The potential of water erosion in Slănic River basin

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Abstract: This study represents a hydrogeomorphological approach and aims to evaluate the potential of water erosion in the Slănic river basin. The analyzed river basin is highly susceptible to water erosion due to synergic actions of morphometric factors (high slope values, high slope convexity, surface runoff acceleration), hydrologic factors (high convergence of the river network in several areas), land cover (low degree of afforestation) and others. In order to analyze the potential of water erosion, GIS techniques were used for geoprocessing several environmental variables (factors) with an important role in water erosion process occurrence. The proposed index, Land Erosion Potential Index (LEPI), obtained by analyzing eight environmental factors, showed that almost 26% (111.1 km²) of the total study area (427.4 km²) is characterized by high and very high potentials of water erosion. The results can be useful for identifying viable measures for the control of the analyzed process.

Keywords: Slănic River basin, water erosion potential, LEPI, GIS techniques.

1. Introduction

Land erosion is one of the most critical environmental hazards in many parts of the world (Jain & Kothyari, 2000), the soil being one of the most affected environmental components. It is estimated that almost 75 billion tons of soil are being annually eroded, globally speaking. The agricultural lands are the most affected, with an annual rate of soil loss ranging from 13 tones/ha to 40 tones/ha in some cases (Piementel & Kounang, 1998). Generally, pedogenesis is a slow process, and, as a consequence, soil loss due to erosion is 13-14 times faster than the recovery rate (Piementel & Kounang, 1998).

The loss of the productive capacity of ecosystems is one of the most important consequences of land erosion, due to surface runoff, water infiltration decrease, loss of nutrients, organic material and soil biota (Jones et al., 1997; Piementel, 2006). At the same time, due to surface runoff erosion, another important global consequence is related to the high values of carbon emissions (the soil being the third most important global environment of carbon storage, after oceans and forests) (Lal, 1999), which is one the most important contributing gasses to the present global climate change (IPCC, 2007).

Globally, there are some areas strongly affected by land erosion (southern Asia, the sub-Saharan region of Africa, the Central America and the Andean region of Southern America) (Ral, 2001). The region of Southern Asia is one of the most affected, especially because of water erosion (Singh et al., 1992). In Europe, the most important water erosion issues are mainly related to its southern part, the Mediterranean region (Gobin et al., 2004), where the natural components of the environment are affected, as are the agricultural systems which suffer from a severe decrease of crop yields (Stoate et al., 2001). Land erosion is a major issue in Romania also, and the Subcarpathians' area is one of the most vulnerable because of the aggressive human impact over time (deforestation), the presence of friable rocks on large areas (clays, marls, sands) and the high potential for surface runoff (due to high slope values, high slope convexity etc) (Grecu et al., 2007; Prăvălie & Costache, 2013; Prăvălie & Costache, 2014).

This study aims, through the use of GIS techniques, to identify the areas with water erosion potential in the Slănic river basin, considering several environmental factors with a key role in the occurrence of land erosion process.

2. Study area

The hydrographical basin of Slănic River is located in the central south-eastern part of Romania and it is a major tributary of the Buzău River (Fig. 1). The surface of the basin is almost 427.4 km^2. The position of the river basin in an area of friable rocks, predominantly represented by clays and marls, and of large deforested areas, makes it vulnerable to geomorphological processes like surface erosion (Grecu et al., 2007).

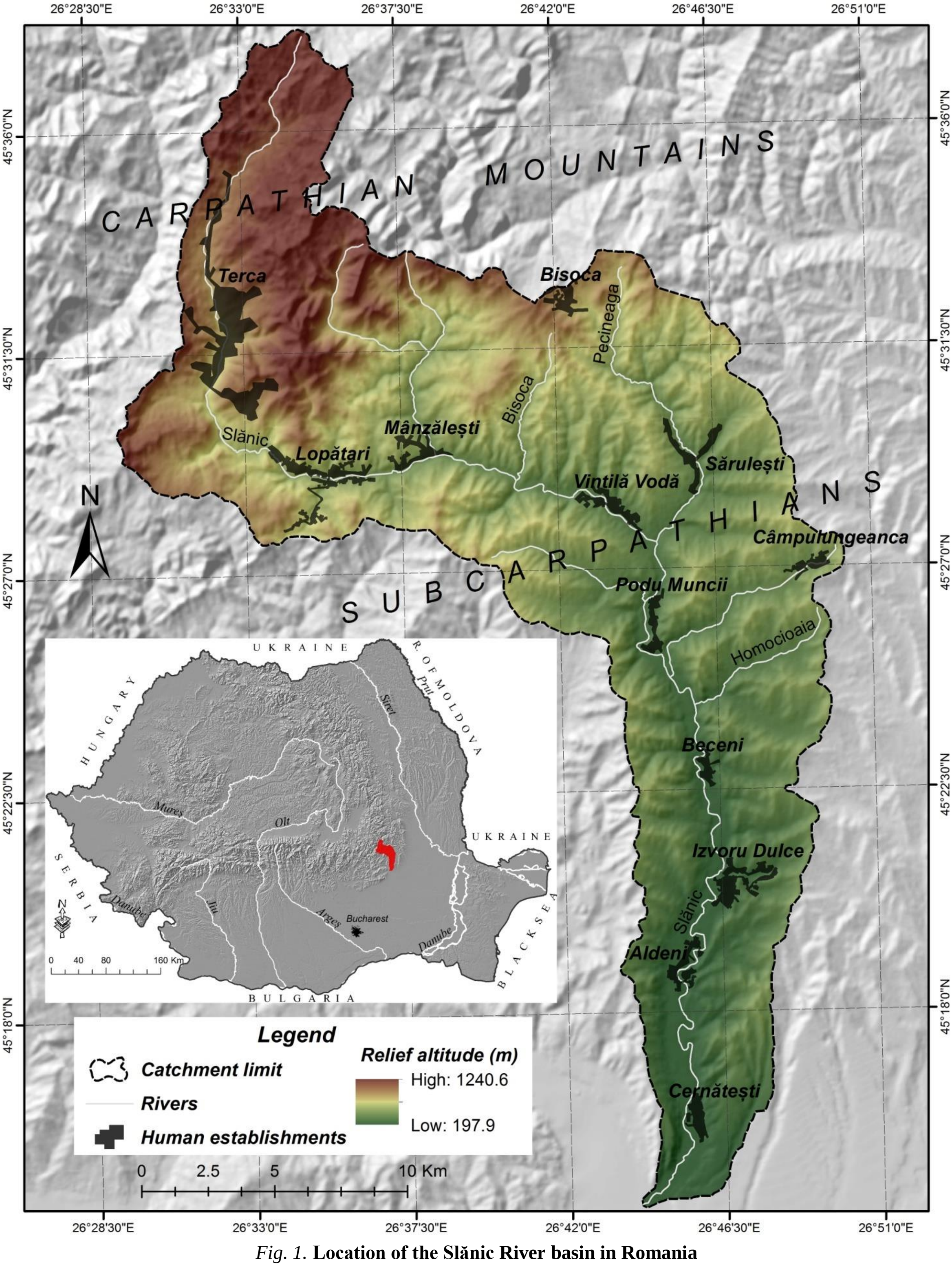

Fig. 1. **Location of the Slănic River basin in Romania**

The degree of afforestation in the Slănic River basin is of almost 40% and the forest covers almost 170 km² of the study area. The northern part of the river basin has a higher degree of forest coverage, therefore erosion processes are less aggressive. Besides the low forest coverage on many areas of the river basin and the friable substrate, slopes that exceed 15°, found in almost 28% (116 km²) of the study area, represent another important factor that increases erosion processes. At the same time, the high convexity of the slopes (in vertical and horizontal profile), as well as the hydrographic particularities (like the high density of the hydrographical network and the high convergence of torrential systems), ensure the conditions of surface runoff, with direct consequences on land erodibility. Also, the absence or the inefficiency of the anti-erosion management in Slănic River basin, can favor the increase of land erosion processes on large surfaces in this catchment river.

3. Data and methods

In order to highlight the areas prone to land erosion in the Slănic River basin, the *Land Erosion Potential Index* (LEPI) was calculated and spatially modeled. The proposed index was obtained by integrating, in GIS environment, eight geographical factors (figures 2 and 3) that influence water erosion. Therefore, the morphometric factors, i.e. slope angle, plan curvature, profile curvature, L-S factor, Stream Power Index and slope aspect, were obtained in raster format, with a 20 m cell size, from the digital elevation model.

The numerical model of altitudes for the Slănic River basin was obtained by interpolating the contours digitized from the Topographic Map of Romania, at a 1: 25.000 scale (DTM, 1981). The other two factors, lithology and the distribution of the average multiannual runoff depth were firstly obtained in vector format, and subsequently converted into raster format at a 20 m cell size.

These factors were selected in the context of their importance in land erodibility. The slope is an important morphodynamic factor that highlights the gravitational development of water flow (Bilașco et al., 2009; Grecu, 2009; Minea & Zaharia, 2011; Fontanine & Costache, 2013). Thereby, the higher the slope values, the more aggressive is the water erosion.

Another factor, largely used in studies regarding the potential to water erosion, is the L-S factor (Weaver, 1991; Moore et al., 1993; Hickey, 2000; Arghiuş & Arghiuş, 2012; Cherni & Samaali, 2012), which is defined as the ratio between the slope angle and the slope length (Moore et al., 1993). The calculation of L-S factor is based on the formula elaborated by Moore et al. (1993): $LS = ((m+1)*(As/22.13)^m)*(\sin\beta/0.0896)^n$,

where As=contributing area, m=0.4 and n=1.3.

The plan curvature represents the change in slope values on a parallel direction to the contours (Blaga, 2012). The positive values show a divergent water flow (with decelerated water flow) and the negative values show a convergent flow (accelerated water flow – high potential to land erosion).

The profile curvature represents the changes in slope values in a vertical plan (Smith et al., 2012) and differentiates the convex surfaces (negative values), with accelerated water flow, from the concave surfaces (positive values), with decelerated water flow.

The slopes aspect is another morphometric factor that influences surface runoff (Costache & Prăvălie, 2013) and, consequently, the process of water land erosion. On sunny slopes, water infiltration is increased by the low degree of water saturation of the soil, whereas on shaded slopes surface runoff is accelerated due to constant humidity.

The Stream Power Index is used to describe the transport capacity of torrential valleys. The index is the multiplication between the contributing area (As) and the slope (p) and is computed by the following formula: $SPI=As* \tan p$ (Constantinescu, 2006). With this index, sectors along torrential valleys, where intense erosion processes occur (high values) or where sediments accumulate (low values), can be identified.

The spatial distribution of the rock types another important factor in assessing the potential to erosion (due to rocks friability), was obtained by digitizing the lithological formations from the Geological Map of Romania, at a scale of 1: 200.000 (IGR, 1968). The classification of lithology, in terms of rocks hardness, was done after Bomboe & Mărunțeanu (1986).

The assessment of the distribution of the average multiannual runoff depth in Slănic river basin (a complex factor which accelerate water erosion in case of high runoff depth) was possible due to the mathematical model SCS-CN (CN = Curve Number), developed by the USDA Natural Resources Conservation Service. This method is based on the formula: $Q = P - Is - I - E - n$ (Bilaşco, 2008), where: Q – volume, P – precipitation, Is – capacity of water infiltration, I – interception, E – evapotranspiration, n – other retentions of rainfall.

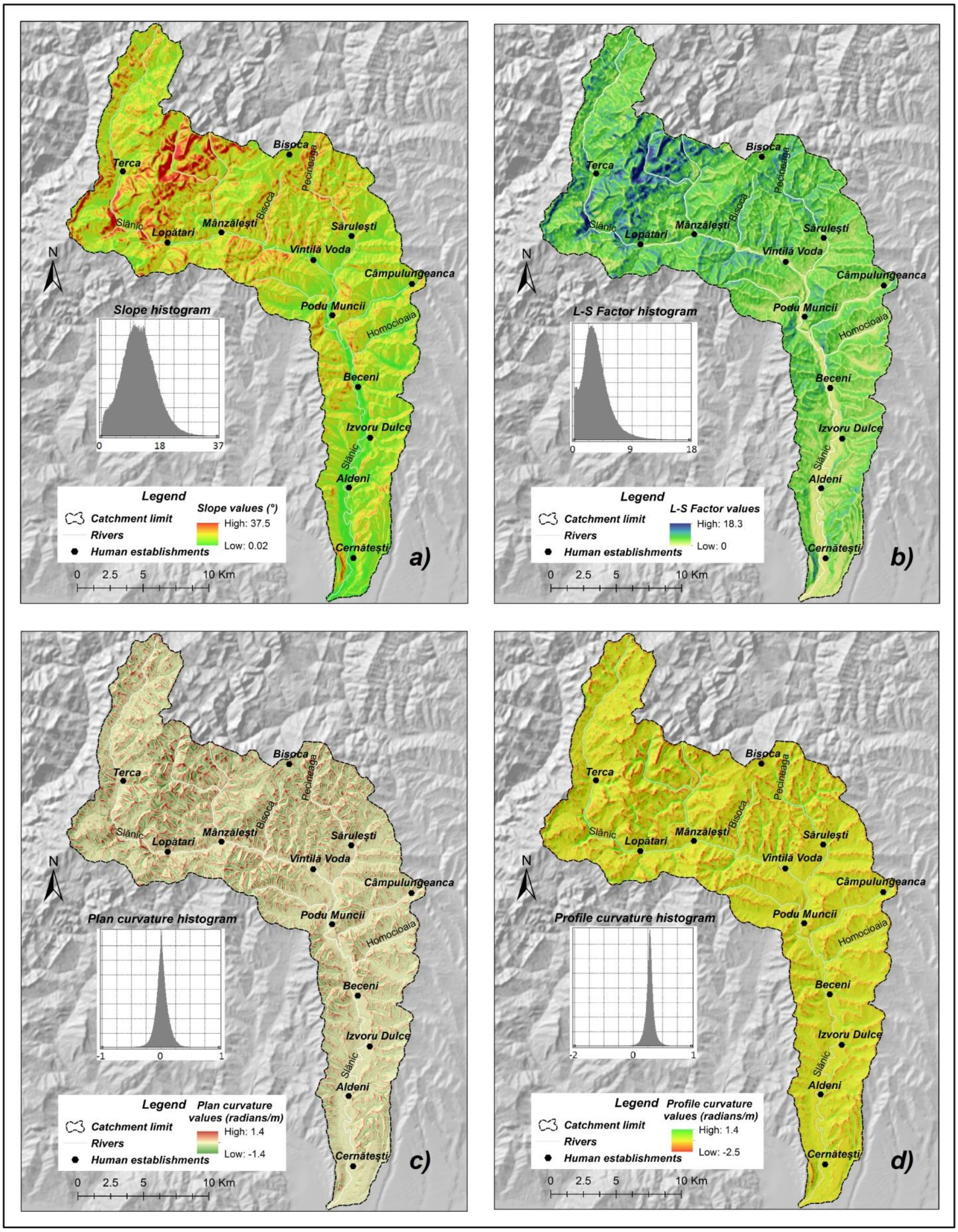

Fig. 2. **The spatial distribution of slope angle (a), L-S Factor (b), plan curvature (c) and profile curvature (d) in the Slănic River basin**

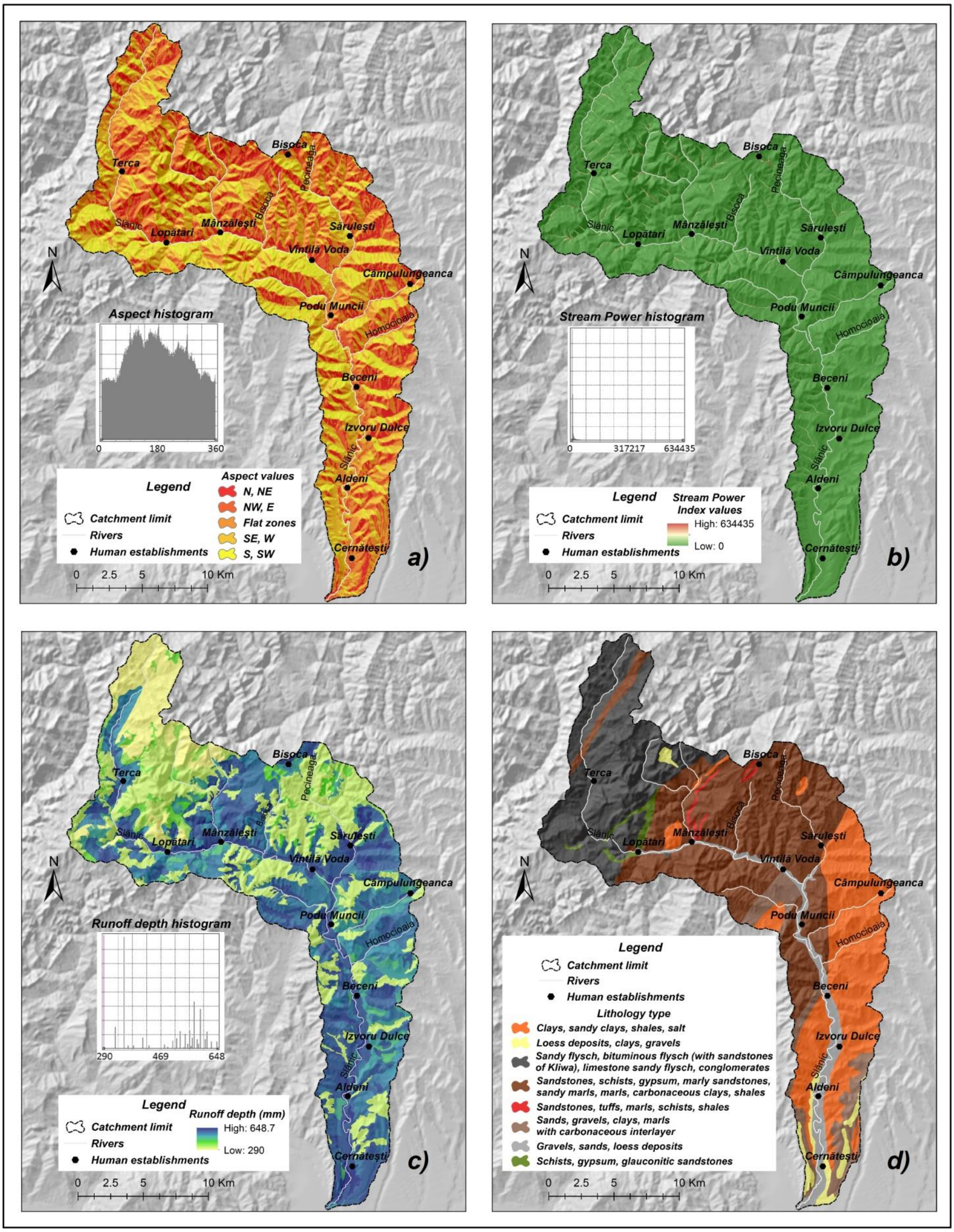

Fig. 3. **The spatial distribution of slope aspect (a), the Stream Power Index (b), runoff depth (c) and rock types (d) in the Slănic River basin**

The CN method is based on the conventional representation of the maximum potential of water retention during rainfall (Bilaşco, 2008), depending on the type of land cover and the hydrological group of soil. Mathematically, the estimation of water flow is based on the following equation: $Q = (P – 0.2*S)^2$

/ (P + 0.8*S) (Ponce & Hawkins, 1996), where Q – water flow (mm), P – precipitation (mm), S (mm) – potential of water retention (computed in accordance with the curve number of a surface depending on the type of land use and hydrological group of soil: CN = 1000 / (10 + S)). In a GIS environment, the computation of the mean multiannual runoff depth was performed with the Curve Number method, by using the ArcCN – Runoff extension (Zhan & Huang, 2004). Thereby, three datasets were inserted in the extension, respectively land use /cover (CLC, 2006), soil types (ICPA, 1976), in terms of the hydrological group (Domnița, 2012) and average value of multiannual precipitation (obtained by interpolation methods) in the river basin (Clima României, 2008).

In order to obtain the *Land Erosion Potential Index*, the classes of the eight factors were given scores, on a scale from 1 to 5. The score 1 corresponds to characteristics that strongly decrease the water erosion potential and the score 5 corresponds to characteristics that strongly increase water erosion potential (Table 1). As the stated factors have different importance regarding their influence on water land erosion process, they were weighted (Table 1) by using the Weight module of Idrisi Selva (Behera et al., 2012).

The values of the resulting index were grouped in five classes. The *Natural Breaks* method was used in ArcGIS 10.1, which is a standard method for grouping a dataset in a homogenous number of classes (North, 2009).

Table 1. **Classification and scoring of geographical factors necessary to compute *Land Erosion Potential Index***

Parameters	**Type/values**				
Slope (˚) - 15%	0 - 3	3.1 - 7	7.1 - 15	15.1 - 25	> 25
L-S Factor - 11%	0 - 2	2.1 - 4	4.1 - 6	6.1 - 8	> 8
Plan curvature (radians/m) - 11%	-	-	0.9 – 1.69	0 – 0.9	-1.4 - 0
Profile curvature (radians/m) - 13%	-	-	0,91 - 1,61	0 - 0,9	(-2.9) - 0
Aspect - 5%	S, SE	V, SE	Flat zones	E, N V	N, NE
Stream Power Index - 10%	0 - 5000	5001 - 10000	10001 - 20000	20001 - 50000	> 50000
Runoff depth (mm) -25%	290 – 368	368.1 – 433	433.1 – 529	529.1 – 586	586.1 – 648
Lithology type - 10%	Sandstones, schists	Gypsum, flysch, tuffs, bituminous flysch (with sandstones of Kliwa, glauconitic sandstones	Marls, clays, marly sandstones, conglomerates, shales, salt, sandy flysch, limestone sandy flysch, carbonaceous clays, marls with carbonaceous interlayer	Sandy marls, sandy clays, sands, gravel	Leoss deposits, gravel, sands
Score given	1	2	3	4	5
***Land Erosion Potential Index* (class values)**	**Very low** 15.8 – 24.3	**Low** 24.31 – 28.6	**Medium** 28.61 – 33.9	**High** 33.91 – 38.5	**Very high** 38.51 – 47.4

4. Results

By applying the described methodology, the *Land Erosion Potential Index* (LEPI) was proposed, calculated and spatially modeled, with values between 15.8 and 47.4, divided in five classes (Fig. 4).

The resulting first two classes of values correspond to surfaces with very low and low potential for land erosion.

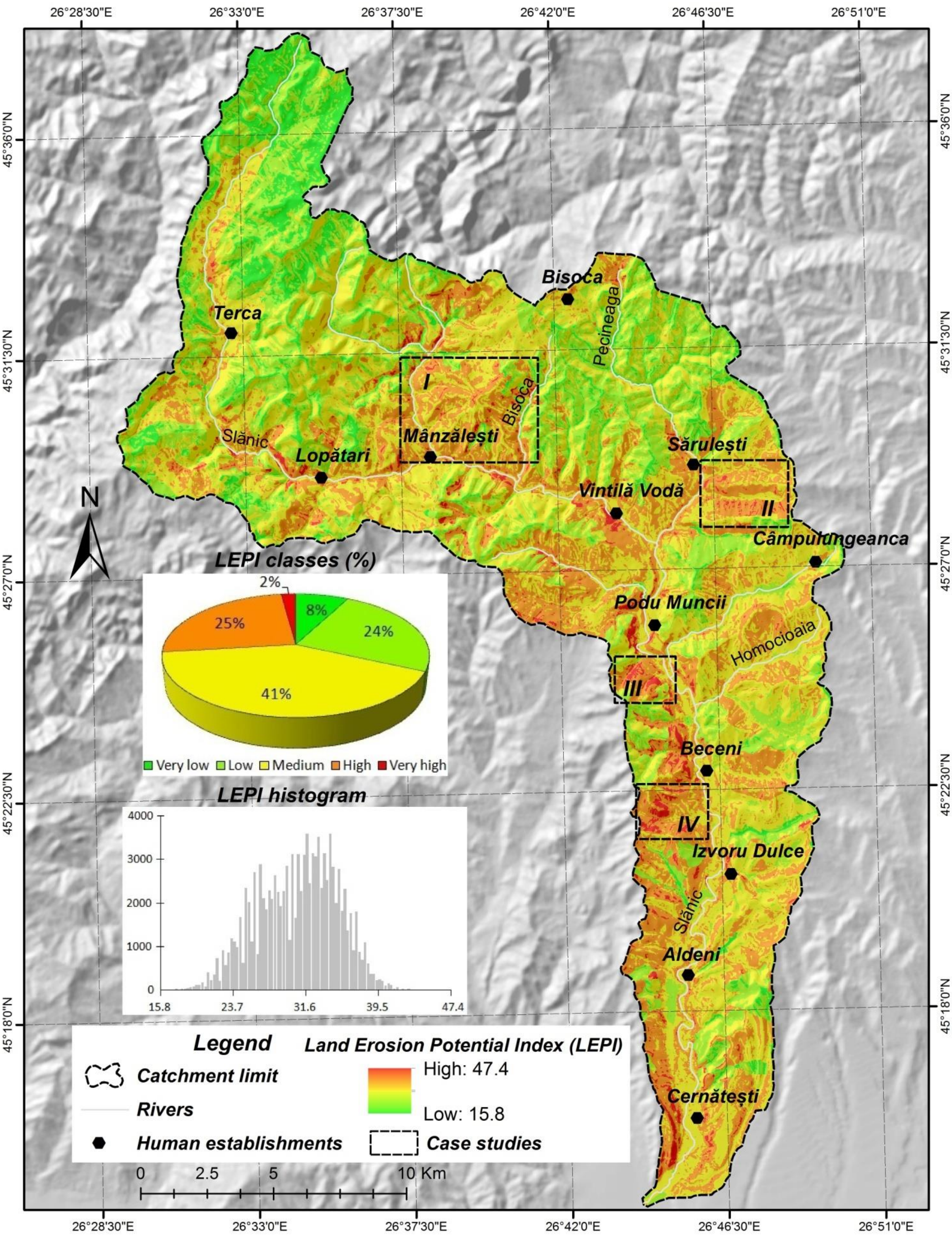

Fig. 4. **Spatial distribution of *Land Erosion Potential Index* in the Slănic River basin**

The cells with values between 15.8 and 28.6 overlap the areas with low slope values, generally under 7º, where the potential of water flow is low due to forest vegetation and cohesive rocks with high resistance to the erosive effect of gravitational water flow. Regionally, these values occur especially in the northern part of the river basin, in the Carpathians' area, but also in the northern half part of Pecineaga sub-basin, near Bisoca locality. On the entire study area, very low and low values of the LEPI occur on almost 32% of the total area of Slănic river basin.

The medium values of the LEPI range between 28.6 and 33.9 and are found on almost 41% of the study area. These values have a uniform distribution and a tendency of concentration in the southern half of the study area, on the left side of the main river. The appearance of moderate values of the potential for land erosion is favored by the combination of several factors, like slope with values between 7º – 15º, agricultural lands and rocks with medium hardness.

High values, between 33.9 and 38.5 are found on almost 25% of the Slănic River basin. These areas occur generally on the surfaces with north-western and eastern exposure, with slope angles of 15 – 25º, a low density of forest vegetation and friable lithological formations, such as clays, marls or loess deposits. Also, these areas are characterized by a high convergence of torrential systems.

The synergic context of these factors favors the flow of a higher volume of water, in an accelerated manner, so that low cohesive soil fragments would be intensively eroded. In the Slănic River basin, the high values of the LEPI occur generally to the south of the confluence between the Pecineaga River and the main river in the study area, on its right side.

The values in the 5th class of LEPI indicate the areas with very high potential for land erosion (critical areas). These values are between 38.5 and 47.4. The areas with very high potential for land erosion have a scattered distribution in the study area. Such values, exceeding 38.5, are found on the right side of the Slănic River, near Beceni locality.

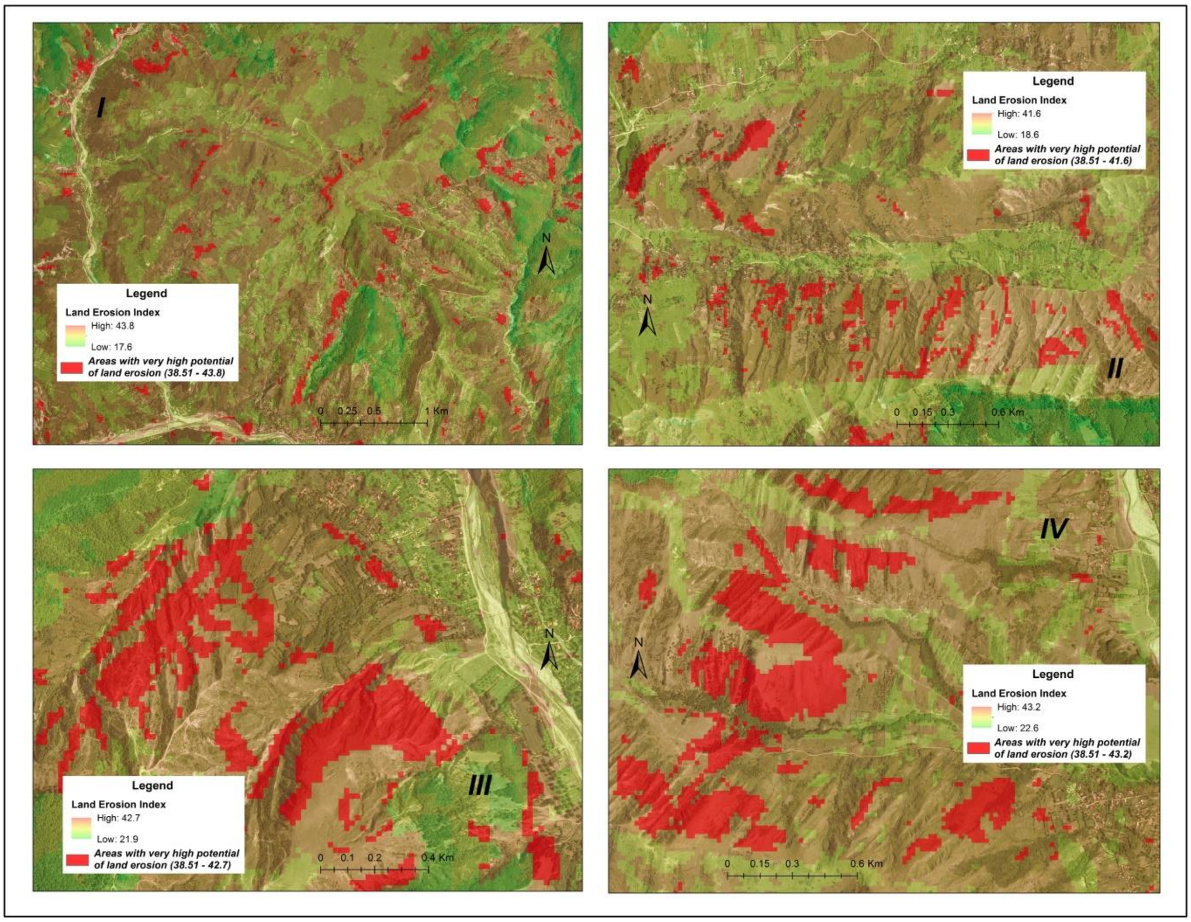

Fig. 5. **Spatial relation between critical values of the LEPI (> 38.5) and geographical particularities highlighted by orthophotomaps, 2008 edition (ANCPI, 2008)**

Another sector on the right side of the main river with a very high potential for land erosion is a 3 km long strip, between Săpoca and Cernăteşti localities. In the study area, the surfaces with very high potential for land erosion cover approximately 2% from the total.

In order to validate the results, a spatial relation between the values of the LEPI and the reality on the field was tested (empirical assessment). As the field surveys did not cover all the study area, the analysis of the relationship between the results obtained using GIS techniques and the actual terrain situation was performed with the aid of orthophotomaps at a scale of 1:5000, 2008 edition (ANCPI, 2008). Four case studies were chosen (Fig. 4), focused especially on the maximum values of the LEPI (class > 38.5). Also, the case studies were selected in such a way that they cover the study area relatively uniformly (Fig. 4).

The results proved that in these case studies there is a correspondence between the maximum values of the LEPI (the 5th class of values) and the geographical particularities of the terrain, typical for intense erosion processes (Fig. 5). According to all the four case studies, the areas with high potential of water erosion occur generally on steep slopes, lacking vegetation, with a high convexity (vertical and horizontal) or torrential convergence, also with predominantly friable substrate (Fig. 5). All these characteristics, to which the lack of anti-erosion management could be added, highly increase the risk of occurrence of other erosion-associated phenomena (flash-floods genesis, landslides).

5. Conclusions

Following the water erosion potential assessment, it was found that the Slănic catchment generally has a high susceptibility to this process, especially in the central-southern area. This is due to a series of geographic factors, of which the most important are the low vegetation cover and steep slopes of certain areas.

The analysis of the proposed index, Land Erosion Potential Index, revealed that critical areas, corresponding to the index class with very high erosion potential (with values exceeding the 38.5 threshold in the 15.8-47.8 interval) cover approximately 2% of the total catchment area (about 8.5 km²).

These areas are the most important, as they can provide the fundamental support for further analysis on erosion risk, in order to assess vulnerable anthropic elements.

It should be noted that the study does have certain shortcomings. They can be related to input data calibration – e.g. lithology and soil data are available at a less detailed scale (1:200.000) than the other data sets. Another issue can be related to the fact that the study does not address more complex analyses, such as mathematical models (e.g. analyses based on the Universal Soil Loss Equation), which allow a quantitative erosion assessment.

However, the proposed methodology can provide satisfactory results, based on which areas with high potential of water erosion can be identified in the Slănic catchment area.

This analysis can therefore be useful primarily for locally-based policy makers who, should they choose not to enforce the appropriate measures to overcome this hydrogeomorphological risk phenomenon, will experience severe medium and long-term consequences, both ecologically (especially soil degradation / soil loss) and socio-economically (agricultural land productivity decrease).

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