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THE USE OF A GEOGRAPHIC INFORMATIONAL SYSTEM IN THE ANALYSIS OF SOIL COVER DIVERSITY

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Abstract: The soil science applications of GIS have greatly developed during the last decades, the digital soil mapping and soil properties estimations being probably the most important of them. Our study attempts to characterize some properties related to soil diversity and variability using some shape indices and to correlate the geometrical features of areas with different soil units with the soil forming factors.

Key words: *soil cover diversity, heterogeneity, GIS database.*

Introduction

The spatial and temporal variability of the natural environment is an inevitable feature. Each environmental element is characterized by its own variability, and at the same time each element affects other landscape components. Lately a special attention has been given to environmental variations as a phenomenon that includes processes that lead to the occurrence of certain landscape conditions. One of the environmental variability types is that of the soil units. Variability and thus diversity are related to the spatial and temporal variations of the soil forming factors and of the human activities. To better understand the temporal and spatial variation of soil properties, we should determine the causes that induce variability (Usowicz and Usowicz, 2004).

The studies regarding soil cover diversity have begun in the 90s, introduced by Ibáñez et al. Later, different soil scientists have conducted interesting studies, bringing their contribution to the theory, methodology and applications in the field. At the same time have been conducted studies at different scales for the analysis of the spatial patterns of the soil cover, the most recent approaching mathematical structures of soil classification systems. At the same time, as some authors affirm, there is no a priori reason to admit that a diversity analysis would be better than other. Departing from the studies of Friedland (1972) and Florea (2003), we consider that the analysis of the soil cover diversity may be conducted and through its spatial variability and the arrangement of the soil units. The present definition of pedodiversity is extended to include the geometric aspects that characterize the soil cover.

The complexity of the soil cover distribution may be expressed by the degree of uniformity or partition of the soil cover (Florea, 1994). The earth surface is made up of differently combined soil segments, determined by the petrography, structure and landforms from the respective territory. The different spatial arrangements of soil groups from a territory aren't isolated or randomly distributed, but are interconnected through different relations with the geographic position, genesis or evolution. Their combination in the territory makes up the soil cover, which reflects soil's spatial organization, strongly correlated with the climatic and landform elements.

For the systematization and classification of the soil cover, Florea proposes as criteria the presentation scale, the nature and proportion of the main components, the nature of the dominant and accessories soil groups combined according to the characteristics that determine the differentiation of the soil cover, the internal organization of the soil cover, the character of exchanges with the environment, the spatial distribution of the main components, the complexity, contrast and heterogeneity of the soil cover, the genetic relations and contrast between the neighboring soil units. From this viewpoint, our study is based on the internal organization of the soil cover and the spatial distribution of the units that make it.

A soil map (graphic representation of soil distribution as natural entities and implicitly of the main properties) presents mainly the soils' nature, variety and geographic repartition; this aspect being most easily visible in the analysis and examination of a soil map. At a closer look, the map will present and other important properties reflected in the spatial arrangement (dimensions, form, distribution and orientation of the soil areas) and relations between soil polygons. This aspect, which refers to the soil cover on the overall, is important because it brings valuable information regarding the complexity and heterogeneity of the respective region.

Florea introduced (1983) and later (1989, 2000) developed the notion of soil cover ensemble, as an expression of the spatial organization of soil systems. In the world have been studied different aspects of the soil cover as landscape or terrain unit, types of soil spatial organization, soil regions and their delineation according to different criteria. The concept of soil cover ensemble is based on the concept of soil cover structure, and refers to the spatial distribution of the soil cover, represented by the soil territorial associations that form superior units strongly correlated with the environmental factors.

Florea had in mind the type of juxtapositions between the soil areas as constitutive elements, independently of dimensions, degree of development or hierarchical level, as well as the way in which soilscapes are organized, taking into account the nature, frequency, dimension, form, orientation of the component areas, that in fact determine the distribution type. This ensemble evidently makes up the result of the combined action in time and space of the natural factors, as well as of the soil forming processes. It mustn't be regarded as a simple juxtaposition of the soil units, but as an organic association, an organized configuration with a specific structure, different from region to region. The whole ensemble does not remain static, but modifies itself in time and space, in connection to the modification of the environmental conditions.

This concept assures a more adequate understanding of the soil as component part of the landscape, and offers a different image on the real functionality of the soil cover, from local to regional level. Thus, our analysis departs from revealing the simplest aspects of this ensemble – the distribution and forms of its constituent units.

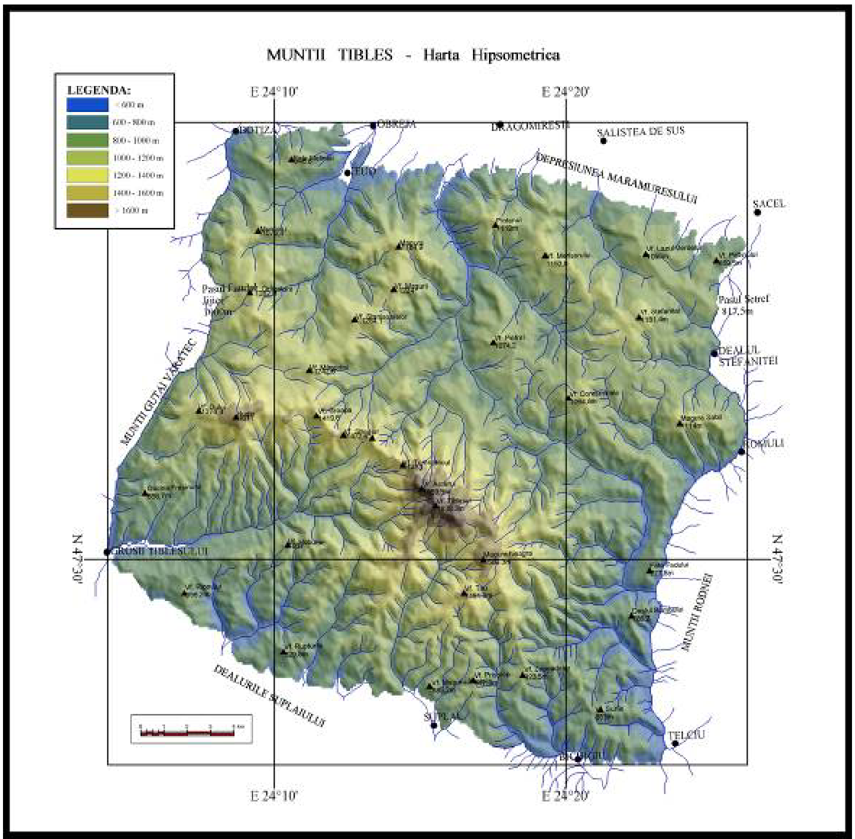
Materials and methods

The materials used in this paper is made up of the statistic database resulted from the digital mapping of the soil cover from the northern part of the Eastern Carpathians volcanic chain, that represents the synthesis of the field surveys conducted between 1994-1998 and 2004-2005. For the mountains in this area have been drawn soil maps, departing from the topographic maps (scale 1:50000, projection Gauss-Kruger, 1967-1984). The new materials have been created with the help of the TNTmips 6.9 software.

At the present moment the analyses of soil cover diversity imply a multitude of mathematical tools, from statistical distributions to fractals and multifractals. We have chosen to analyze the units' (polygons) form from the digital soil maps. Thus were used the data from the polygons' attribute tables, as well as the standard and fuzzy attributes automatically computed by the software. For the construction of the repartition histograms of the values of the different indices, the number of classes has been determined with the help of the Sturges formula: $K = 1 + \log_2(N)$.

In relation to the quantification of the soil cover from the viewpoint of its form, Florea separated the main characteristics of the basic elements of the mapped soil cover, these being the dimension, form and content.

The dimension of a soil area (polygon) is expressed by the average, minimum and maximum surface of the area, the variation coefficient of the surface and the surface distribution curve.



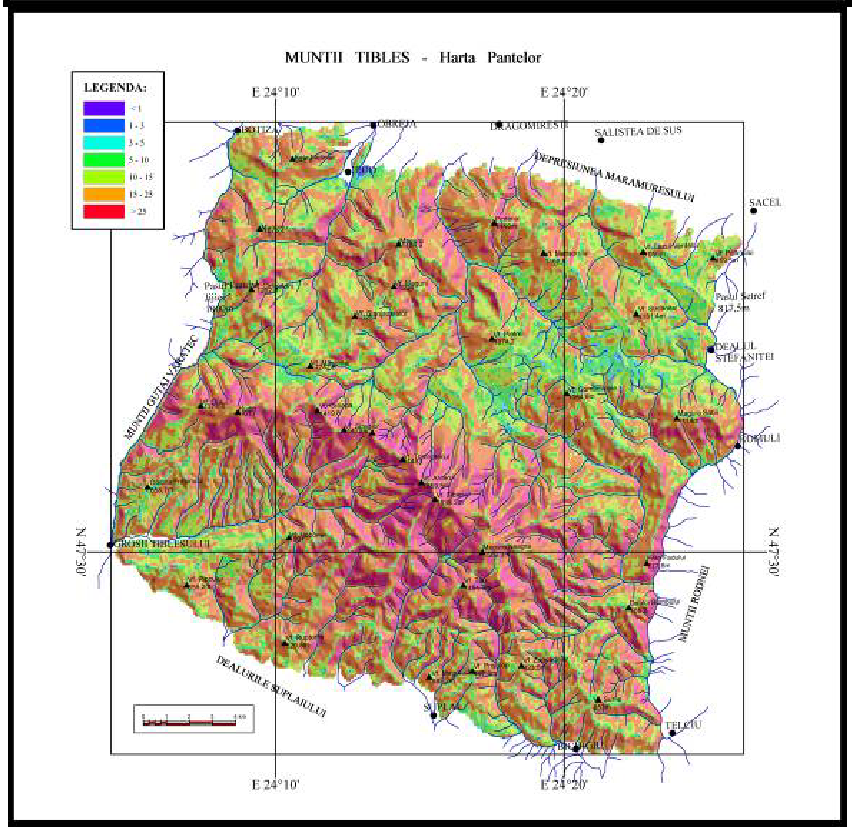


Figure 1. *The hypsometric and slope maps (Țibleş mountains)*

The average surface S_m is given by the relation $S_m = \frac{\sum_{i-1}^{n} S_i}{n}$, where *S* is the surface of each polygon, and *n* the number of polygons. The values of the average surfaces vary according to the nature of the component elements and the conditions of the soil forming factors that determine the diversification of the soil cover.

The variation coefficient is established with the formula $CV = \frac{\sum_{i=1}^{n} |S_i - S_m|}{nS_m}$, and presents the degree of similarity between the polygons from the region.

The **form** of the different polygons is an important characteristic that may be defined according to Friedland (1972) and Florea through different sinuosity, elongation, circularity indices. Our study regarded the calculation of such indices. From this viewpoint, TNTMips allows the automatic obtaining of some standard and fuzzy properties, process through which is created a database that includes statistical values for the form ratio, form index, compactness, elongation ratio, circularity ratio, normalized dispersion, perimeter development, correlation, orientation, elongation, values derived from the analysis of the vector object that represents soil polygons. These properties reflect form properties of the polygons from the vector object. A form is difficult, if not impossible to measure or precisely and mathematically define, and it is also impossible to construct a unique measure of a certain form. The formulas used are useful if we wish to locate all objects of similar form from a vector, to define characteristics values of some form measurements associated to a known form, and then to look for elements with similar forms through comparison. These form measurements may be used in the same manner as any other descriptor, and thus in the characterization of the soil units. Other advantages of the calculation program are the possibility to calculate statistics, to include measurements and variations for a group of polygon-type elements. Each of these properties is calculated through the evaluation of a polygon element using an equation based on its properties.

Grain Shape index may be used to measure any form, having values of 2 for the form of elongated polygons, π for circles, 4 for rectangular shapes, and it may take very high values for fractals. The equation for the calculation of this property is in fact the ratio between the polygon perimeter and its large axis.

Compactness may be used for shape calculations, the maximum value of 1 estimating a circle shape. The calculus equation is: $\frac{2\sqrt{\pi A}}{P}$, where *P* is the perimeter.

The elongation ratio may be used for measuring shapes of thinned polygons, the equation being $\frac{4\pi A}{P^2}$.

Circularity is a property that reflects the similarity between an element and a circle, the maximum value of 1 denoting this shape. TNTMips calculates two such indices, the formulas being $\sqrt{\frac{A}{(\pi MinR)^2}}$ and $\sqrt{\frac{MinR}{MaxR}}$, where *MaxR* is the length of the polygon's maximum radius measured from the border of the centroid, and *MinR* in the minimum radius length.

The normalized dispersion gives a value of 1 approximating circles. The equation for calculating this property is $\frac{\pi WR}{A} = \pi \frac{\sum (d^2 w)}{A}$, where WR is the sum of the squared distances between the centroid and vertex of each margin, that may also be expressed as sum of (d^2 * w), where d^2 is the square of the distances between the centroid and the vertex, and *w* the weight of each distance, equal to the distance to the previous vertex and divided to the polygon perimeter.

Simplicity may be used for measuring the simplicity of a shape, being useful in the separation of the polygons with the same form but with different number of vertexes in the perimeter: $\frac{SL^2}{A}$, where SL is the average distance between the vertexes of the polygon perimeter.

Perimeter development may be used for measuring polygon generalization, being useful in cartography in studying the relations between the measured distance and the map scale: $\frac{P}{2\sqrt{\pi A}}$.

Orientation measures polygon orientation, being determined by the relation arccos (Correlation), the correlation being the function presented above. *Elongation* measures the proportions of the polygons, being calculated by dividing the large axis to the small one. *Roughness* is a measure of the irregularity of a polygon perimeter, being calculated as the ratio between the large axis multiplied with the perimeter and the polygon area.

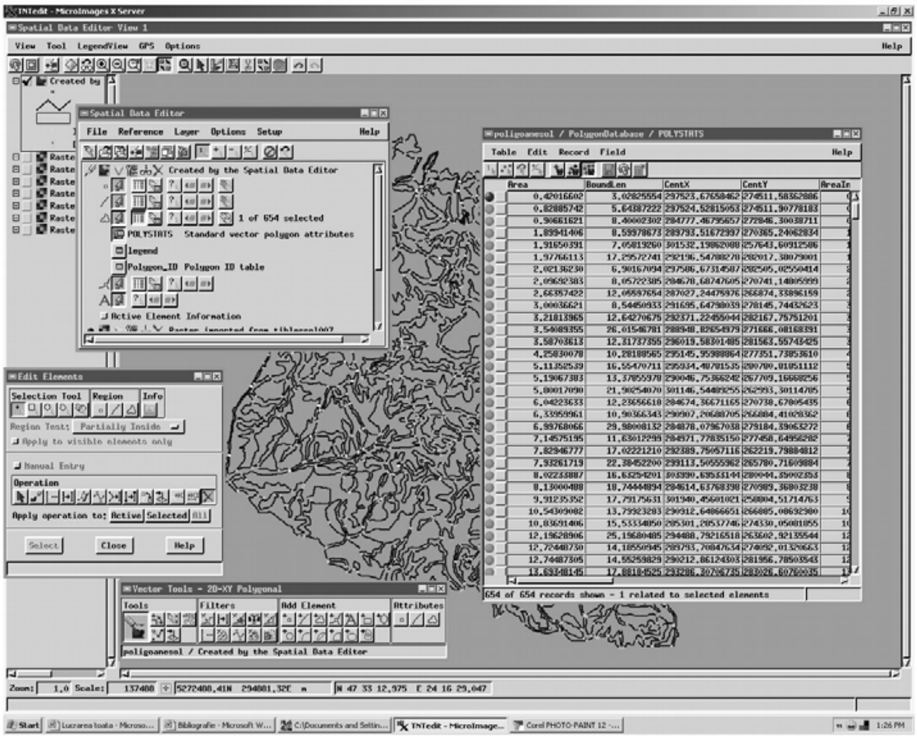


Figure 2. *The TNTMips window with the soil polygons and the standard attribute table*

Results

From the analyses of the used parameters, the first aspects were those related to the surface of the soil polygons. Although their dimensions vary between 0.00 and 26.42 km^2, the average dimension of a polygon is of 0.89 km^2, fact that denotes a high proportion of the small dimensioned polygons. The frequency histograms show that over 50% of the soil units are between 0 and 0.3 kmp, and the proportion of the polygons situated between 0.0 and 0.8 kmp is over 70%.

Although theoretically the polygons' areas and perimeters should be perfectly correlated, this situation does not happen, the determination coefficient between the two parameters being of only 0.75. The majority of the perimeter values are grouped between the minimums 0 and 7 km (the maximum in this case being of 96.78 km), yet not in the proportion that we would have expected. Also there is a noticeable difference between the r^2 of 0.833 for areas and that of

0.643 for perimeters. The explanation was searched in the variations of the polygons' shapes, being given by the indices and ratios that analyze circularity.

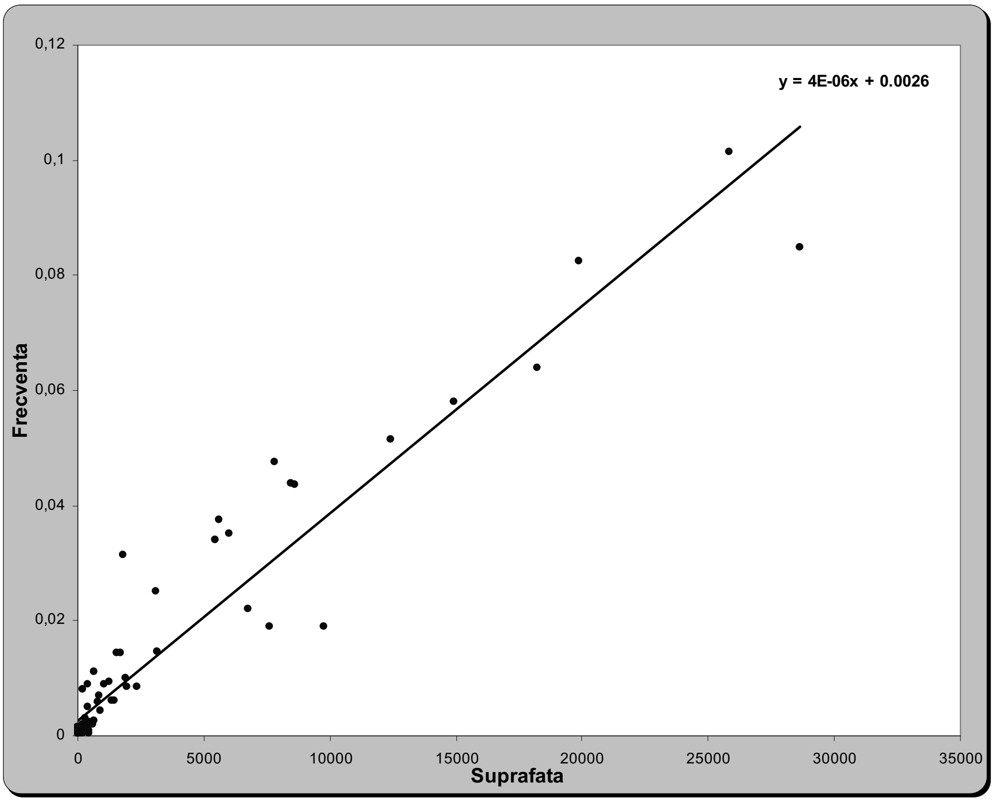


Fig. 3. *Correlation between polygon surface and frequency*

Table 1. *The parameters of the indicators taken into account*

	Sample number	**Minimum**	**Maximum**	**Average**	**Median**	**Interval**
Surface (km^2)	**2583**	0.00	26.42	0.89	0.44	0.33
Perimeter (km)		0.34	96.78	6.13	4.15	0.31
Shape		2.07	9.70	3.23	3.02	0.26
Compactity		0.12	0.98	0.57	0.56	0.05
Elongation		0.01	0.96	0.35	0.31	0.065
Circularity		0.13	0.90	0.47	0.46	0.057
Normalized dispersion		0.78	15.50	1.96	1.61	0.28
Simplicity		0.00	5.39	0.01	0.001	0.006
Perimeter development		1.01	7.83	1.92	1.76	0.26
Correlation		-0.99	0.98	0.007	0.001	0.2
Orientation		11.03	172.03	89.47	89.92	17.1
Elongation 2		0.12	0.99	0.68	0.69	0.1
Sturges formula: 12.33						

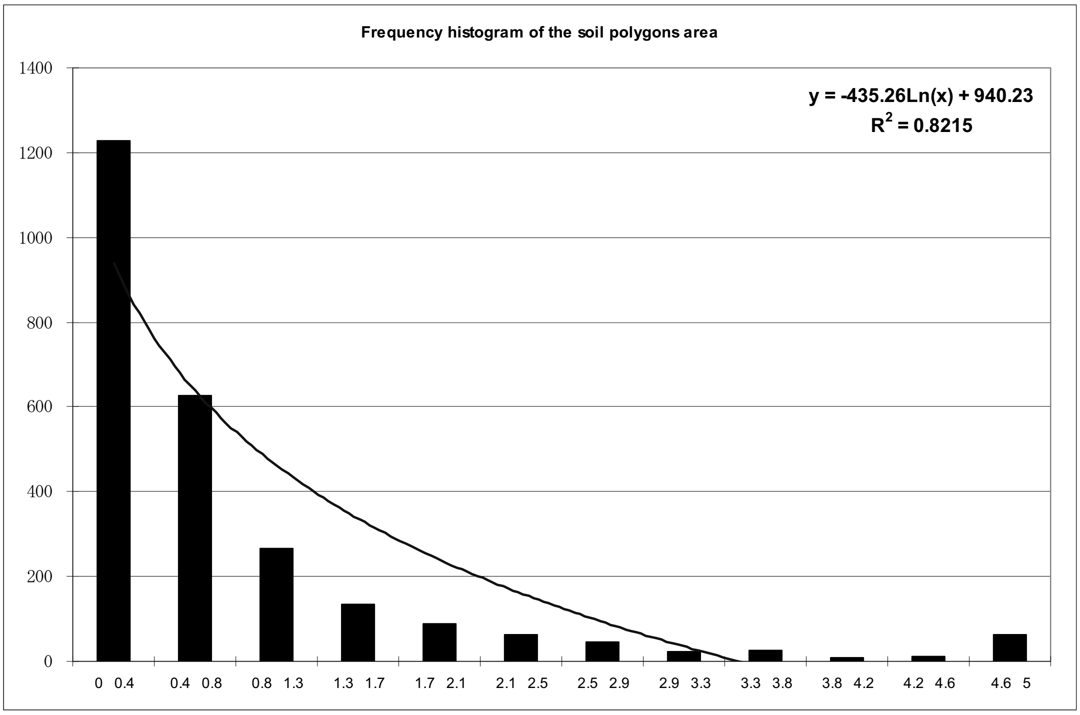


Figure 4. *Frequency of the soil polygons' surface*

A better correlation between area and perimeter would exist if the polygons would be closer to the shape of a circle, yet very few polygons are close to the value of 1, the absence of the correlation being partially explained. From the analysis of the Grain Shape values, we see that only about 13% of the polygons have a shape close to that of a circle. Most of the polygons depart from the circle shape, being elongated, and a third category is that of the polygons with shapes close to rectangles. An interesting aspect is that according to which a reduced proportion of the polygons are characterized by values close to those for fractals (fig. 7a), in general these areas being represented by mature soils (in our case skeleti-dystric and skeleti-eutric Cambisols). The repartition of the polygons' perimeter and area values confirms this aspect, evidencing soil units with extremely rugged perimeters.

The compactity values have a more equilibrated, Gaussian distribution and frequency. Still the values present the same aspect of polygons' shape difference from a circle, the maximum value being of 0.92. More, over 75% of the polygons have values of the index smaller than 0.70. From the analysis of the index's repartition map, we may observe the positioning of the areas with shapes closer to circles generally at the border of the mountainous area, where the lower declivities of the landscape offers relatively homogeneous soil forming conditions. Again the smaller areas of the index characterize the areas with mature soils.

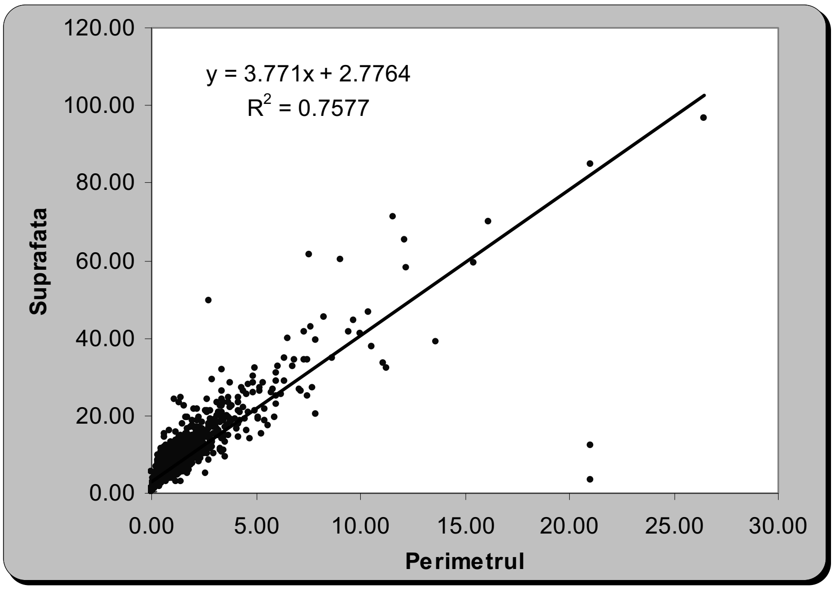


Figure 5. *Correlation between soil polygons' surface and perimeter*

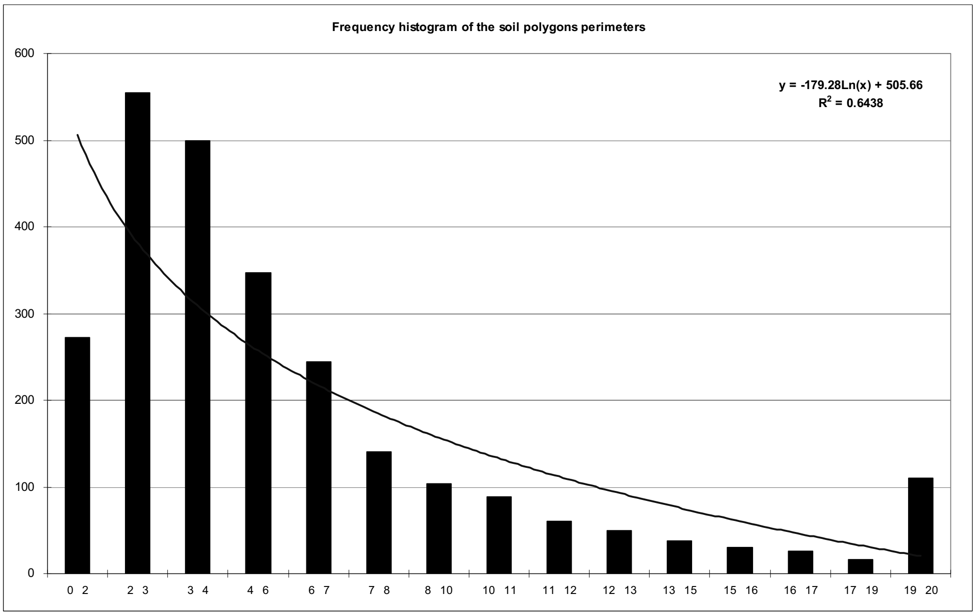


Figure 6. *Frequency histogram for the distances of the soil polygons' perimeters*

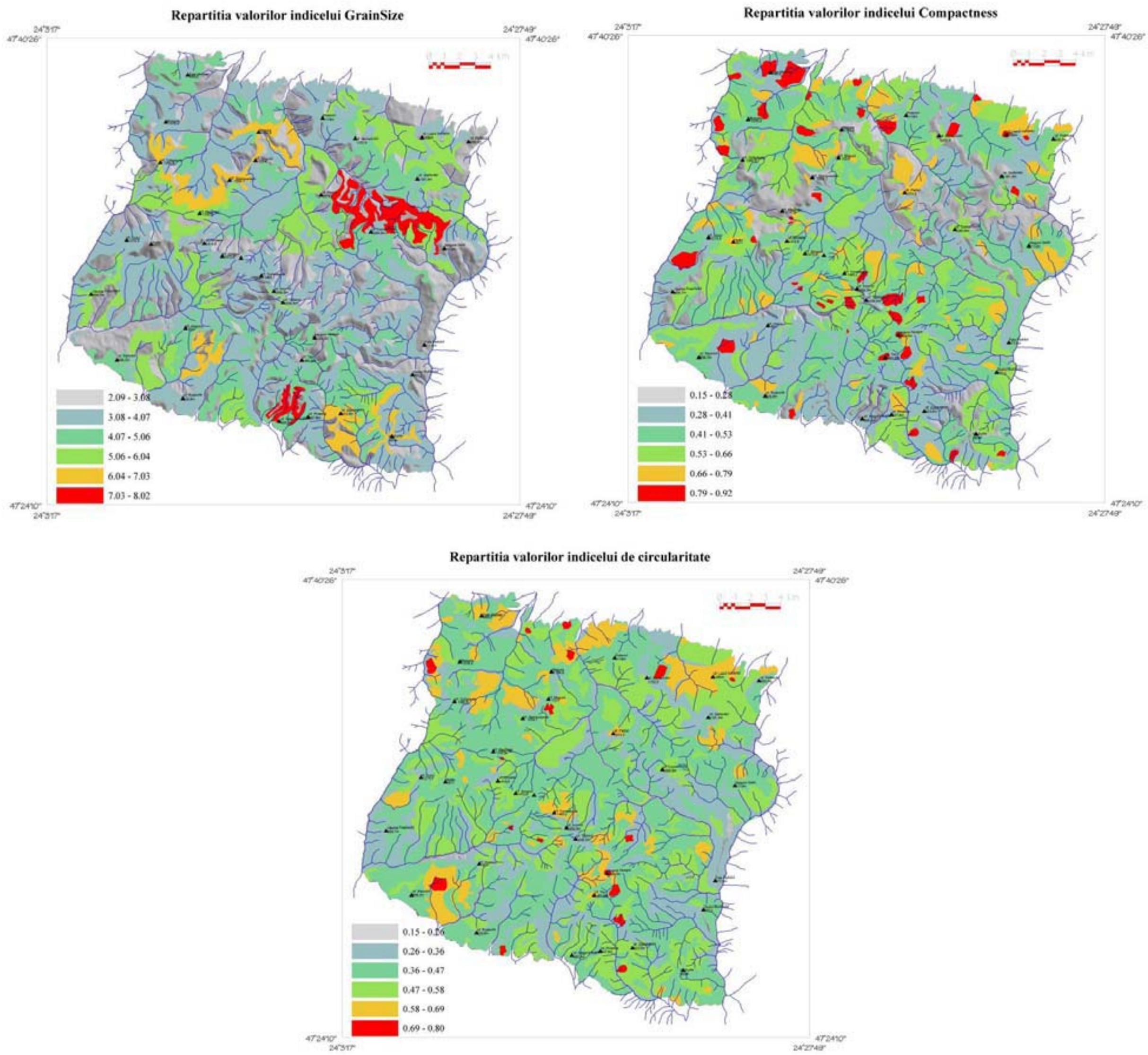


Figure 7. *Repartition of the Grain Shape, Compactness and Circularity indices' values*

The circularity index reflects even better this aspect, taking into consideration the fact that the proportion of the polygons close to the value of 1 is extremely small. In fact in the case of the Ţibleş mountains chosen as example in the cartographic representations, the values do not exceed 0.8. The repartition of the polygons with almost circular shape is the same as in the case of compactity, only that circularity reflects better the rounded polygons.

The normalized dispersion index presents the same results, the values between 0.8 and 1.1 being scarce. They have been analyzed with the help of the elongation ratio, whose values denote a quite large proportion of the elongated soil polygons. The inconsistency between area and perimeter is obvious and from the comparison between the maximum and average values. More, these aspects revealed by the application of different indices are confirmed and by the fact that the values obtained are poorly correlated, this aspect excluding the probability of similitude between the results.

Table 2. *Correlation coefficients between different area and shape indices*

	Surface	**Perimeter**	**Compactity ratio**	**Compactness**	**Elongation**	**Circularity**
Surface	1.00	0.37	0.14	0.01	0.01	0.02
Perimeter	0.37	1.00	0.78	0.01	0.01	0.04
Compactity ratio	0.14	0.78	1.00	0.03	0.03	0.05
Compactness	0.01	0.01	0.03	1.00	0.98	0.78
Elongation	0.01	0.01	0.03	0.98	1.00	0.79
Circularity	0.02	0.04	0.05	0.78	0.79	1.00

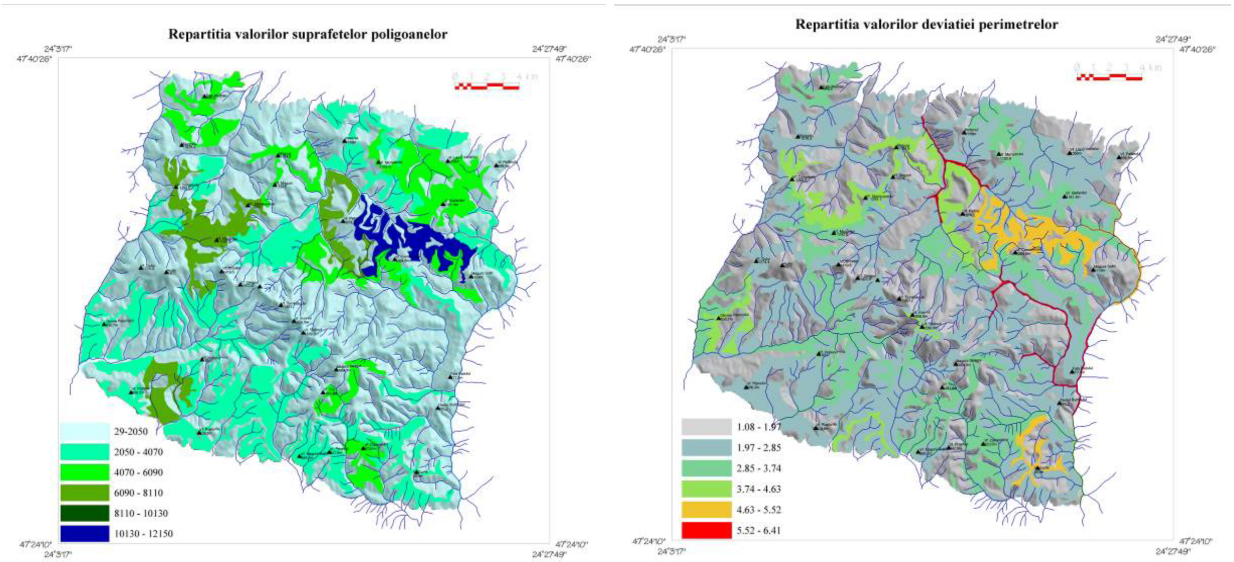


Figure 8. *The repartition of the values of polygon surfaces and perimeter deviation*

The geographic explanation of this situation is given by the fact that the soil polygons' perimeter is determined by the irregular shape of the relief contour lines, consequence of the altitudinal zoning and of the characteristics of the soil survey. Another geographic aspect revealed by the polygons' analysis is that of the repartition of their surfaces. The surfaces are "allocated" differently to different landforms; the polygons of large dimensions cover the margins of the mountainous region (with lower altitudes and low declivities), while in the area of the main summit the secondary peaks and the confluence sectors are occupied by small-dimensioned polygons (especially due to relief fragmentation). Regarding the positioning of the soil polygons in relation to the landforms, the perimeter deviation evidences clearly the differences induced by the river sectors, which have higher values of this parameter. In the same category enter again the polygons with mature soils, most probably due to the fact that being situated at the upper part of some slopes of average altitudes, their contour coincides with that of the contour lines.

Conclusions

In conclusion, the use of the shape indices may explain certain disparities in the repartition of the soil units, and may be used in the characterization of the soil cover ensemble from the viewpoint of its organization, variability and complexity. Correlated with the landscape characteristics, the geometric properties of the soil cover may reveal and certain genetic links between the soil units.

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