on SRTM data; on the left side there are represented the distributions of altitude (a), slope (c), slope height (d) and slope aspect (e,f); for the map (a) the letters indicate the geomorphological regions: a – Jijia Hills, Bârlad Plateau composed from b – Central Moldavian Plateau, c – Tutova Hills, d – Fălciu Hills, e – Covurlui Plateau, f – Huşi-Sărata-Elan-Horincea Hills, Suceava Plateau composed from g – Siret Hills, h – Fălticeni Plateau, i – Dragomirnei Plateau

Plain. Toward east, the Moldavian Plateau continues on the territory of the Republic of Moldova. In between these limits, the study area covers 24,803 km^2, with altitudes ranging between 5 to 794 m a.s.l. The relief of the plateau was modelled on a monoclinal sedimentary structure with a mean inclination of 7-8 m/km from north-west to south-east, contrasting with crystalline basement of East-European Platform which sinks toward west, under Carpathian Orogene (Ionesi et al. 2005). This monoclinic structure of the sedimentary coverture has controlled and designed a repetitive pattern of landforms (Niculiţă, 2011) with obvious influences for many other environmental and human life characteristics (hydrographic network, land use pattern, the main transport corridors, etc.).
The age of surface lithological formations is comprised between Cretaceous (which outcrop in north-east, along Prut river banks) and Quaternary deposits (alluviums of floodplains and terraces of the main rivers, and loess in southern part), with a large extension of Buglovian to Romanian formations. Due to unequally and earlier uplifting of the northern part, which progressively transformed actual plateau into an continental area, the sedimentary deposits outcrop, in order of age, from north to south (Ionesi et al. 2005). The lithology is represented by alternances of consolidated rocks (sandstones, limestones, tuffs and fewer micro-conglomerates) which mainly occur on the ridges and unconsolidated rocks, like clays, silts, and sands, which occur beneath. The erosion has detached many morphological alignments, supported by these consolidated rocks, some of these alignments being impressive, with a remarkable and repetitive occurrence of deep seated landslides (Mărgărint and Niculiţă, 2014). These morphological alignments have delineated three main subunits of the Moldavian Plateau (the Central Moldavian Plateau, the Suceava Plateau and the Jijia Hills – Figure 1).

METHODS

As source for landslide affected areas and delineation, a wide range of remote sensing imagery were used. These include optical satellite imagery available in the Google Earth® and Bing Maps archives (SPOT, Formosat, WorldView, GeoEye, Pleiades, QuickBird, KOMPSAT, IKONOS), national ortorectified imagery and where available, LIDAR DEM data (for approx. 40% of the studied area). The digitization was performed in Google Earth® and Quantum GIS software. Shading maps computed from LIDAR DEM data with 0,5 m spatial resolution was used for the delineation of the landslides. Geomorphometric analysis of the entire studied area and subsequently for the landslide inventory was performed by using SRTM data (SRTM v.2), resampled at 30 m resolution with a bilinear interpolator and SAGA GIS v. 2.12. Slope and aspect were computed with the maximum gradient method.
Landslide width and length was computed by considering the direction of the mass flow. In this context, there is a special situation, with the landslides which develop on cuesta scarp slopes. These landslides, usually have widths larger than the lengths, and requested special processing for the separation from the landslides which have lengths larger than widths. The processing involved the computation of the mass flow direction using the difference of height for the lengths and widths of the bounding box rectangle for each landslide. The landslides with widths larger than the lengths (Figure 2e), have smaller height difference on the long side of the bounding box, while the landslides with lengths larger than the widths (Figure 2a) have smaller height difference on the short side of the bounding box. Landslide height of each landslide was computed as the difference between the minimum and maximum slope height for that landslide. The slope height is computed for every pixel, as the difference between the altitude of that pixel and the local drainage path. The slope and aspect angles, for each landslide were considered as the mean values of all the DEM pixels corresponding to the landslide extent. Beside the mean slope angle of the landslide affected topography, the general slope given by the ratio between slope height and landslide length was computed. Structural landforms (cuesta scarp slope and dip slope) classification was described by Niculiţă, 2011.

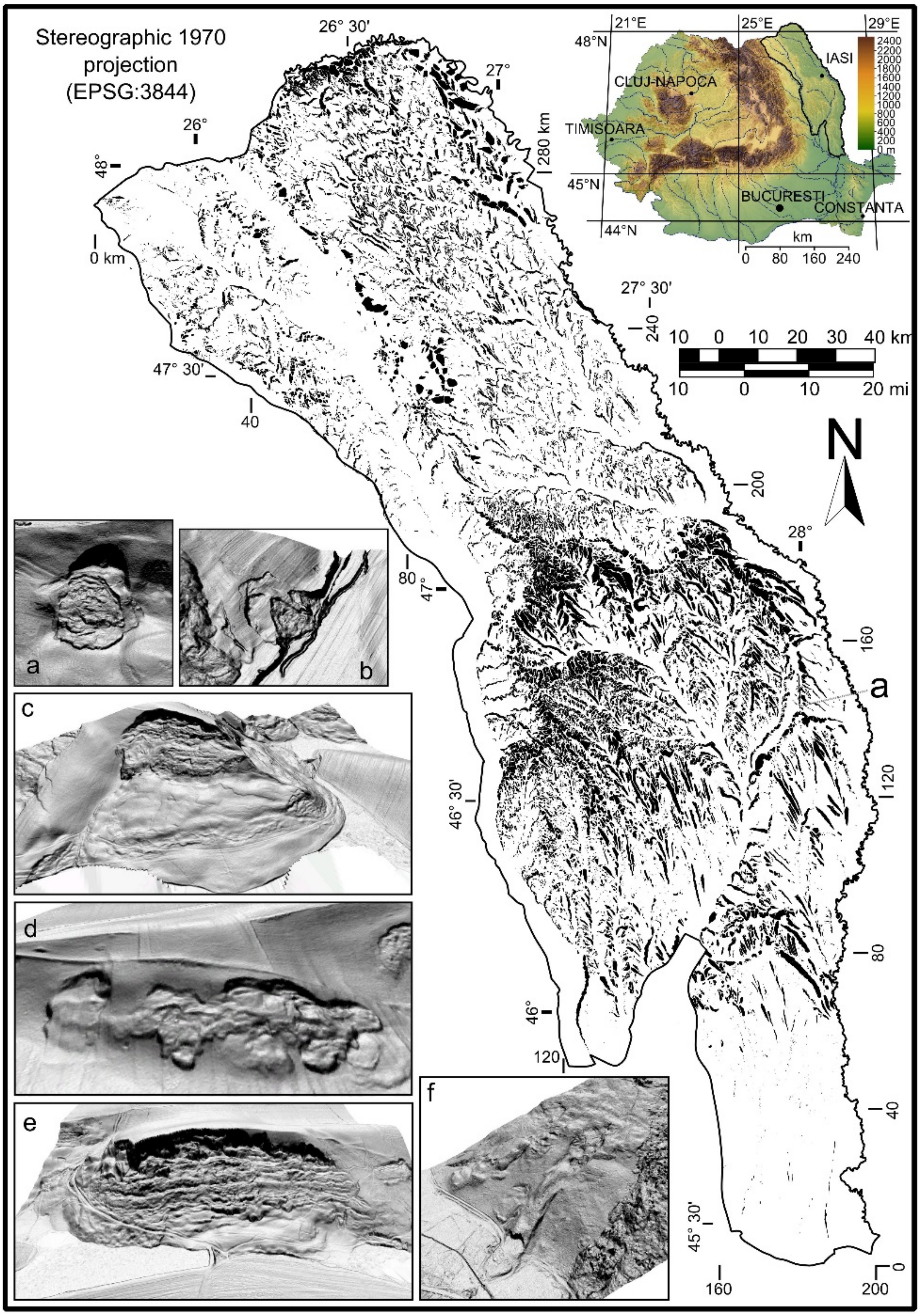

Figure 2. The spatial distribution of landslide inventory (the insets represent 3D perspectives of LIDAR shading for typical landslides): a, e – rotational, b – lateral spread, c – translational, d – translational and flow like, f- flow.

For the Moldavian Plateau, a geomorphological historical landslide inventory (Malamud et al., 2004, Guzzetti et al., 2012) was prepared by using a large series of remote sensing imagery and data, and numerous field campaigns. This was realized during more than 18 months, by the two authors of this article. This experience confirm us the fact that the landslide inventories are essentially factual in nature (Fell et al., 2008). Firstly, a number of five obvious elements of mass displacement, were used as main criteria, and selected to identify, locate and to de-lineate the occurrence and spatial extension of landslides: (i) crowns (undisplaced material, still in place), (ii) scarps (main and/or minor), (iii) roughness of the mass displaced, (iv) flanks, and (v) toes. Subsequently, using the line editors of specialized software, the surfaces affected by landslides were drawn individually as polygons features. In the next step, especially in the cases when an obvious spatial continuity was reported, the following operations of mapping generalization have been applied: simplification, amalgamation and refinement.

This landslide inventory is classified as a geomorphological and historical one in the sense that the optical imagery used as data source for a large area of the Moldavian Plateau, doesn't always allowed the delineation of event based landslides, but instead requested their inclusion in the entire area affected by landslide processes. The same approach was applied to the areas where LIDAR DEM shading was used as source for landslide delineation (data available only for 40% of the study area) for getting consistency, although this data source allowed the delineation of event based landslides. Only the small event based landslides, recognizable both on remote sensing images and LIDAR DEM shading were considered as individual landslides, attributable to a certain event. This is consistent with methodology applied by other authors (Ardizzone et al, 2007, Van den Eeckhaut et al, 2005).

Lastly, through geomorphometric analysis of polygons, environmental settings of landslide locations, field experience and many verifications, the polygons were attributed according to Varnes (1978) and Cruden and Varnes (1996) systems.

RESULTS

Overall, the landslide inventory of Moldavian Plateau contains 24,263 landslide polygons, which correspond to a landslide density of 1.02 landslides per km^2. The total area of the landslides is 4534.7 km^2 (the overlapping landslides were merged before computing the total area) that represent 18.3% from the total area of the plateau, corresponding to a landslide density of 0.19 km^2 of landslide area for every km^2. The following types of landslides have been identified: 1 – rotational, 2 – translational, 3 – lateral spread, 4.1 – rotational-translational complexes, and 4.2 – rotational-translational-flow complexes. The absolute frequency of these types for the physiographic regions of the Moldavian Plateau (Figure 1) is presented in Table 1.

The most frequent landslide area is 2500 to 3500 m^2 (1044 counts), because the majority of landslides have small areas (Figure 3b). Meanwhile the small landslides cover a small proportion of the area affected by landslides: landslides with areas under 10,000 m^2 represent 22.2% from the total number of landslides and 0.6% of the total landslide area. Those with areas between 10,000m^2 and 100,000 m^2 represent 44.5% from the total number of landslides and 9.5%of the total landslide area.

Large landslides although represent a small proportions of the total number of landslides, cover the biggest area. Landslides with area comprise between 100,000 m^2 and 1 km^2 represent 29.8% from the total number of landslide sand 49.4% of the total landslide area. Landslides exceeding 1 km^2 (3.5%from the total number of landslides) cover 40.5% from the total landslide area.

The spatial distribution of landslide index (Fig. 3a), defined (Trigila et al, 2010) as the proportion of landslide surface for a grid of 1x1 km, show the hotspots of landslide density. The distribution of the landslide index values show an exponential distribution, so we can state that spatially, the areas prone to landslide processes are occupied in a large proportion.

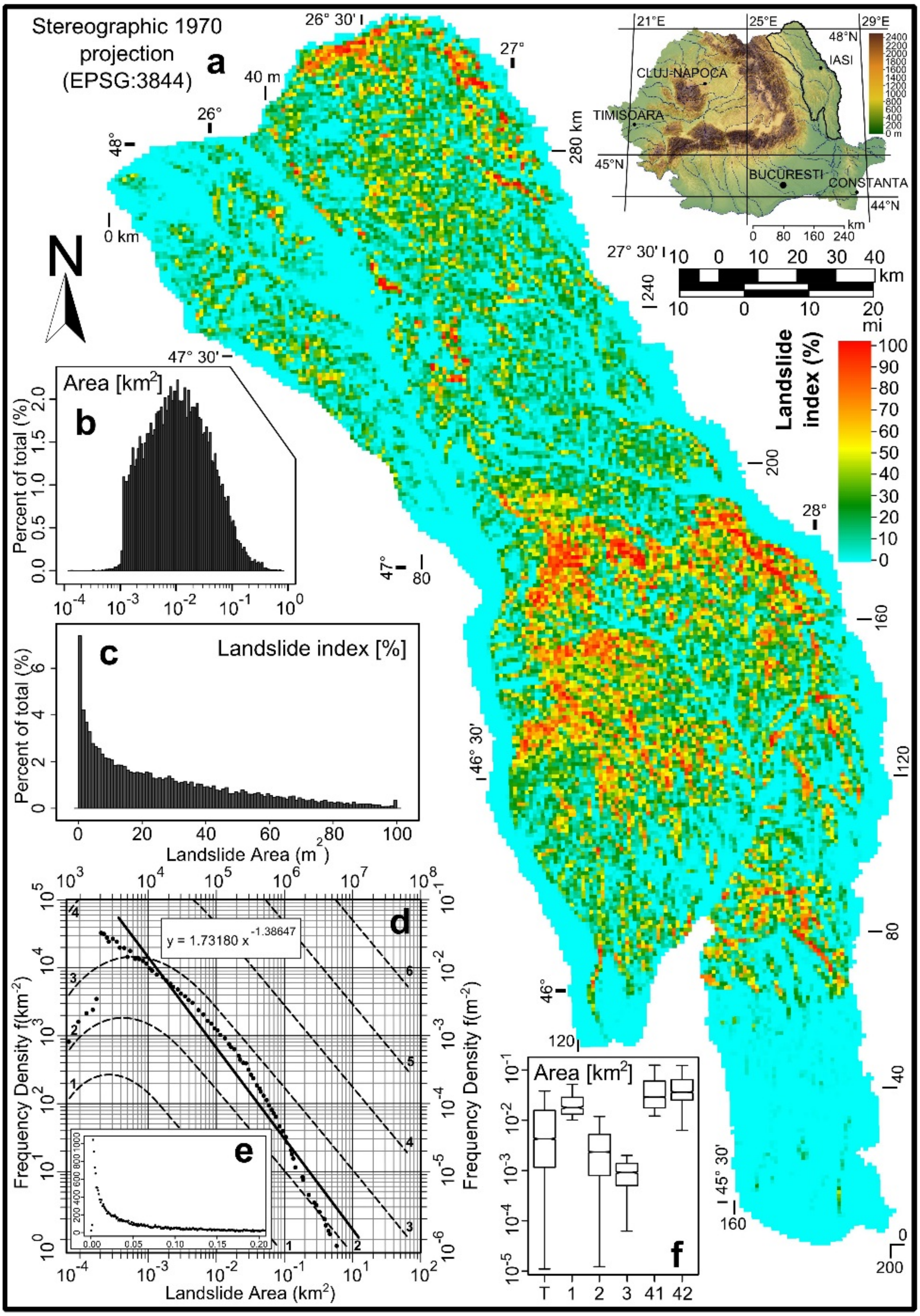

Figure 3. Landslide area patterns in Moldavian Plateau: a – landslide index for 1x1 km (1 km^2) grid; b – histogram of landslide area in logarithmic scale; c – histogram of landslide index for 1x1 km grid; d – frequency distribution in log-log scales; e - frequency distribution in linear scales; f – boxplots for landslide area, of all landslides (T), and of landslide types (1, 2, 3, 41, 42).

Rotational slides comprise 2.5% of the inventaried landslides, translational 12.2%, river induced 0.2%, rotational-translational complexes 62.8% and rotational-translational-flow complexes 22.3%.
Considering the physiographic regions of the Moldavian Plateau, the proportion of landslide area from the total landslide area are: Central Moldavian Plateau (30.4%), Jijia Plateau (26.5%), Tutovei Hills (20.3%), Siret Hills (7%), Suceava Plateau (6.2%), Fălciu Hills (4.1%), Covurlui Plateau (2.3%), Huşi-Sărata-Elan-Horincea Hills (2.3%). Regarding the density (proportion of landslide area from total area) the rank changes: Central Moldavian Plateau (38.2%), Sucevei Plateau (33.6%), Tutovei Hills (29.1%), Huşi-Sărata-Elan-Horincea Hills (26.5%), Fălciu Hills (21.8%), Jijia Plateau (19.3%), Siret Hills (17.9%), Covurlui Plateau (4.5%).

Table 1. The absolute frequency of landslide types from the physiographic units of Moldavian Plateau.

physiographic units	1*	2*	3*	41*	42*	Total**
Covurlui Hills	5	733	139	118	3	998
Fălciu Hills	12	580	45	114	106	857
Tutova Hills	129	4179	288	1251	72	5919
Central Moldavian Plateau	124	2925	107	92	811	4059
Jijia Hills	92	4271	90	1427	660	6540
Siret Hills	61	950	64	479	23	1577
Suceava Plateau	89	1874	301	464	31	2759
Huşi-Elan-Sărata-Horincea Hills	4	353	13	104	1	475
Total**	516	15865	1047	4049	1707	23184
physiographic units	1*	2*	3*	41*	42*	Total**

** the columns 3 to 7 represent the landslide type code according to the text*
*** The inconsistency of the row and column total surface and proportion is due to the multiple superposing of landslide polygons along regions borders, and the inclusion of some landslides to Siret, Prut and Bârlad rivers valleys (Figure 1)*

CONCLUSIONS

Using a historic landslide inventory for the Moldavian Plateau, this article has analysed the typology, causal factors and patterns of landslides. While the landslide inventory is not complete, as the frequency density of area shows, the distribution shape is similar to the theoretical one and we conclude that the acquired landslide information can be used to assess the spatial patterns. Further expansion of the landslide inventory requires the estimation of landslide age and the separation of event based landslides.
The present landslide inventory, prove that Moldavian Plateau is an important hotspot for these gravitational processes (18.3% from the total area in 24 263 polygons), despite a relative lifelessness recorded of the mass movement processes for the last decades.
In the Moldavian Plateau the following types of landslides have been identified: rotational, translational, lateral spread, flow and complex landslides. The analysis allows us to consider that geological conditions (monoclinic structure and clayey-silty lithology) and morphostructure have a strong control in the spatial distribution of landslides. Landslides occur on all lithological classes, mostly on clays, sands, limestones and sandstones. The landslides occupy the entire range of slope positions (upper, middle, lower), with differences depending on the type. Spatial and and geomorphometric analysis of the landslide polygons variables: altitude, length, width, height, slope angle, aspect, have proved this link between mass movements processes and the geologic, morphostructural and topographic setting. This general pattern is completed by a large range of local preparatory factors.
Further extensions of the inventory by including age, event based and multi-temporal attributes and locations will complete the general image of landslide types and patterns in

Moldavian Plateau, and will contribute to a better understanding of landslide phenomenon, natural risk assessment and sustainable management of landscape resources.

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