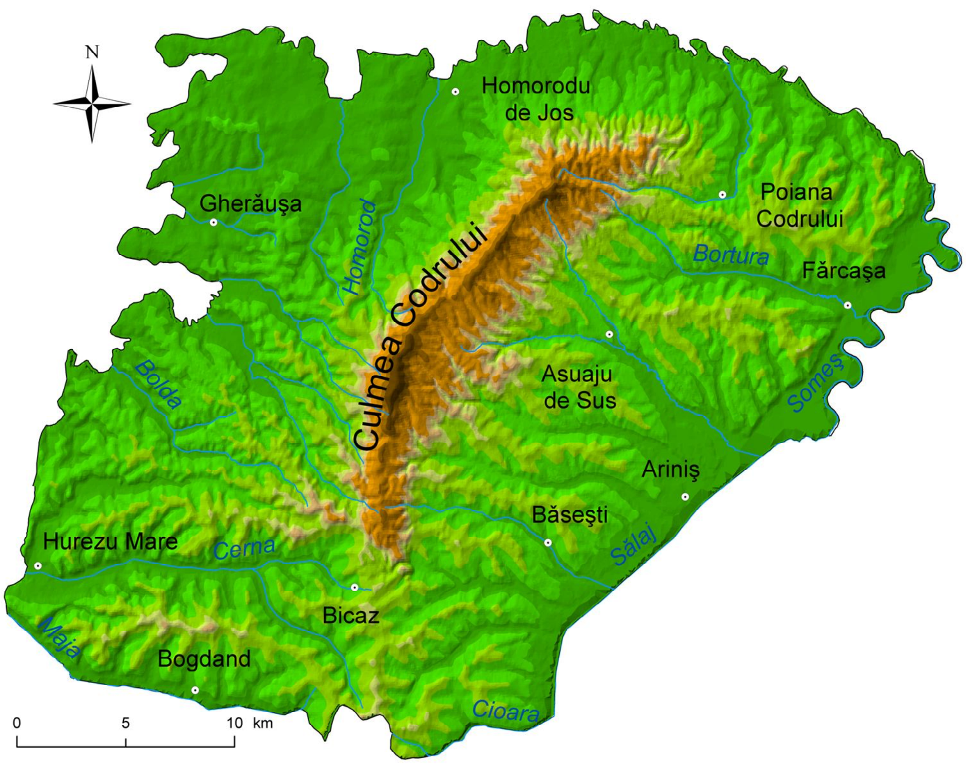
„BABEŞ-BOLYAI'' UNIVERSITY, CLUJ-NAPOCA
FACULTY OF GEOGRAPHY
DEPARTMENT OF PHYSICAL GEOGRAPHY

THE CODRULUI RIDGE AND PIEDMONT - GEOMORPHOLOGIC STUDY

PhD thesis

-summary-



Advisor,
Professor Virgil Surdeanu, Ph.D.

Ph.D. student,
Corina Arghiuş

Cluj- Napoca

2010

TABLE OF CONTENTS

Key- words: methodology, morphogenetic factors, morphometry, morphology, trends, susceptibility, USLE

1. Introduction

The present PhD thesis, ,,The Codrului Ridge and Piedmont- geomorphologic study" represents the research results performed during the period 2001-2009. *The aim* was to analyze present morphodynamics in order to forecast trends and future directions of development and to create a methodology of geomorphic investigation by integrating GIS techniques in obtaining and analyzing spatial data, providing a scientific model for geomorphologic issues.

In order to achieve the intended purpose, the following *specific objectives* were set:

⇒ to create a methodology of geomorphologic analysis (methods and techniques) according to current trends in the field;

⇒ to implement GIS analysis in the geomorphologic studies at local and regional level;

⇒ to highlight the morphological features at different hierarchical levels of slope- valley system (longitudinal profile, cross-section, river sector etc.);

⇒ to assess the interdependencies between control factors (interpreted as assumptions/ reasons), morphological/ morphometric features and contemporary modeling processes;

⇒ to identify the spatial-temporal dynamics of various parameters or geomorphologic processes using mathematical statistical procedures;

⇒ to reveal the river and slopes trends of evolution by quantification and geomorphologic reconstruction of past behavior;

⇒ to assess the hillslopes susceptibility to geomorphologic processes, such as landslides or gullying.

The research methodology aimed at a geomorphologic investigation on past (paleogeomorphologic evolution) - present (represented by morphogenetic factors and morphometric and morphologic features) -future axis (susceptibility to geomorphologic processes) (Fig. 1)

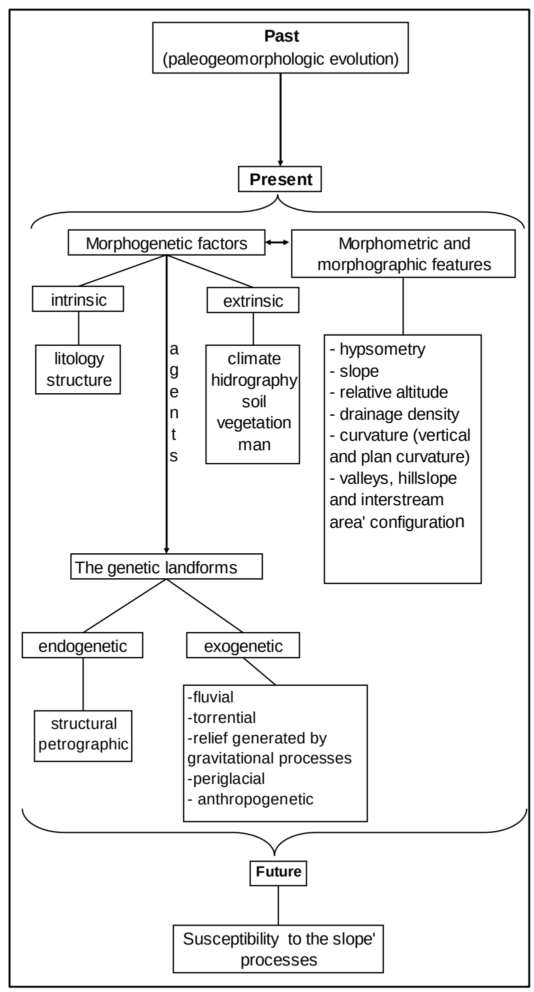


Fig.1. The general methodology of geomorphic investigation

2. The Codrului Ridge and Piedmont - geographical position, limits and spatial relationships with adjacent units

The area under geomorphologic investigation was individualized at the morphological and structural contact of the Codrului Ridge with Baia Mare (east) and Pannonian depressions (west). It combines the features of the adjacent units: terraces and floodplain specific to Western Plain, piedmonts peculiar to Banato-Crişene Hills, crystalline horsts and intrusive igneous bodies specific to the Apuseni Mountains

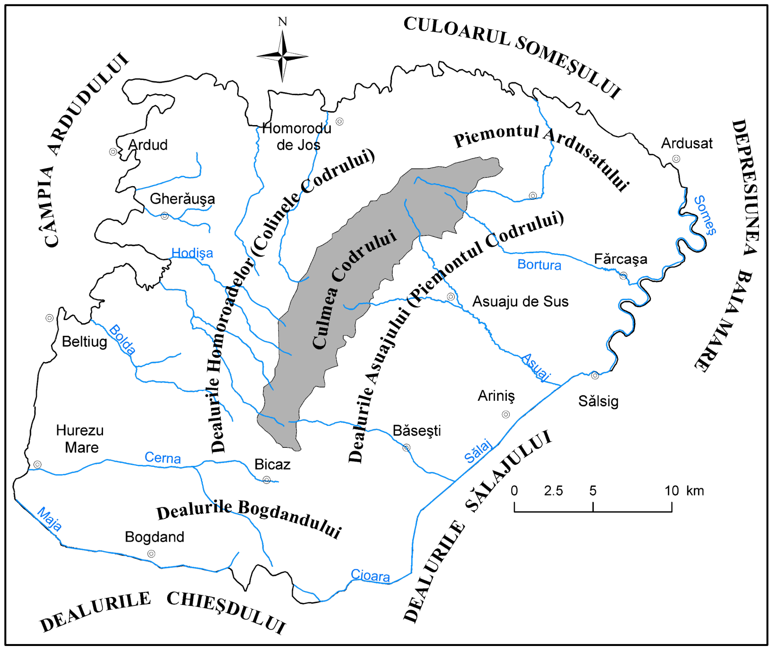


Fig.2. The adjacent units and subdivisions

3. The paleogeomorphologic evolution

The paleogeomorphologic evolution represents the premises of the present morphogenesis, highlighting the morphologic and structural diversity of the territory, lying to the contact of the two tectonic basins- Pannonian Basin and Baia Mare Depression. The Codrului crystalline ridge represents a unit of relief individualized in Paleozoic, later subjected to peneplanation. The horst character was acquired in the Paleocene, as a consequence of disjunctive movements which caused fragmentation of the hidden Apuseni Mountains. The Codrului Piedmont represents the result of accumulation within Paleocene-Romanian, after being subjected to aerial modeling; now it is in the downward phase of development, of piedmont hills. In terms of evolution, it is a drained, nonfunctional piedmont. It has a stacked structure (Sarmatian and Dacian-Romanian piedmonts), determined by repeating dives on the border of the ,,mountain''; on the other hand, it is a juxtaposition of two different types of piedmonts: erosional on the crystalline border and accumulative to the periphery.

4. The morphogenetic factors

The present relief was created by internal factors, passive (lithologic and structural features), and external factors, with natural (climatic and hydrological conditions and types of vegetation and soil) or anthropogenic origin.

4.1. The endogenetic factors

The analysis of the lithostructural factors' influence on morphogenesis demonstrates the following list of specific issues: The Codrului Ridge represents a faulted anticline, as a cuesta oriented to north-west, forming the main node of morphohydrographic divergence in the region; the presence of igneous rocks as plutons consisting of gneiss, granite and syenit (fig.3) is an element of individuality of Codrului Ridge to the other crystalline islands of ,,intra-Carpathian yoke''.

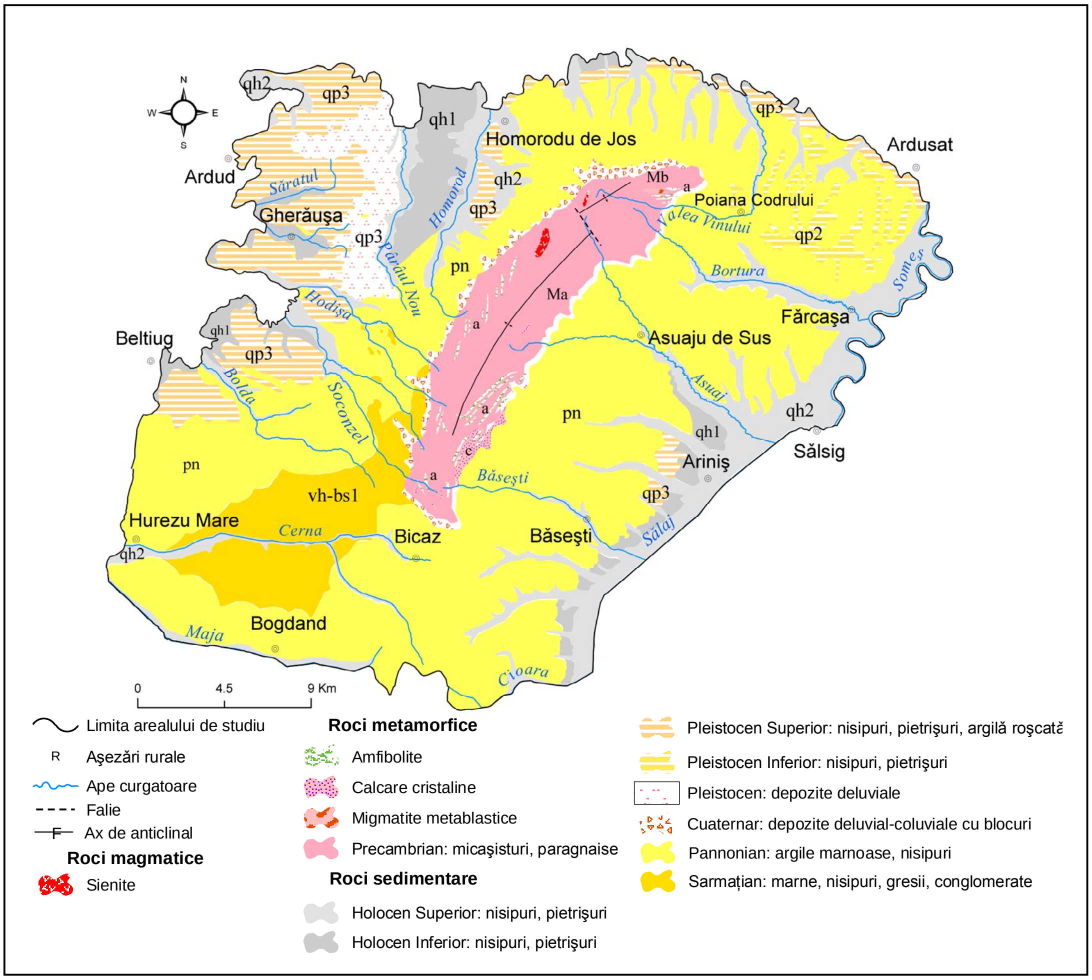


Fig. 3. Geological map (after geologic map, scale 1: 200 000, Baia Mare and Satu Mare sheets)

The quasi-parallel system of faults has important morphohydrographic implications: imposed flow direction (Crasna, Maria) or determined deviation of the river courses (Dersida- Corund fault imposed the diversion of the Maja stream to northwest). The Codrului Hills overlap a rather homogeneous homocline in terms of petrography (uncemented clastic sedimentary rocks) and gently tilting strata, reflected in a reduced structural involvement at landforms' level: local cuestas, consequent valleys, sectors of subsequent valleys and outliers. Sedimentary rocks make up 91.4% of the studied area, sarmatian (in southern part of the Homoroadelor Hills), pannonian (fig.4) and quaternary deposits (consists of sand, gravel, clay and loessoid clay) being present on the surface. Thus, in terms of lithology dominate the landforms shaped in clay facieses (landslides, mudflow, badlands) and developed on sand and gravel deposits (rill erosion and gullying). The joining of the two different lithologic units - crystalline ridge and sedimentary monoclinic, led to the development of contact depression joined by low saddles (260 - 300 m), marking the piedmont detachment of ,,mountain'' stage.

Fig. 4. Pannonian deposits (sand and low cemented sandstone), Stremț

4.2. The exogenetic factors

The external factors of modeling are represented by hydro-climatic factors, vegetation, soil features and anthropogenic activities.

In relation to the theme of doctoral thesis, there were analyzed only **climatic factors** with geomorphologic implications: rainfall associated parameters (intensity, amount, irregular variations), snow (water equivalent) and air temperature (diurnal amplitudes and freeze-thaw cycles). The spatial-temporal analysis of the air temperature was based on data from Baia Mare, Satu Mare, Zalau and Supuru de Jos meteorological stations for a period of 30 years (1977-2006) (source: http://www7.ncdc noaa.gov/climvis/CdoDispatcher). Data analysis revealed a specific thermal regime of low hills areas in most of the territory, except the Codrului Ridge, belonging as high hills region. The mean annual temperature values are between 8.8-9.8 ° C in the hills and 7.5-8.8 ° C in the Codrului Ridge (fig. 5), providing an average vertical thermal gradient of about 0.55º C / 100 m .

The frost weathering, characterized by the intensity and frequency of freeze-thaw cycles, are one of the most important factor involved in weathering, but influencing some slope processes such as creep and solifluxion, also. The number of freeze-thaw cycles varies between 75-85 days / year (83 days in Satu Mare, 79 days in Baia Mare).

The diurnal thermal variations induce the intensity of expansion-contraction cycle of rocks, phenomena that caused weakening of cohesion, generating the process of insolation weathering.

The mean diurnal thermal amplitudes were based on hourly average values of temperature (table 1).

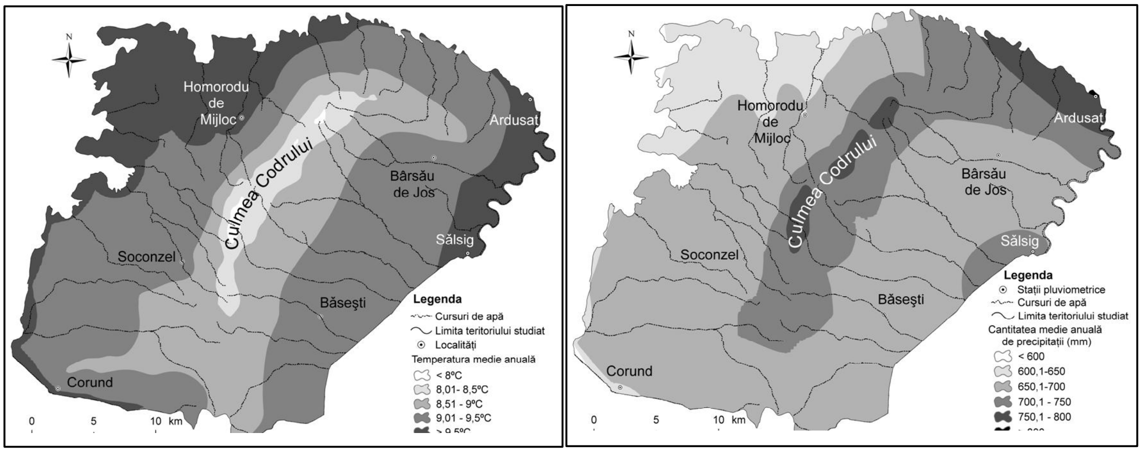


Fig. 5.The mean annual temperature distribution map(left). The mean annual rainfall distribution map(right)

Table 1. The mean annual diurnal amplitudes, maximum and minimum monthly average (° C) (period 1977-2006) (source: http://www7.ncdc.noaa.gov/climvis/CdoDispatcher)

No.	**Meteorological station**	**Multi- annual average**	**Maximum monthly average (Jully)**	**Minimum monthly average (January)**
1	Baia Mare	7.3	9.9	3.5
2	Satu Mare	8.2	11.3	3.9
3	Supuru de Jos	8.2	11.7	3.6
4	Zalău	6.4	9	3.2

The precipitations are one of the main climatic elements, being characterized by a high spatial-temporal variability of the associated parameters (amount, intensity, duration, frequency). To characterize precipitations data from a period of 33 years (1970-2002 reference period) from all rain gauge stations in region and from neighboring meteorological stations were used. Being situated in the path of moist air masses with a predominantly western advection determines relatively high amounts of precipitation in the Codrului Hills. The lowest annual average amounts are characteristic for the territories situated at the border with Western Plain, where value is about 550-600 mm (Supuru de Jos, 540 mm; Hrip, 602 mm). The highest values (more than 800 mm) are characteristic for the north-eastern extremity (Ardusat, 817 mm), located in the vicinity of Gutâi Mountains, and higher altitudes of the Codrului Ridge. In the most of the Codrului Hills precipitations are between 640 and 680 mm (fig.5).

The number of consecutive days with precipitation and the sums for different time intervals represents important factors of control for the slope processes, especially for landslides. The frequency analysis of the consecutive days with precipitation exceeding 0.1 mm performed on daily data from Sălsig station (1984-2008), revealed that the most frequently is the 2-days duration (47%) (table 2); almost every year, at least once a year, the maximum amount of precipitations exceeds 40 mm in 2 days, sometimes even 100 mm.

Table 2. Average annual number of consecutive days with precipitations (Sălsig, 1984-2008)

The number of consecutive days with precipitation	2	3	4	5	6	7	8	9	10	11
Annual average number of cases	15.9	6.7	4.8	2.7	1.8	0.7	0.7	0.2	0.15	0.15

To calculate the values of rainfall intensity with certain annual probability of exceedance for shorter periods of time (5-120 minutes), 24 hour rainfall with different return periods calculated from the representative stations in the region have been converted to rainfall with durations ranging between 15 and 120 minute by multiplying their values by some conversion factors (Diaconu, Serban, 1994). The values obtained for $I_{1\%}$ varies between 3-4 mm/min when the rain lasting 5 minutes, decrease to values lower than 1 mm/min for rain lasting more than one hour (table 3).

Table 3. The rainfall intensity with different annual probability of exceedance

$I_{1\%}$						
Duration (minutes)	5’	10’	15’	30’	60’	120’
Baia Mare	3.96	2.97	2.38	1.58	0.96	0.55
Băseşti	3.12	2.34	1.87	1.25	0.75	0.44
Homorodu de Mijloc	3.32	2.49	1.99	1.33	0.80	0.46
Zalău	3.52	2.64	2.11	1.41	0.85	0.49
Sălsig	3.44	2.58	2.06	1.38	0.83	0.48
$I_{2\%}$						
Duration (minutes)	5’	10’	15’	30’	60’	120’
Baia Mare	3.56	2.67	2.14	1.42	0.86	0.50
Băseşti	2.88	2.16	1.73	1.15	0.70	0.40
Homorodu de Mijloc	3.04	2.28	1.82	1.22	0.73	0.42
Zalău	3.20	2.40	1.92	1.28	0.77	0.45
Sălsig	3.08	2.31	1.85	1.23	0.74	0.43
$I_{5\%}$						
Duration (minutes)	5’	10’	15’	30’	60’	120’
Baia Mare	3.04	2.28	1.82	1.22	0.73	0.42
Băseşti	2.52	1.89	1.51	1.01	0.61	0.35
Homorodu de Mijloc	2.64	1.98	1.58	1.06	0.64	0.37
Zalău	2.76	2.07	1.66	1.10	0.67	0.39
Sălsig	2.64	1.98	1.58	1.06	0.64	0.37
$I_{20\%}$						
Duration (minutes)	5’	10’	15’	30’	60’	120’
Baia Mare	2.24	1,68	1.34	0.90	0.54	0.31
Băseşti	1.92	1,44	1.15	0.77	0.46	0.27
Homorodu de Mijloc	1.96	1,47	1.18	0.78	0.47	0.27
Zalău	2.04	1,53	1.22	0.82	0.49	0.28
Sălsig	1.96	1,47	1.18	0.78	0.47	0.27

In order to evaluate rainfall erosivity, the modified Fournier index (F_M) was determined:

$$F_M = \sum_{i=1}^{12} \frac{p_i^2}{P} \text{ where,}$$

p_i -average sum of precipitation for month i (mm);

P -average annual amount of rainfall (mm).

The average values of this indicator are between 65 mm in the extreme western area and 95 mm in the highest Codrului Ridge and northeastern area. The results, according to rainfall aggressivity classes (Yuksel et al., 2008, table 4.), show a low aggressiveness in the hills and one moderate for the Codrului Ridge and northeastern area (F_M > 90) (fig. 6). There have been years when the most rain gauge stations in the region indicate values that belonged to a class of high pluvial aggressivity (1978, 1980, 1998, 2001) and very high (1974), in some cases reaching values over 200 mm (Corund, 220 mm in 1974).

Table 4. Classes of rainfall aggressivity based on the F_M index (Yuksel et al.,2008)

Classes	F_M **(mm)**	**Rainfall aggressiveness**
1.	<60	very low
2.	60-90	low
3.	90-120	moderate
4.	120-160	high
5.	> 160	very high

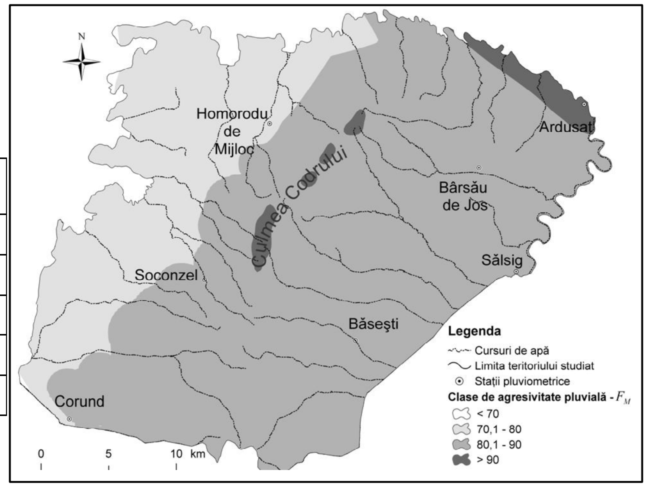


Fig. 6. The F_M distribution values map

Among **hydrological factors**, the floods, characterized by high peak discharges, duration and water velocity, are mainly responsible for changes of the longitudinal and cross section of stream channel. The most floods occur in winter (along water courses developed on west of the Codrului Ridge) or spring seasons (the Someş River and the water courses of eastern and northern part of the region), being generated by heavy rainfall or rapid snowmelt or, more frequently, due to the combination of rainwater and snow water.

Vegetation has an important role in ensuring slopes stability, forest owning the largest percentage in the functional land use units (37.45%).

In terms of **soils**, the Luvisols class, represented by Haplic Luvisols and Albic Luvisols (WRB-SR – 1998), is specific to the studied area, covering three quarters of the area (86.73%). Soils with fine texture (silty clay and clay) hold the largest percentage (63.21%), confirming the high susceptibility of soils in the area to sheet erosion and landslides.

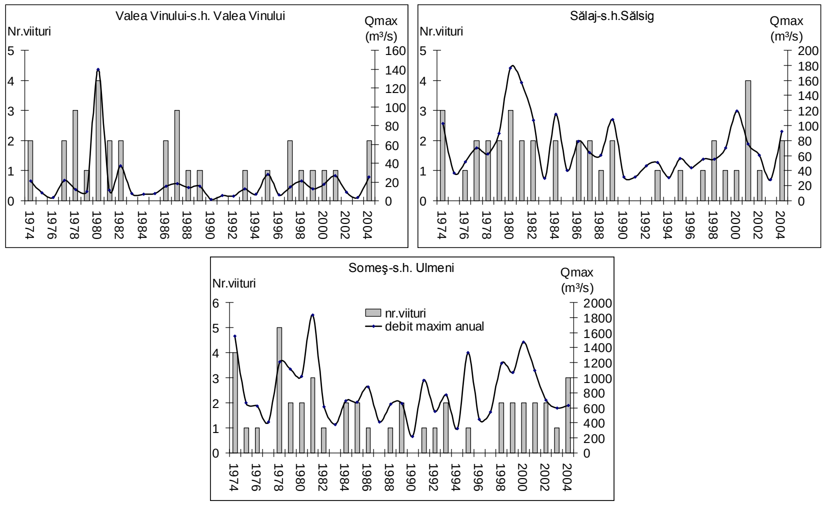


Fig. 7. Annual distribution of the number of flood and maximum annual flow (1974-2004)

The anthropic factor represents the environmental component with major influence on relief, anthropogenic activities taking place in territory (fig.8) having a dual, contradictory effect.

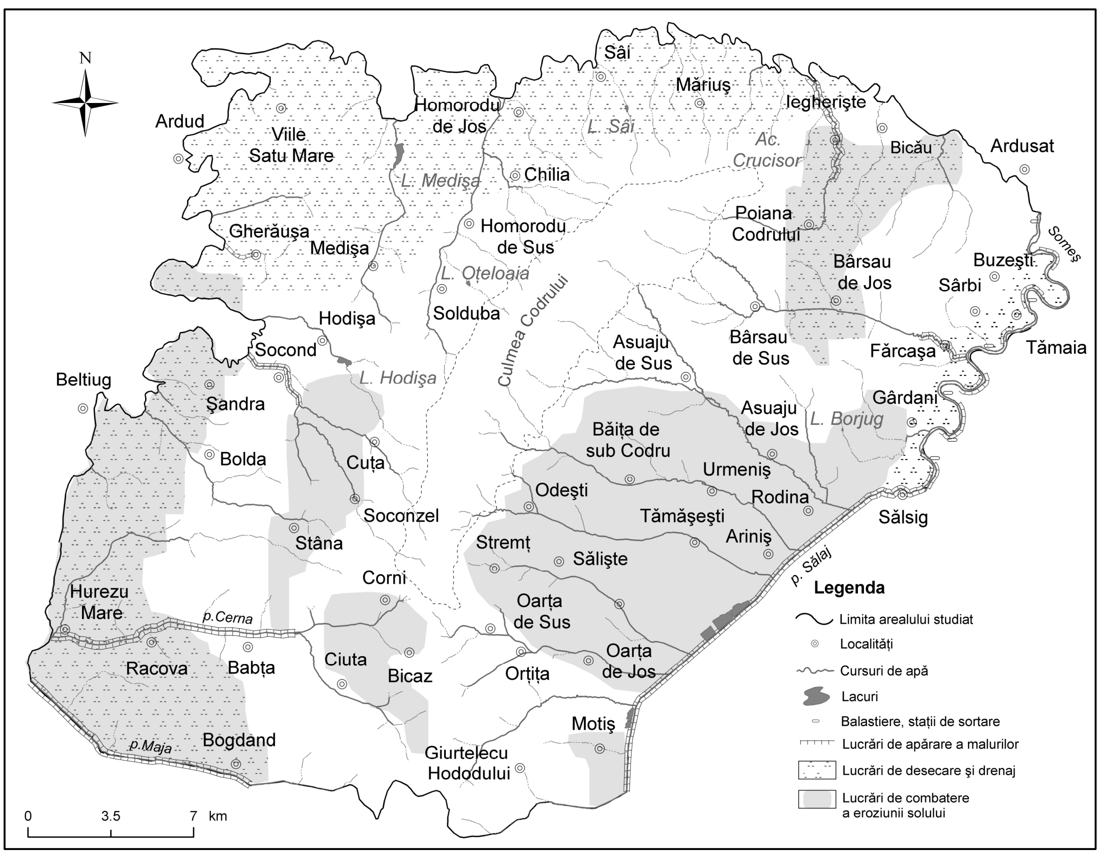


Fig. 8. Land reclamations map (source: ANIF, 2009)

Thus, man has contributed to the reduction of erosion processes by planting orchards (on the left side of Someş) or afforestation, the channelization works and building embankments. Other activities results in increasing the instability of slopes by opening quarries, mining gravel and sands from river channel, the development of forest or farming roads, agricultural works carried out improperly or intensive grazing. Anthropogenic pressure on the territory (fig.8) is, however, reduced, the density of population being below the national average - 47 inhabitants / km ² (2002).

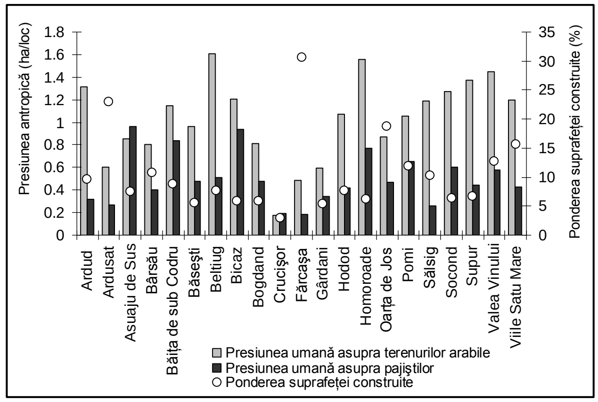


Fig.9. The indices of landscape' artificialisation

5.The morphometric features

The morphometric parameters provide information on the territories which are likely to be affected by contemporary geomorphologic processes, outlining the first images of morphodinamics' slopes in territory. This is a low relief unit, registering an average altitude of 219.7 m and a gently slope, the slope under 6º owning a percentage of 71.25%.

The morphometric characterization of the relief was made based on Digital Elevation Model (DEM) generated by contour lines represented on topographic maps at scale 1: 25000. This stage involves the derivation of terrain parameters from numerical altitude model (slope angle, slope aspect, relief intensity and drainage density, the plan and profile curvature; fig. 10-11) and analysis of their distribution by cartographic (maps, sections, block diagrams) and statistics methods (histograms of frequency). All morphometric parameters were generated on a grid-type support with a 10-m resolution, to enable detailed topographic analyses.

6. The morphology of the Culmea and Piemontul Codrului

The interfluves preserve four levels of erosion: two in the Codrului Ridge (lower level of 400-460 m and maximum level of 500-580 m), carved by marine/lacustrine abrasion during transgression periods, and two in piedmont - level of 240-300 m and 300-350 m.

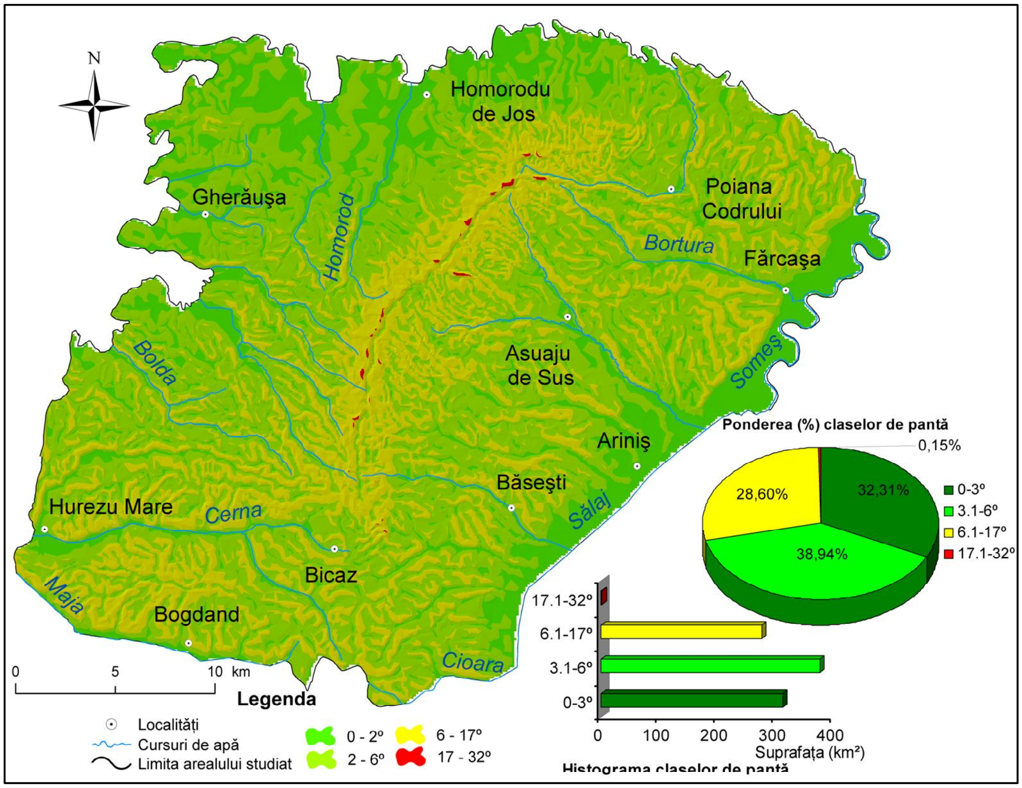


Fig. 10 The slope angle map

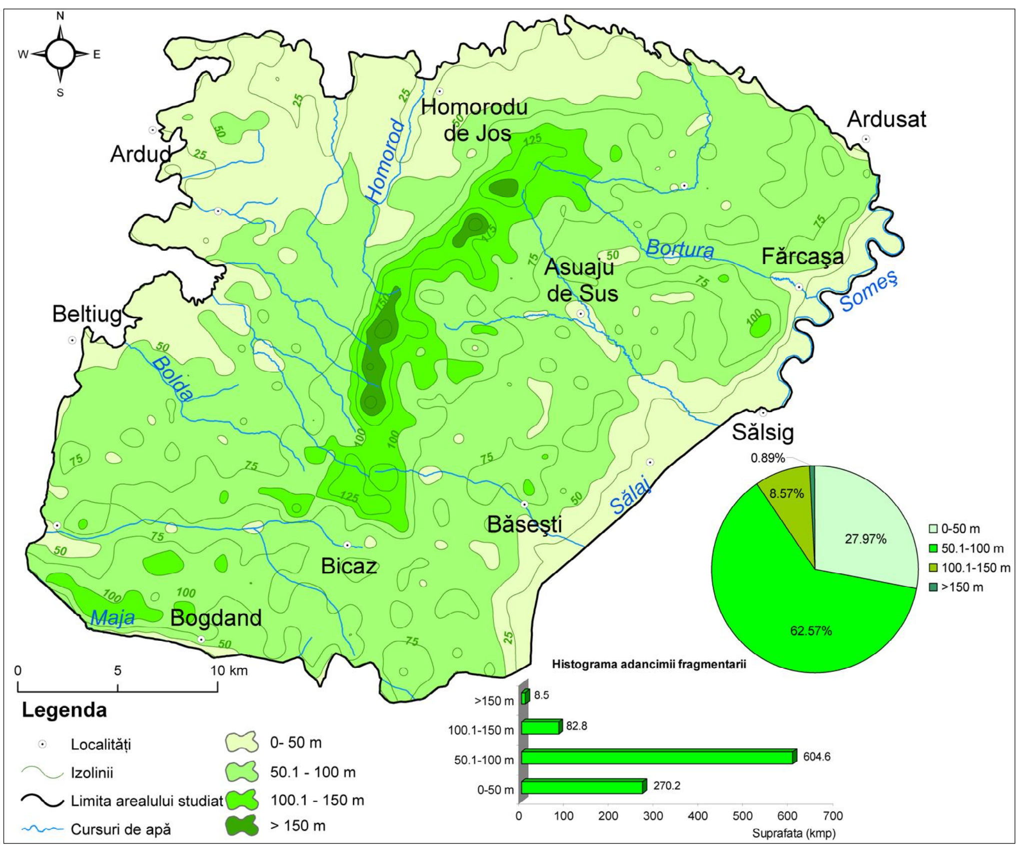


Fig. 11. The relief intensity map

The shape of the hill slopes, an element that influences the dynamics of modeling processes, reflects the lithologic constitution and structure, the stage of river basins development, and the character of the past and present denudation. The slope' profile is different and may have a concave shape, convex, straight or in steps. Frequently, these types are found in the same slope, as a complex profile. The lithologic constitution induces differentiation in the profile slopes. Thus, the domination of clays or marls generates a concave profile, their alternation with consolidated rocks (sandstones, conglomerates) in the sarmatian area gives a slope profile in steps, with structural thresholds, and the presence of crystalline schists generate a linear or convex profile.

Fig.12. The lower level of erosion, Poiana Codrului

The rivers show in longitudinal profile a characteristic concave shape, being characterized by the abrupt changes (knick points) attributed to lithologic differentiation (in the metamorphic or sarmatian deposits), the transition from one cycle of erosion to another, the presence of local or regional faults (a threshold is clearly observed around the altitude of 350 meters for valleys in eastern area, which can be attributed to Codru fault) etc. For a detailed analysis of the shape profile of channels, there have been selected three representative autochthonous courses, with different characteristics (4-6 Strahler stream order, 26-112 km² catchment area, the maximum altitude 294-506 m, 12-19 km length) and tributaries (Someş, Sălaj and Crasna). The morphometric parameters of the longitudinal profile of the investigated water courses reveal a steep slope gradient for the rivers that spring from the Codrului Ridge, with a high altimetric difference between source and mouth, meaning more than 230 m: Bortura and Băseşti more than 20 m / km , while the Cerna brook register a gently slope gradient (9 m / km), due to low relief intensity, below 150 m . The values of the concavity index indicate that the three water courses have a strong concave longitudinal profile, being in a "late" maturity stage.

Comparative analysis of the valleys' longitudinal profiles required their reduction in an unit (fig. 13), so that both axles have the same variation ecart, without inducing changes of their form.

The analysis of resulting graph shows the following:

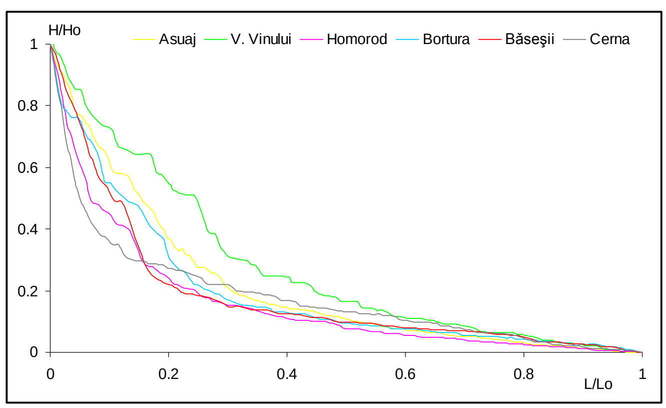


Fig.13. The longitudinal profiles of water courses reduced in a unit (H/Ho- altitudes rate; h = altitude at the point of measurement, Ho = difference in elevation between the source and the mouth; L/Lo- length rate, L = distance from the mouth till the point of measurement, Lo = the distance between source and mouth, according to Rădoane, 2003)

→ the existence of many knick points tectonic, lithologic and evolutive induced in the longitudinal profile of the river;

→ the Asuaj, Bortura and Valea Vinului streams are still quite far from the ,,grade'' stage, with the confluence near the areas of tectonic instability (subsidence-Sălsig and Ardusat);

→ the streams in the southern part are older, having a higher concavity index (Cerna, Băseşti).

7. The genetic landforms

7.1. Structural and petrographic landforms

The structural relief is represented by local cuesta, plutons, epigenetic gorge, consequent valleys (the majority), the sectors of the subsequent valleys, basins of structural contact etc. (fig. 14).

Fig. 14. a. The structural basin of Bârsău; b. The Tincului epigenetic gorge; c.The cuesta of Crasna, upstream of Dobra

The rocks variety gives distinctive notes to the geomorphologic landscape. Thus, metamorphic rocks of the Codrului Ridge give massiveness, presence of valleys with the bedrock channel, petrographic steep slopes with altered differentiated niches and developing processes such as thermal weathering (fig. 15-17).

Fig. 15. Channels shape in metamorphic rock (left- Tincului Valley, Oarța de Sus; right- right tributary of the Sălişte brook, Stremț)

Fig. 16. Weathering processes in metamorphic rocks (left- thermal weathering, Stremț; right- chemical weathering, Stremț)

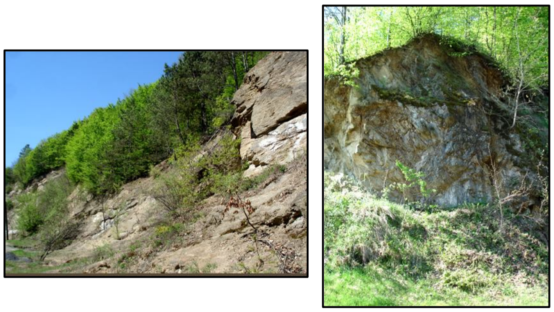


Fig. 17. The petrographic steep slopes with alteration differentiated niches, Oarța de Sus (left-left side of the Măgurici brook; right- left side of the Tincului brook)

In areas within clays facies are created landforms such as landslides, mud flows, mud cracks and the alternation with sand facies built up bad-lands (fig. 18-19).

Fig. 18. Landslides (left- left side of the Someș River, downstream of Gârdani; right- the Lung Hill, Cuța)

Fig. 19. Badlands, the right side of the Maria brook, upstream of Rățești

Sandy deposits are associated to linear erosion formations such as gullies and rarely trovants, which are specific to the sarmatian deposits occurring in the southern part of the Homoroadelor Hills (fig. 20).

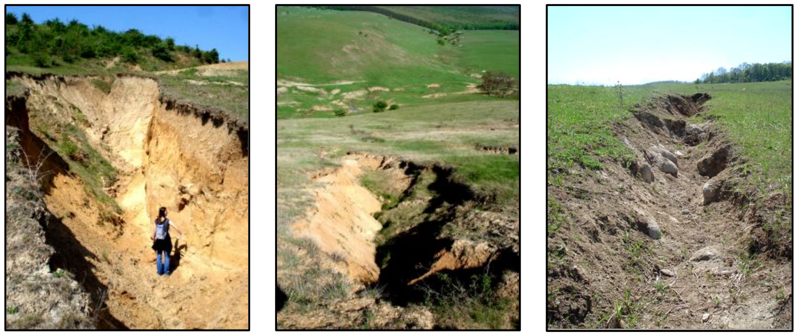


Fig. 20. Gullies developed on the pannonian deposits: left –Stremț; center-left side of the Copăcişului valley, Cuta; right- trovants on the left side of the Cerna brook, upstream of Hurezu Mare

The presence of loessoid deposits favored the development of the piping cellar and tunnels and sinkholes (fig. 21).

Fig. 21. The piping cellar and tunnels (left, Stremț; center, Fărcaşa).
The sinkhole (right, right slope of the Fânațelor Valley, Bârsău de Sus)

7.2. The fluvial landforms

The morpho-evolutive features of the monitored river channels were investigated: the Someş River with Sălaj and Valea Vinului tributaries and Maja, a affluent of Crasna River. The channels present a series of morphometric parameters, the values determined for the period 1981-2004 being presented in table 5. Data analysis revealed an increasing trend in morphometric features after 1995, compared with the period 1981-1984, due to channels degradation both vertically and horizontally (through lateral erosion).

The cross-section of a channel represents a subsystem in a constant adjustment process by changing width-depth and erosion-accumulation ratio. The balance of the riverbed processes was carried out both in case of natural (Someş River, Sălaj and Maja Stream) and modified water courses (Valea Vinului, a tributary of the Someş). Alluvial balance was calculated using data obtained by measurement in ArcGIS 9.2 software, the accumulated or eroded surface from a measurement to another and transforming the obtained values in units' volume (m^3).

Table 5. The morphometric parameters of cross-river sections (1981-2004)

Water courses		**1981**	**1982**	**1983**	**1984**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**Med.**
Someş, Ulmeni section	S	467,4	-	-	-	534,3	531,0	573,1	591,1	573,8	600,9	577,7	-	577,8	560,3	568,9
	B	133,6	-	-	-	143,3	143,5	144,7	146,1	144,3	144,8	138,5	-	146,7	134,4	142,9
	h	3,4	-	-	-	3,7	3,6	3,9	4,0	3,9	4,1	4,1	-	3,9	4,1	3,9
	H	4,3	-	-	-	4,6	4,6	4,6	4,9	4,7	4,7	4,8	-	4,8	4,6	4,7
	P	142,4	-	-	-	152,7	152,8	154,1	155,9	153,7	154,3	148,1	-	156,4	143,7	151,4
	R	3,2	-	-	-	3,4	3,4	3,7	3,7	3,7	3,8	3,9	-	3,6	3,8	3,6
Sălaj, Sălsig section	S	-	30,54	30,19	29,34	-	-	40,99	47,95	46,82	42,81	43,59	43,13	42,18	41,03	39,87
	B	-	21,03	21,07	21,23	-	-	23,6	26,35	25,49	24,98	24,65	24,81	24,4	23,54	23,74
	h	-	1,45	1,43	1,38	-	-	1,73	1,81	1,83	1,71	1,76	1,73	1,72	1,74	1,66
	H	-	2,09	2,01	1,99	-	-	2,45	2,62	2,69	2,44	2,55	2,42	2,57	2,48	2,39
	P	-	25,22	25.09	25,22	-	-	28,50	31,59	30,87	29,86	29,75	29,65	29,54	28,50	28,52
	R	-	1,21	1,20	1,16	-	-	1,43	1,51	1,51	1,43	1,46	1,45	1,42	1,43	1,38

(S-cross-section area, m²; B- channels width, m; h- average depth, m; H- maximum depth, m; P- wetted perimeter, m; R- hydraulic radius, m)

Investigations and measurements performed on cross-sections of the Sălaj stream channel in the period 1982-2004 reveal the following features (fig.22):

→ the channel are in a process of degradation, both by deepening the riverbed and by withdrawing the right bank;

→ the total alluvial balance (1982-2004) was negative, with 4.18 m³ deposits discharged per unit of length;

→ the minor riverbed had the most powerful degradation during 1984-1997 (9.6 m³/m material discharged);

→ there were several periods (1983-1984, 1999-2000 and 2002 - 2004) with alluvial positive balance, the peak being registered in 2000 (4.25 m³ accumulated material per unit of length);

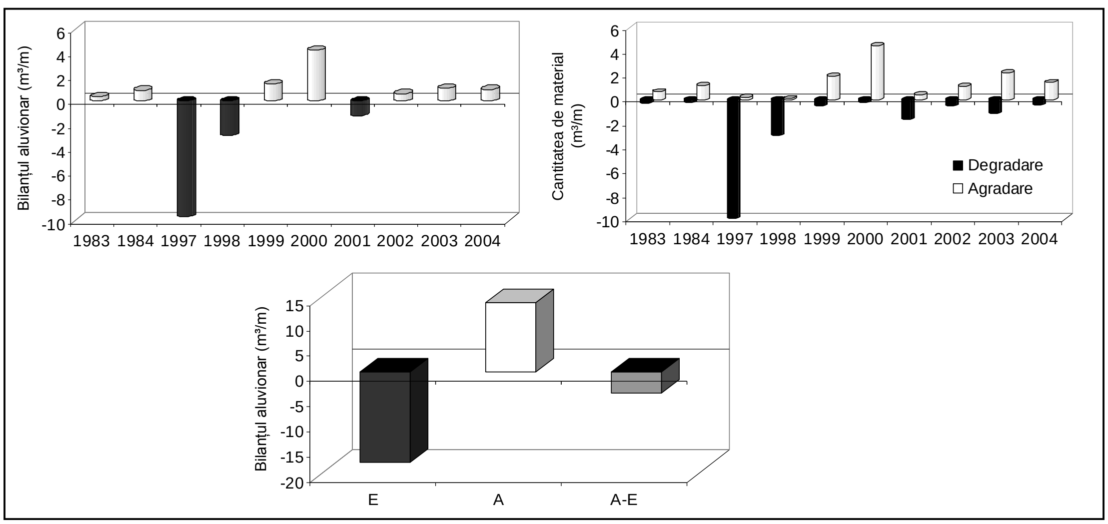


Fig. 22. The riverbed balance processes for the Sălaj river in the 1982-2004 period (Sălsig section)

→ the annual riverbed degradation ratio was 0.17 m³ / m, higher in 1984-1997 period (0.74 m³ / m / year) and decreasing significantly over the recent period (1997-2004) – 0.78 cm ³ / m / year.

The performed measurements revealed a generalized process of degradation for the rivers, both in the thalweg, and the banks, with an annual ratio significantly reduced after 1995, due to the trend of decreasing the average annual peak discharge. The trend of deepening the Somes riverbed was transmitted also to the tributaries, but with a low intensity: 0.7 cm / year for Sălaj, compared to 1.21 cm / year for the Someş River. The intervention of anthropic factor through embankments caused intensification of erosion, the annual ratio of riverbed degradation recording the value of 1.6 cm / year for the Valea Vinului.

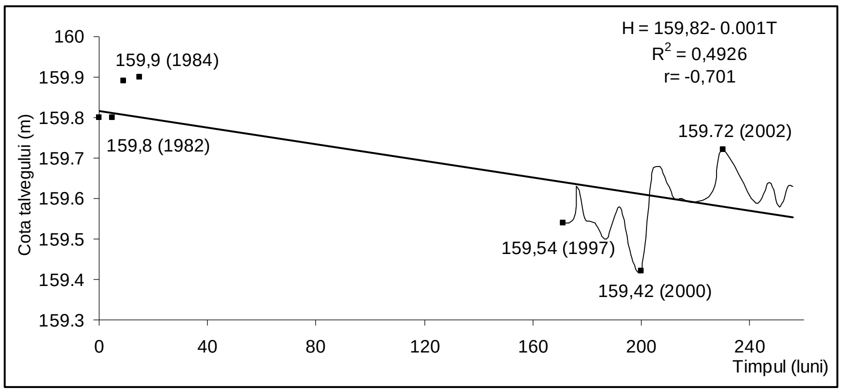


Fig. 23. The dynamic of the Sălaj thalweg in Sălsig section (1982-2004)

The analysis of the maximum depth value reveals the following riverbed trends for the Sălajului Stream (fig. 23):

→ the riverbed bed is in a process of thalweg' degradation, from an altitude of 159.84 m in the period 1982-1984, at 159.58 m in 1997-2004;

→ the thalweg dynamics indicate the existence of aggradation-degradation cycles with a periodicity of 3-4 years;

→ the processes of the thalweg' degradation overlapps the periods of peak flows and the aggradation overlaps the low discharge period, when the alluvial process dominates, due to reduced capacity of current transport;

→ the mobile riverbed is 48 cm thick.

The Someş channel in the Salsig-Ardusat sector is meandered, with a trend of increasing sinuosity index (from 1.57 in 1962 to 1.86 in 2005); it presents, locally, the features of a winding river, with islets (downstream Sălsig, downstream Tămaia). The islets are predominantly longitudinal and lateral (35.7% proportion of each type) and have small sizes: 71.4% present 40 m average width and 28.5% lengths below 100 m. In the Someş channel there are two different types of bars: simple bars and scroll-bars (fig.24).

Fig.25. A islet and a scroll- bar, downstream of Gârdani (may,2009)

The cartographic analysis and field mapping indicate the presence of 8 terrace along Someş River, 7 for Sălaj River and 5-6 levels for tributaries, the highest being situated on an absolute altitude of 280-290 m (table 6).

Table 6. The terraces in the Codrului Hills

Water courses	**The relative altitude of the terraces (m)**							
	T1	T2	T3	T4	T5	T6	T7	T8
Someș	4-6	8-12	18-22	30-40	50-60	70-75	90-110	130-140
Sălaj	2-4	5-10	15-25	30-35	40-45	50-60	75-80	-
Homorod	2-4	6-10	15-20	30-35	45	-	-	-

7.3. The torrential landforms. Gullies

The study of the gullies aimed at their classification, the determination of their morpho-evolving peculiarities, the analysis of their distribution, emphasizing the role of the variables involved in the gullies' initiation and at the creation of a gullies erosion intensity map in the territory. In this paper we considered gullies as linear forms of erosion with a depth of more than 0.5 m.

The inventory processes of the gullies, which includes elements like number, density, length and types, have been achieved using satellite image with 0.5 m resolution, which enabled to obtain the highly accurate information, supplemented by direct geomorphologic mapping in the field. The dimensions were obtained using the XTools extension, of the software ArcGIS 9.2. The cells for collecting the information were delimited on the basis of parallels and meridians grid in the 1:25 000 maps, resulting in a system of squares of 1 km ². The information obtained (type, length, number and gullies' density, the position in relation to the slope aspect, slope angle, lithology, soil texture, land use) were further processed using GIS techniques in order to establish empirical relationships between the variables involved and the processes favorability to gullies' erosion.

This study revealed that the main form of slope' degradation is represented by gullies, although only 34.36% of the area is affected by this kind of process. The explanation lies in the presence of the metamorphic and igneous rocks (8.6%) and high share of the horizontal or sub-horizontal surfaces (32.31%), areas without susceptibility to initiation of such formations. 48.49% of the affected area is the subject to low erosion, 44.88% to very low erosion, and a relatively small percentage (6.63%) is held by the territories affected by moderate erosion. The most intense erosion is present in the surroundings of the Gherăuşa, Hurezu Mare and Odeşti villages (fig.26).

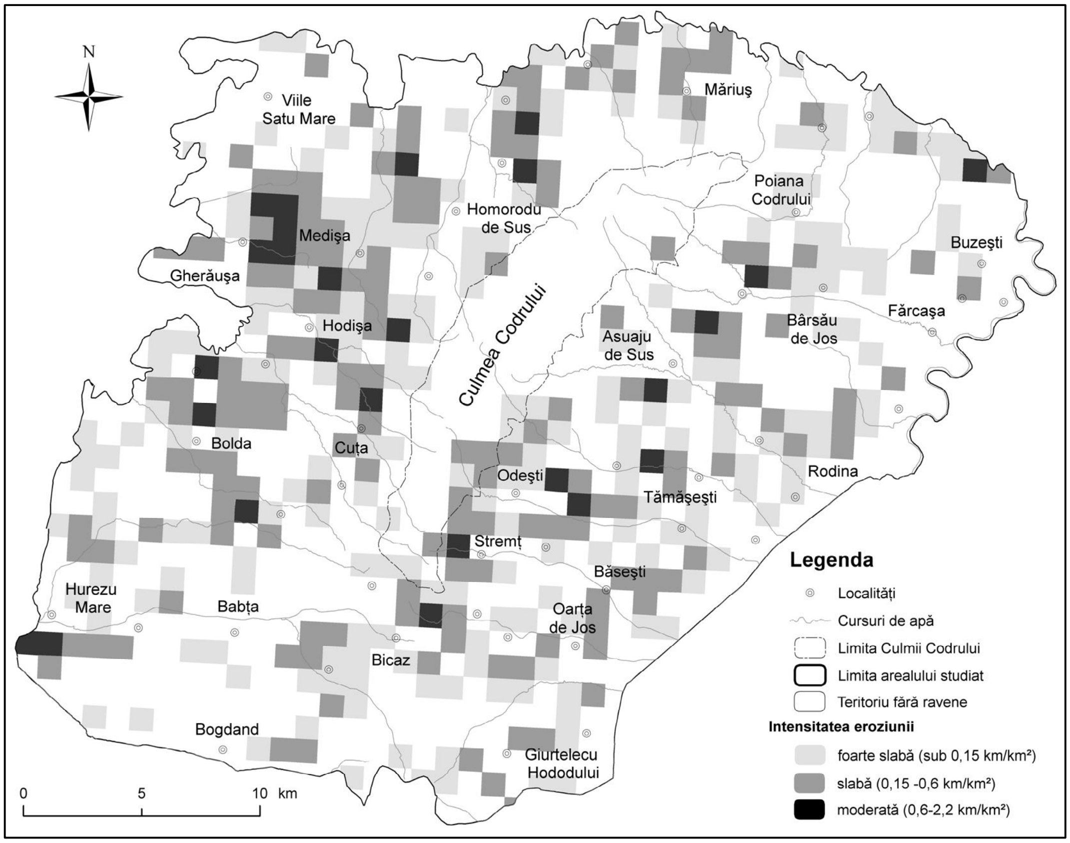


Fig.25. The intensity of gullies' erosion map

The analysis of the climate susceptibility based upon the Zachar hydrothermal coefficient reveals that the gullies may occur wherever they meet favorable conditions. The gullies present the following features: they are generated by anthropogenic causes, by the establishment of farming roads on steep slopes; most of them are discontinuous, with a linear longitudinal profile and small. By increasing slope fragmentation by gully erosion, the local forms of degradation, like bad-lands are developed.

Statistical spatial analysis using ArcGIS 9.2. allowed the exploration of the relationship between the number and density of the gullies and the control factors such as morphology, climate, geology, soil and land use. Thus, most gullies are generated on the slope between 3-6° (60.6%), occupied by pastures (42.68%) and arable land (30.8%); half of them (50.58%) are developed on silty-clay texture. The gullies developed on the pannonian deposits of clays and sands (64.3%) are dominant.

7.4. The relief generated by gravitational processes. Landslides

The study aimed at revealing the local specificity of the mass movement, morpho-dynamic analysis using the case study, statistical analysis of their distribution and emphasizing on the role of variables involved in triggering and development of landslides in territory.

The landslides are mostly superficial and small in size, because the hill slope, through the morphometric features (slope angle, in particular), are less likely sensitive to such processes; they are sliding in grooves or lenticular slide, with semi-circular area of detachment. The landslides' activation/ reactivation occur in springs with long duration and abundant rainfall following winters with consistent snow layer. By testing the method applied by Szabo (2003) in the hills of the northeastern part of Hungary, to compare the amount of rainfall recorded in winter to the amount fallen in early spring, there were identified several periods with high susceptibility to triggering landslides (fig. 26)- springs 1970, 1977, 1979, 1988, 1995, 2000, 2001, 2004, 2006 and 2009; the period 2000-2009 being confirmed by field observations and survey population.

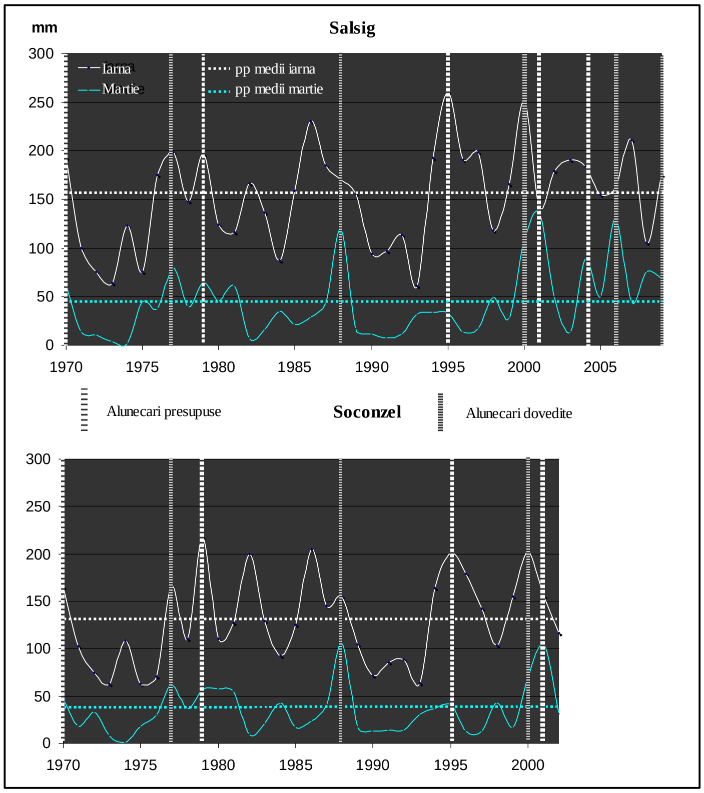


Fig.26. The relationship between periods of resurgence of landslides and the rainfall in winter season (1970-2009)

In order to analysis the landslides' morpho-dynamics, the case- study method was used for Gârdani sliding, located on the left side of the Someş River, downstream from the homonym village. It was triggered in 2000, by the reactivation of an old deluvium deposit. It was monitored by GPS in the springs of the years 2001, 2005 and 2009 (fig. 27). This is a sliding type as hourglass (Posea, 1969)/ double funnel (Donisă, 1968, quoted by Surdeanu, 1998) and it has three components: watershed, with function of the area deluvium material supply, off take and the area of deluvial submitting material, with quasi-conical shape.

During the surveying lifts, a number of morphometric parameters (perimeter, area, slope, volume, maximum width and average elevation of cornice etc.) were determined. The resulted maps allowed the determination of the slope degradation by landslides (table 7). This analysis revealed an advance of the headscarp toward the top of the slope with a speed of 9.6 m/year. The annual

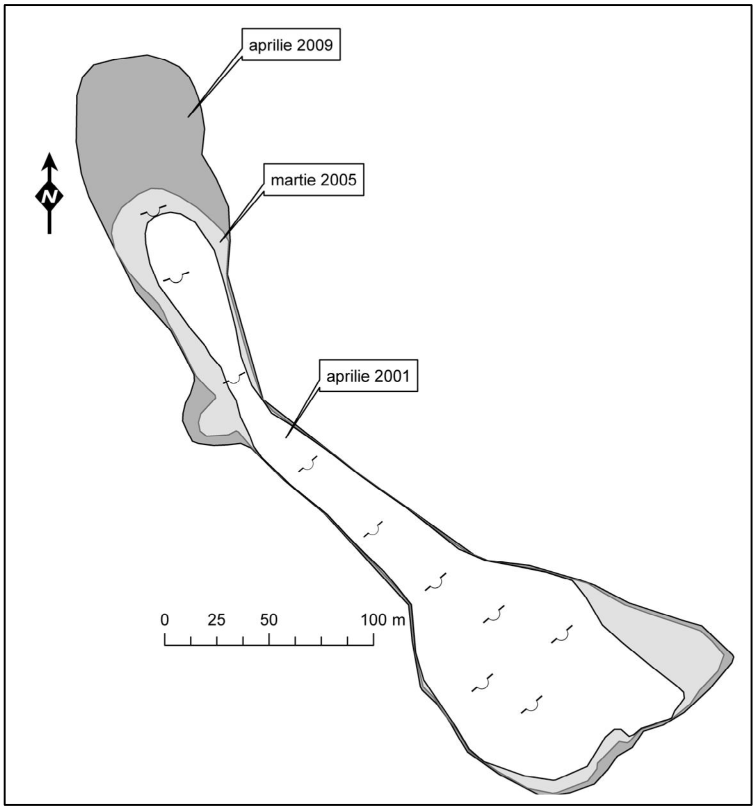


Fig.27. The Gârdani landslide evolution (2001-2009)

degradation ratio by increasing surface slope occupied by the landslide recorded the value of 1188.3 meters/year, with an average annual volume of material involved in the slip of 1542.8 m³/year. The indicators reveal a more dynamic development of sliding during the 2005-2009 period, the average annual rate of withdrawal regression being 5 times higher than in the previous period (2001-2005) and annual rate of slope' degradation of 1.3 times.

Table 7. The main indicators of hillslope' degradation by landslides (2001-2009)

Degradation index	**2001-2005**	**2005-2009**	**Total**
Regressive average withdrawal index (m / year)	3,2	16,0	9,6
Medium average degradation' rate (m² /year)	1024,1	1352,5	1188,3
Average annual trained material (m² / year)	1559,1	1526,5	1542,8

Currently, the Gârdani landslide is in an active phase of evolution, proven by the modification of the micro-morphology. The existence of cracks in the north-east is a sliding indicator that marks the development stage, by involving new areas in the system. On the other hand, sliding will extends towards the southwest, through small adventitious slidings (fig.27).

7.5. The periglacial landforms

The periglacial landforms (fig.28) were generated by the freeze-thaw processes, being present both surface periglacial (solifluctions and pipkrake) and fossil structures (ice wedges, involution), included in deep periglacial.

Fig.28. The periglaciar landforms

(left- pipkrake on the right side of Tinoasa Brook, Fărcaşa, 26/12/2006;

right- ice wedge on the right side of Maria stream, upstream of Răţeşti)

7.6.The anthropogenetic landforms

The anthropogenic factor is an important factor in morphogenesis; although there are different genetic landforms, they are developed as points in the geomorphologic landscape as quarries, agricultural terraces, mounds, excavations, dams, sink lake, craters of explosion (fig.29) etc.

Fig.29. Right -Limonitic clays quarries, Răţeşti; left- agricultural terraces, upstream of Răţeşti

8. The contemporary modeling processes

The use of GIS spatial analysis in the study of contemporary geomorphologic processes aimed to determine the slope susceptibility to the processes such as landslides and gully erosion and to quantify the soil sheet erosion using the USLE model.

8.1. The susceptibility of territory to the slope processes.

The methodology for determining the slope susceptibility to contemporary geomorphologic processes is based on the premise that processes will occur under the same geological, geomorphologic and climatic conditions as in the past, in other words, the past represents the key of the future (Ermini et al., 2005). Thus, the idea that the future processes can be modeled by statistical relationship between the old locations and data sets of their control factors (slope angle, slope aspect, lithology, land use, etc.) emerged (Zêzere, 2002).

Mapping susceptible areas to gully erosion processes used the Frequency Ratio Model, based on analysis of the relationship between spatial distribution of the gullies and control factors (fig.30).

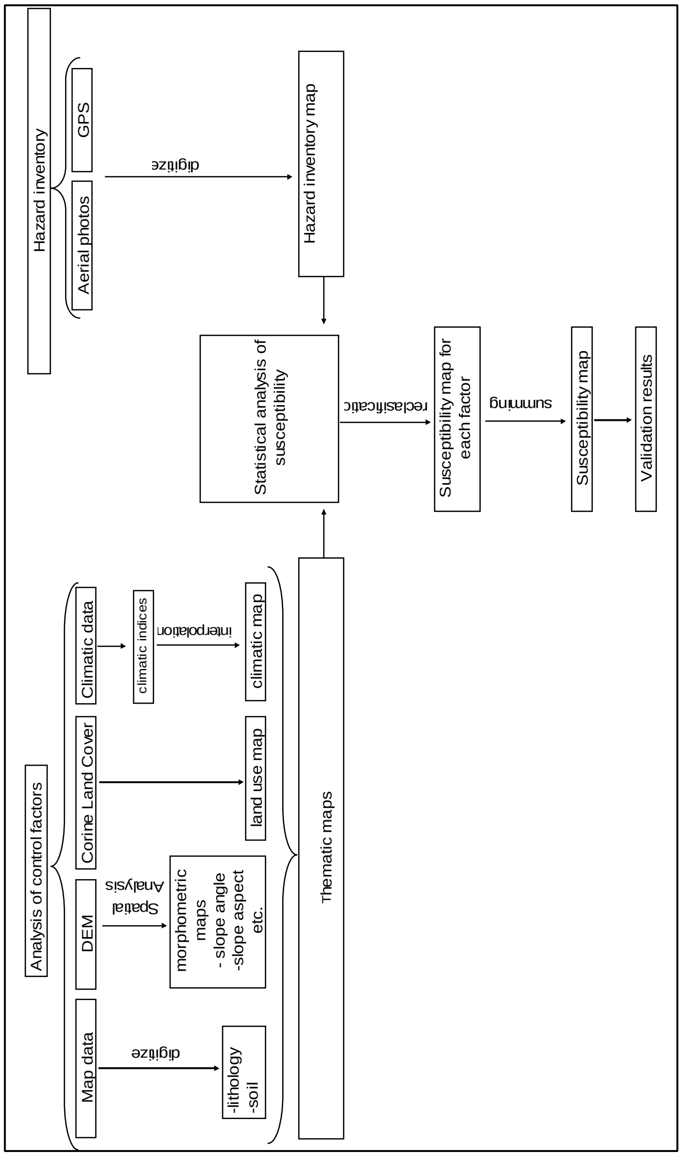


Fig. 30. Flow chart of susceptibility analysis

The gully susceptibility index (GSI) results by summing frequency rate related to each considered factor, according to the equation:

$$GSI = \sum F_r \text{ or } GSI = F_{r1} + F_{r2} + \ldots F_{rn} \text{ where,}$$

GSI- gully susceptibility index;

Fr- frequency ratio for each control factor.

The gully susceptibility analysis in Codrului Ridge and Codrului Hills took into account six factors: slope angle and slopes aspect, the climate, Zachar hydrothermal coefficient, lithology, soil texture and land-use (fig.31).

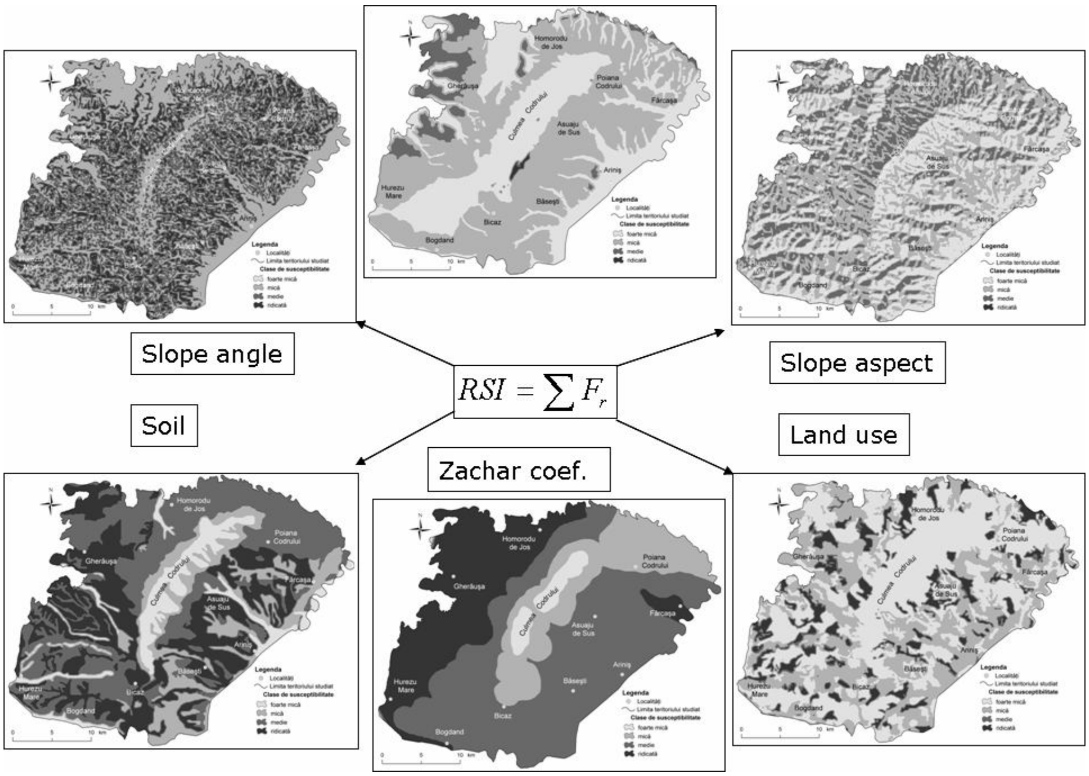


Fig. 31. The methodology for determining gully erosion susceptibility

Following the operations of reclassification of thematic maps based on achieved index, using the GIS methodology (Raster Calculator tool of ArcGIS 9.2) the gully susceptibility map was obtained (fig.32).

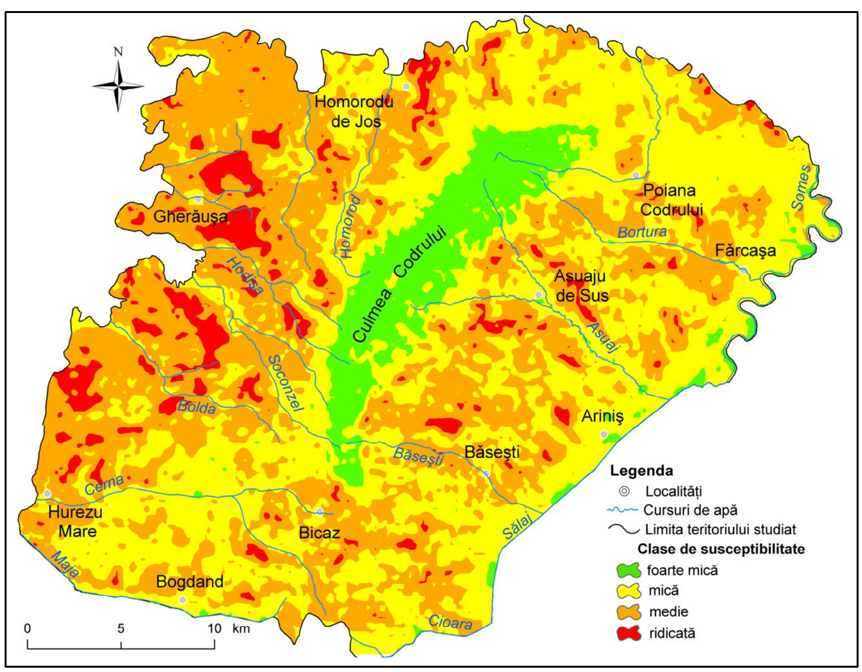


Fig.32. The gully susceptibility map

The resulted map demonstrates that 60% of the territory is characterized by low probability of gullying, only 3.79% of the area belonging to a class of high susceptibility, a higher frequency being recorded in the western half, in the surroundings of the Socond, Homoroade, Beltiug villages. The most susceptible areas overlap the Pleistocene deposits, which formed soil with silty-clay texture, with 3-6º slope and oriented to north-west, covered by pastures and characterized by a HTK of 1.75-2.00. The overlapping of the susceptibility map with the gullies distribution allowed the validation of the results. The model was considered valid, considering that 87.37% of the present gullies are overlapping the areas characterized by susceptibility, whereas only 0.15% are developed on low susceptibility areas.

The factors that generate landslides development, according to Castellanos (2008), are included in two categories: conditional factors, represented by the slope, land use, lithology, and triggering factors- rainfall and earthquakes. Thus, the landslides' susceptibility analysis in the Codrului Ridge and Codrului Hills took into account seven factors (fig.33). In the category of static factors (conditioning) we included morphometric parameters (slope angle, slope aspect, relative altitude and drainage density), lithology and land use, and as triggering factors, rainfall.

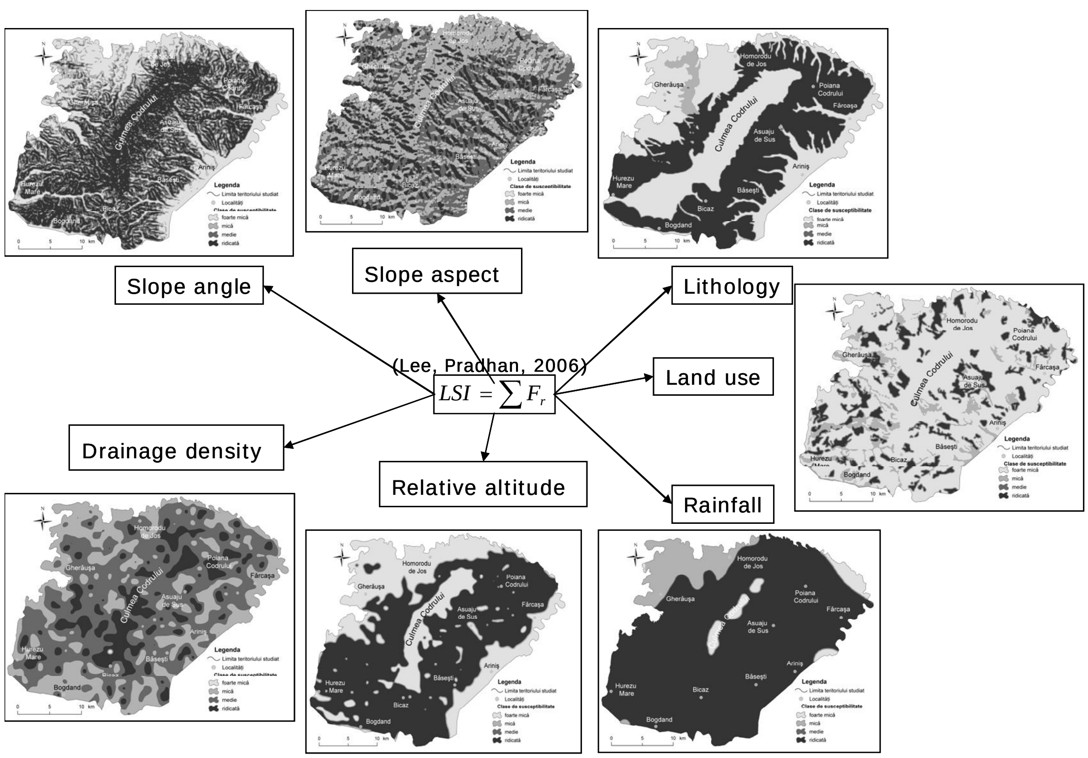


Fig. 33. Methodology for determining landslide susceptibility

By reclassification of the thematic maps based on the obtained index and using GIS methodology (Raster Calculator tool) resulted the landslides susceptibility map (fig.34). The susceptibility indices varies between 1.39 (minimum value) and 14.41 (maximum value), the sequence of values being divided into 4 equal classes of susceptibility (table 8) (after Barreto et al., 2000).

Table 8. The classes of landslides susceptibility

Susceptibility classes	Fr values	Area (km²)	%
Very low	<4,64	185,623	19,21
low	4,64-7,90	477,730	49,44
moderate	7,90-11,16	216,544	22,41
high	>11,16	86,385	8,94

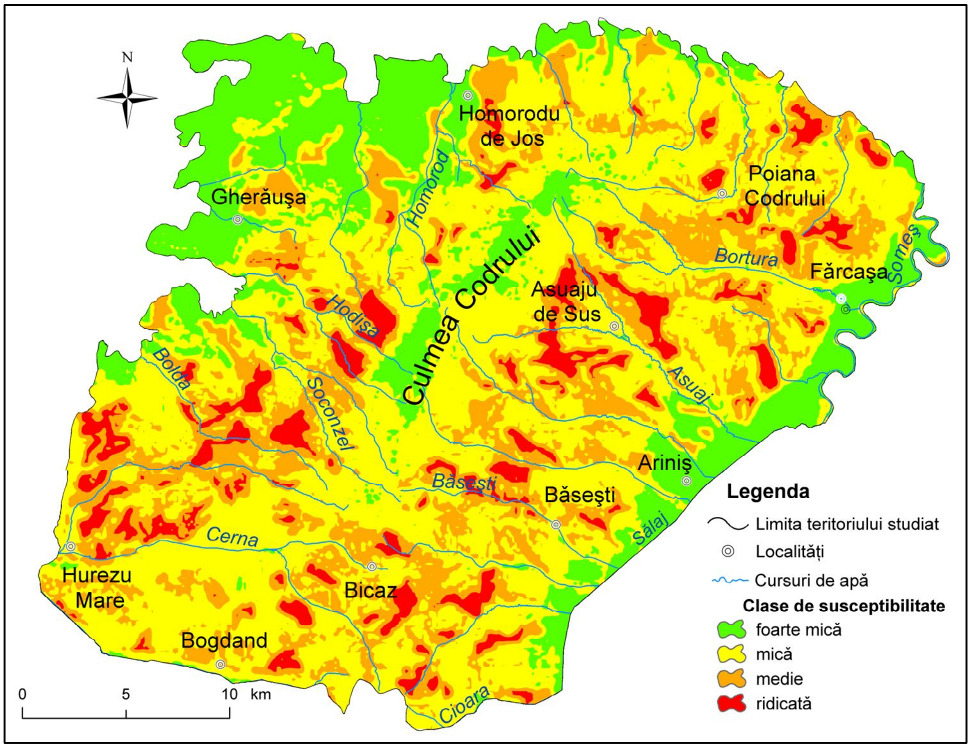


Fig.34. The landslides susceptibility map

The most susceptible areas are the ones with 6-17º slope angles, oriented towards south-west and with a high drainage density (4-6 km/km²), overlapping Early Pleistocene or Pannonian deposits, covered by pasture and an amount of precipitation in the cold season between 225 and 250 mm.

The susceptibility map was verified using existing landslide location. The verification results showed a satisfactory agreement between the susceptibility map and the existing data on slide location. Thus, 92.41% of the existing landslides match the areas characterized by high susceptibility and only 0.14% of the current landslides are located in the low susceptibility area (fig.35).

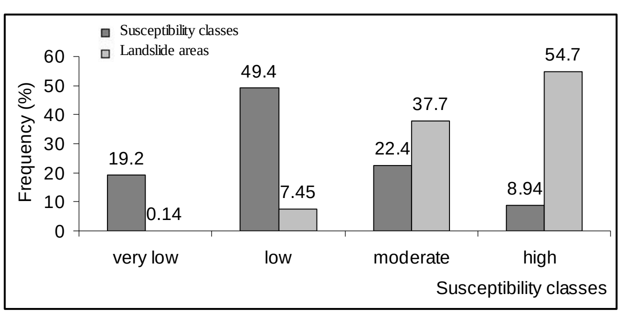


Fig.35. Validation of the landslide susceptibility map

The susceptibility GIS analysis of slope processes revealed the high share of stable land (59.97% for gully erosion, 68.65% for landslides), which may be unbalanced through deforestation, over grazing or improper farming practice techniques, leading to the development of new geomorphologic processes.

8.2. The estimation of soil sheet erosion using USLE Model

The purpose of the sheet erosion investigation was a quantitative estimation of the current annual rate of erosion in the area and spatial representation of the results obtained by implementing the GIS techniques, providing to decision-makers in territorial management information which allow them to adopt the most appropriate measures in the soil protection and conservation.

The estimation of the annual soil loss is based on USLE equation, adapted to the climatic conditions of Romania in the form of ROMSEM model (Romanian Soil Erosion Model):

$$E = K \cdot S \cdot L^m \cdot i^n \cdot C \cdot C_s \text{ where,}$$

- E - annual average sheet erosion ratio (t/ha/an);
- K- pluvial erosivity, based on rain aggressivity, obtained as a result of H·I15 (H- amount of precipitation fallen during the entire rainfall, I15- intensity of the torrential core during 15 minutes);
- S- soil erodability;
- L- slope length;
- i^n, i is slope in %, and n=1,4;
- C – cover factor;
- Cs – soil erosion management.

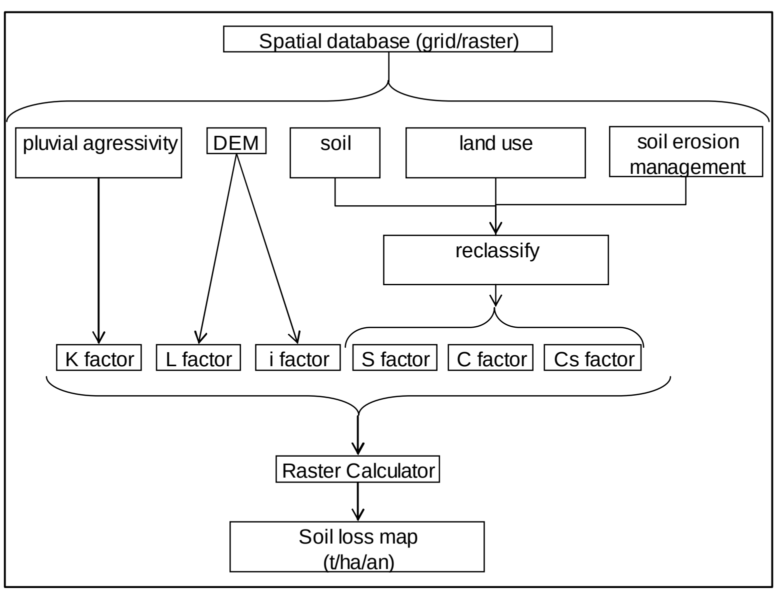


Fig.36. The methodology for quantifying the sheet erosion using GIS

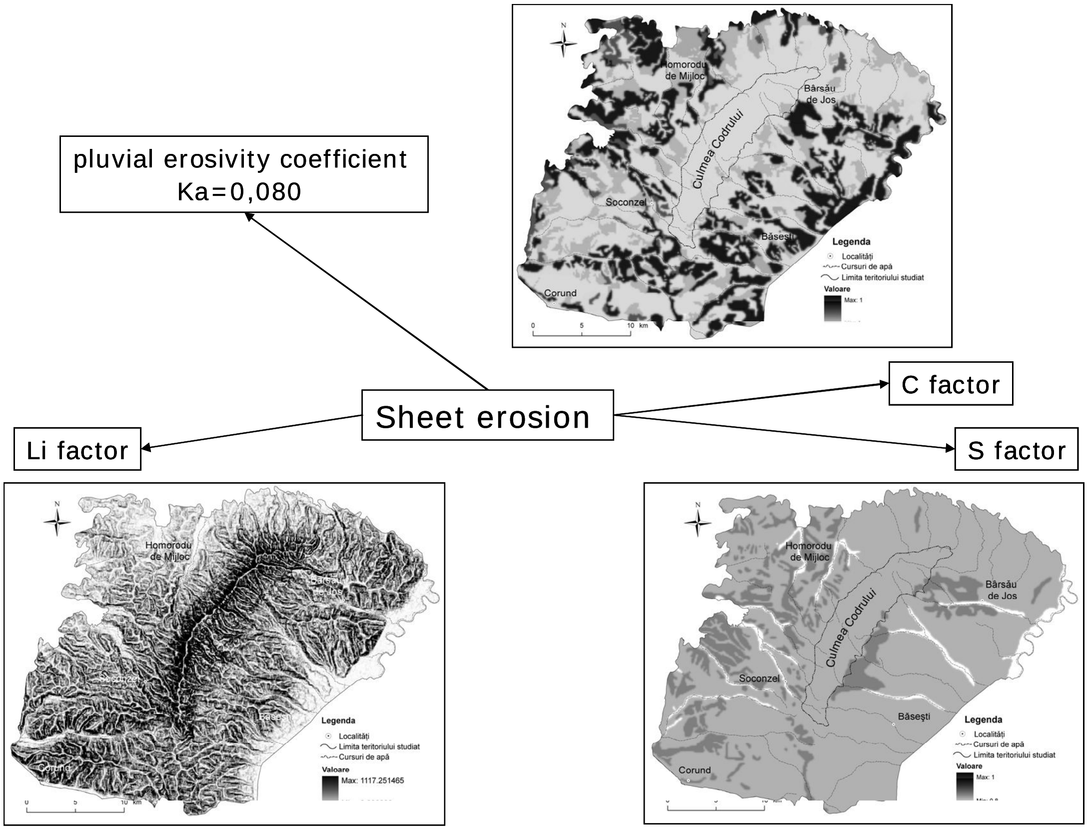


Fig.37. Methodology for estimating soil loss by sheet erosion

By integrating GIS technology and using the overlay technique, which consists in combining and analyzing the layers (fig.37), resulted the final product, the sheet erosion map (fig.38).

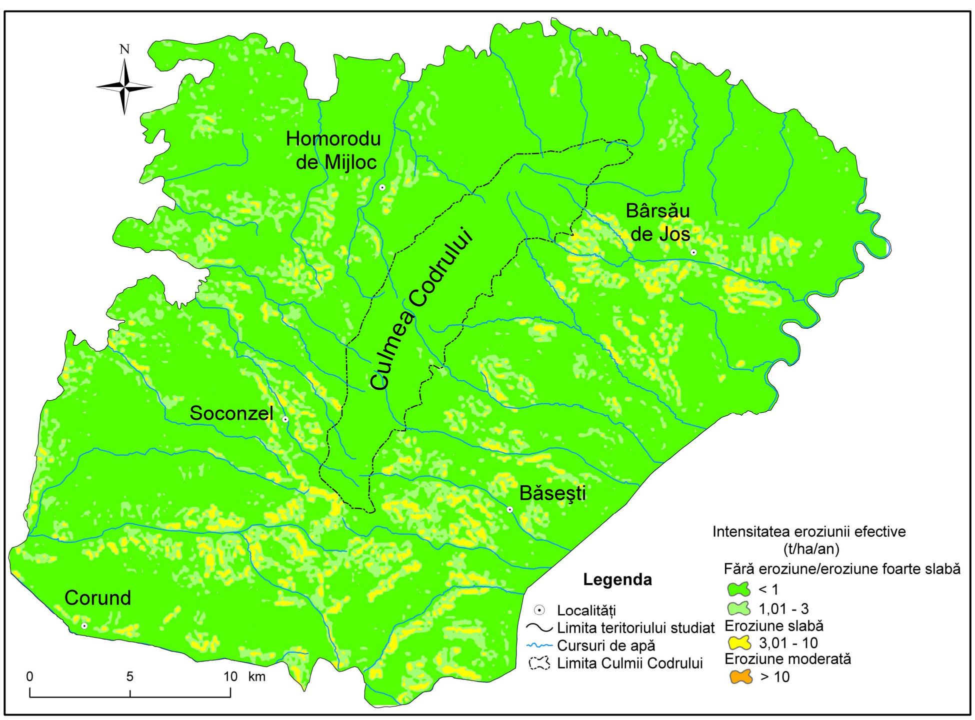


Fig.38. The spatial distribution of actual annual effective rate of sheet erosion

The obtained map allowed the establishment of the following features of sheet erosion in territory:

→ The Codrului Ridge and Codrului Hills are characterized by a very low erosional risk, the mean value of the potential erosion being 0.254 t/ha/year. Areas without erosion / insignificant erosion (less than 3 t/ha/year) have an overwhelming share- 96.9%; further more, 88.1% is characterized by potential erosion with a value below 1 t/ha/year. Areas within the moderate, high or very high susceptibility to sheet erosion have a low frequency, accounting 0.18% percentage of the total studied territory; they overlap steep slopes, covered by eroded luvisols.

→ annual average rate of effective erosion is 0.294 t/ha/year, the integration of land use in equation leading to increased annual average rate of soil degradation by sheet erosion with 115.7%. Paradoxically, although the vegetation cover protects the soil, the intensity of erosion increases. The conclusion is that anthropogenic factor, through its methods and techniques of land use, increases erosion.

→ the sheet erosion map analysis indicates that 97.46% of the territory presents tolerable values (<3 t/ha/year), highlighting the low level of human impact, the adequate vegetation cover (forest, shrubs) and dominate the low slope angle, less susceptible to erosion.

This paper is intended to be an applied geomorphology study, given its role in investigating and solving environmental and territorial management problems. The practical problems investigated will make this study a practical tool and a database of real help for local and regional authorities in taking the proper anti-erosional measures for soil protection and territorial planning.

SELECTIVE BIBLIOGRAPHY

1. Arghiuş, Corina (2003), *The geomorphologic size for the rural development and territorial planning in the Codrului hills*, Studia Universitatis Babeş- Bolyai, Geographia, XLVIII, 1, pp. 29-34
2. Arghiuş, Corina, Surdeanu, V., Arghiuş, V. (2004), *Morfodinamica albiei Someşului între Ulmeni şi Ardusat (1981-1996),* în vol. ,,Geography within the Context of Contemporary Development – 2001-2003'', Babeş-Bolyai University, Faculty of Geography, Cluj- Napoca, pp. 140-148
3. Arghiuş Corina, Arghiuş, V., Surdeanu, V., (2009), *Analiza morfodinamică a alunecărilor de teren. Studiu de caz: alunecarea Gârdani*, în vol. Riscuri şi Catastrofe, an IX, nr. 7, editor Victor Sorocovschi, Editura Casa Cărţii de Ştiinţă, Cluj-Napoca (în curs de publicare)
4. Arghiuş, Corina, Arghiuş, V., Ozunu, Al., Muntean, L., Mihăiescu, R., (în curs de publicare), *Case Study. Landslide Susceptibility in the Codrului Hills (North-Western Part of Romania),* In "Course 2: Environmental Safety and Risk Assessment", Editors: Transilvania University of Braşov, Babeş- Bolyai University of Cluj Napoca, Romania
5. Arnoldus, H. M. L. (1980), *An approximation of the rainfall factor in the Universal Soil Loss Equation*, în vol. Assessment of erosion (editori M. de Boodt & D. Gabriels), Wiley, Chichester, UK, pp. 127-132
6. Barredo, J., Benavides, Annetty, Hervás, J., van Westen, C. (2000), *Comparing heuristic landslide hazard assessment techniques using GIS in the Tirajana basin, Gran Canaria Island, Spain*, în JAG, vol. 2, issue 1, pp. 9-23
7. Boardman, J., Poesen, J. (2006), *Soil erosion in Europe*, John Wiley & Sons Ltd., Chichester, England, 855 pp.
8. Castellanos, E. A. (2008), *Multi-scale landslide risk assessment in Cuba*, doctoral dissertation, University of Utrecht, Olanda, 293 pp.
9. Ciulavu, D., Dinu, C., Cloetingh, S. A. (2002), *Late Cenozoic tectonic evolution of the Transylvanian Basin and northeastern part of the Pannonian Basin (Romania): Constraints from seismic profiling and numerical modeling*, European Geosciences Union, Stephan Mueller Special Publication Series, vol. 3, pp. 105–120
10. Cocean, P., Filip, S. (2008), Geografia regională a României, Presa Universitară Clujeană, Cluj- Napoca, 242 pp.
11. Coteţ, P. (1957), *Depresiunea Baia Mare. Observaţii geomorfologice*, în Probleme de geogr., vol V, pp. 141-160
12. Cubito, A., Ferrara, V., Pappalardo, G. (2005), *Landslide hazard in the Nebrodi Mountains (Northeast Sicily),* Geomorphology, 66, pp. 359-372
13. Dai, F. C., Lee, C. F. (2002), *Landslide characteristics and slope instability modeling using GIS, Lantau Island, Hong Kong*, Geomorphology, 42, pp. 213-228
14. Dârja, M.(2000), *Îmbunătăţiri funciare- combaterea eroziunii solului* (curs), Editura Risoprint, Cluj-Napoca, 391 pp.
15. Desmet, P. J. J., Govers, G. (1996), *A GIS-procedure for automatically calculating the USLE LS-factor on topographically complex landscape units*, Journal of Soil and Water Conservation, 51 (5), pp. 427- 433.
16. Ermini, L., Catani, F., Casagli, N. (2005), *Artificial Neural Networks applied to landslide susceptibility assessment*, Geomorphology, 66, pp. 327-343
17. Ferro, V., Porto, P., (1999), *A comparative study of rainfall erosivity estimation for southern Italy and southeastern Australia*, Hydrological Sciences- Journal des Sciences Hydrologiques, 44 (1), pp. 3-24
18. Fournier, F. (1960), *Climat et érosion: la relation entre l'erosion du sol par l'eau et les précipitations atmosphériques*, Presses Univ. de France, Paris, 201 pp.
19. Ghiurca, V. (1969), *Geologia bazinului neogen Baia Mare* (teza de doctorat), Bucureşti, 364 pp.
20. Glade, T., Anderson, M., Crozier, M. (2005), *Landslide hazard and risk*, Jonh Wiley & Sons Ltd., Chichester, England, 801 pp.
21. Goţiu, Dana, Surdeanu, V. (2008), *Hazardele naturale şi riscurile asociate din ţara Haţegului*, Presa Universitară Clujeană, Cluj- Napoca, 336 pp.
22. Grecu, Florina (2002), *Mapping geomorphic hazards in Romania: small, medium and large scale representations of land instability*, Géomorphologie: relief, processus, environnement, nr. 2, pp. 197-206
23. Goudie, A., Lewin, J., Richards, K., Anderson, M., Burt, T., Whalley, B., Worsley, P. (2005), *Geomorphological techniques*,Taylor & Francis e-Library, New York, 692 pp.
24. Günther, A., Thiel, C. (2009), *Combined rock slope stability and shallow landslide susceptibility assessment of the Jasmund cliff area (Rügen Island, Germany),* Nat. Hazards Earth Syst. Sci., 9, pp. 687-698
25. Guzzetti, F., Carrara, A., Cardinali, M., Reichenbach, P. (1999), *Landslide hazard evaluation: a review of current techniques and their application in a multi-scale study, Central Italy*, Geomorphology, 31, pp. 181-216

26. Hughes, A. O., Prosser, I. P. (2003), *Gully and riverbank erosion mapping for the Murray- Darling Basin*, CSIRO Land and Water, Technical Report, nr. 3, Canberra, 20 pp.
27. Ichim I., Bătucă D., Rădoane Maria, Duma D. (1989), *Morfologia şi dinamica albiilor de râuri*, Ed. Tehnică, Bucureşti, 408 pp.
28. Irimuş, I. A., Vescan I., Man, T. (2005), *Tehnici de cartografiere, monitoring şi analiză GIS,* Editura Casa Cărţii de Ştiinţă, Cluj-Napoca, 244 pp.
29. Lastoria, B., Miserocchi, F., Lanciani, A., Monacelli, G. (2008), *An estimated erosion map for the Aterno-Pescara River Basin*, European Water 21/22, pp. 29-39
30. Lee, S., Sambath, T. (2006), *Landslide susceptibility mapping in the Damrei Romel area, Cambodgia using frequency ratio and logistic regression models*, în Environmental Geology, vol. 50, nr. 6, pp. 847-856
31. Lee, S., Pradhan, B. (2007), *Landslide hazard mapping at Selangor, Malaysia using frequency ratio and logistic models*, Landslides, 4, pp. 33-41
32. Lu, D., Li, G., Valladares, G. S., Batistella, M. (2004), *Mapping soil erosion risk in Rondônia, Brasilian Amazonia: using RUSLE, remote sensing and GIS*, Land Degradation &Development, 15, pp. 499-512
33. Mac, I. (1986), *Elemente de geomorfologie dinamică*, Ed. Academiei R.S.R., Bucureşti, pp. 51-147
34. Moore, I. D., Turner, A. K., Wilson, J. P., Jenson, S. K., Band, L. E. (1993), *GIS and land-surface-subsurface process modeling*, în Environmental modeling with GIS, pp. 196-230
35. Moţoc, M., Sevastel, M. (2002), *Evaluarea factorilor care determină riscul eroziunii hidrice în suprafaţă*, Editura Bren, Bucuresti, 60 pp.
36. Pandi, G. (1997), *Concepţia energetică a formării şi transportului aluviunilor în suspensie. Aplicaţie în nord-vestul României,* Editura Presa Universitară Clujeană, Cluj Napoca, 229 pp.
37. Panizza, M. (1996), *Environmental geomorphology,* Developments in earth surface processes, vol. 4, Elsevier, Olanda, 268 pp.
38. Patriche, C. V., Căpăţână, V., Stoica, D. L. (2006), *Aspects regarding soil erosion spatial modeling using the USLE/RUSLE within GIS*, Geographia Technica, nr. 2, Cluj-Napoca, pp. 87- 97
39. Paucă, M. (1961), *Probleme geologice în bazinul Băii Mari*, Dări de seamă ale şedinţelor, Institutul de Geologie, vol. XLIX, pp. 161-168
40. Petrea, Rodica, Petrea, D. (1994), *Tipurile genetice de relief din Dealurile de Vest*, Analele Universităţii din Oradea, fascicula geografie, tom IV, Oradea, pp. 16-24.
41. Pinna, M. (1977), *Climatologia*, Unione tipografico-editrice torinese, Torino, Italia, 206 pp.
42. Pop, P. Gr. (2005), *Dealurile de Vest şi Câmpia de Vest*, Ed. Universităţii din Oradea, Oradea, pp. 5-21, 60-73
43. Posea, Gr., Popescu, N., Ielenicz, M. (1978), *L' évolution de la plaine alluviale du Someş dans la depression de Baia Mare et dans la plaine de l'ouest,* Rev. Roum. Géol. Géophys. et Géogr., seria géographie, tom XXIII, nr. 2, pp. 213-226
44. Rădoane, Maria, Ichim, I., Rădoane, N., Dumitrescu, Gh., Ursu, C. (1996), *Analiza cantitativă în geografia fizică. Metode şi aplicaţii*, Ed. Univ. „Al. I. Cuza'', Iaşi, 350 pp.
45. Rădoane, Maria, Rădoane, N., Ichim, I., Surdeanu, V. (1999), *Ravenele. Forme, procese şi evoluţie*, Ed. Presa Universitară Clujeană, Cluj- Napoca, 260 pp.
46. Rădoane, Maria, Rădoane, N., Dumitriu, D. (2003), *Geomorphological evolution of river longitudinal profiles*, Geomorphology, 50, Elsevier, Olanda, pp. 293-306
47. Rădoane, Maria, Rădoane N., Cristea I., Gancevici-Oprea D. (2008), *Evaluarea modificărilor contemporane ale albiei râului Prut pe graniţa românească*, Revista de geomorfologie, vol. 10, pp. 57-71
48. Rhea, Susan (1993), *Geomorphic observations of rivers in the Oregon Coast Range fron a regional reconnaise persepctive*, Geomorphology, vol. 6, nr.2, Elsevier Science Publisher B.V., Amsterdam, pp. 135-150
49. Richard, G. A., Julien, P. Y., Baird, D. C. (2005), *Statistical analysis of the lateral migration of the Rio Grande, New Mexico,* Geomorphology, 71, Elsevier Science Publisher B.V., Amsterdam, pp. 139-155
50. Rusu, C. (2002), *Masivul Rarău. Studiu de geografie fizică*, Editura Academiei Române, Bucureşti, 417 pp.
51. Saavedra, C. (2005), *Estimating spatial patterns of soil erosion and deposition in the Andean region using geo-information techniques. A case study in Cochabamba, Bolivia*, Ph.D. dissertation, Wageningen University, The Nederlands, 244 pp.
52. Savu, Al. (1963), *Podişul Someşan. Studiu geomorfologic*, teza de disertaţie, Cluj-Napoca, pp. 4-216
53. Savu, Al. (1981), *Les monts moyens insulairea du nord- oust de la Transylvanie*, Rev. Roum. Géol., Géophys., Géogr., seria géographie, tom 25, nr. 1, Bucureşti, pp. 85-89
54. Shrestha, P., Tamrakar, N. K. (2007), *Bank erosion process and bank material loss potential in Manahara River, Kathmandu, Nepal*, Bulletin of the Departament of Geology, Tribhuvan University, Kathmandu, Nepal, vol. 10, pp. 33-44
55. Snow, R. S., Slingerland, R. L. (1987), *Mathematical modelling of graded river profiles*, Journal of Geology, vol. 95, pp. 15 - 33.

56. Surdeanu, V. (1998), *Geografia terenurilor degradate. I. Alunecări de teren*, Editura Presa Universitară Clujeană, Cluj-Napoca, 274 pp.
57. Surdeanu. V. (2003), *Landslides in the mountains areas of Eastern Carpathian Flysch*, Wurzburger Geographische Manuskripte, 63, pp. 153-163
58. Surdeanu, V., Rădoane, Maria, Rădoane, N. (2003), *Erosion and gulling in Romania*, în ,,Gully Erosion in Mountain Areas: Processes, Measurement, Modelling and Regionalization'', France, pp. 150-155
59. Surdeanu, V. (2004), *The study of landslides*, în vol. dedicat Congresului Internațional de Geografie, Glasgow, 2004, Buletinul Societății de Geografie din România, tom 10, CD Press, pp. 63-67
60. Surdeanu, V., Rădoane, Maria, Rădoane, N. (2004), *Eroziunea terenurilor prin ravenare în România*, în vol. ,,Geography within the Context of Contemporary Development'', Ed. F&F Internațional, Cluj- Napoca, pp. 35-47
61. Szabo, J. (2003), *The relationship between landslide activity and weather: examples from Hungary*, Natural Hazards and Earth System Sciences, 3, pp. 43-52
62. Tricart, J., Raynal, R., Besançon, J. (1972), *Cônes rocheux, pédiments, glacis*, Annales de Géographie, nr. 443, an LXXXI, Librairie Armand Colin, Paris, pp. 1-24
63. van Westen, C. J., Getagun, F. L. (2003), *Analyzing the evolution of the Tessina landslide using aerial photographs and digital elevation models*, Geomorphology, 54, pp. 77-89
64. Wilson, J. P., Gallant J. C. (2000), *Terrain Analysis: Principles and Applications*, John Wiley and Sons, New York, pp. 87-131
65. Wischemeier, W. H., Smith, D. D. (1978), *Predicting rain fall erosion losses- a guide to conservation planning*, Department of agriculture, Handbook No.537, US Dept. Agric., Washington, DC., 58 pp.
66. Yuksel, A., Gundogan, R., Akay, A. E. (2008), *Using the Remote Sensing and GIS Technology for Erosion Risk Mapping of Kartalkaya Dam Watershed in Kahramanmaras*, Turkey, Sensors, nr. 8, pp. 4851-4865
67. Zachar, D. (1982), *Soil Erosion. Developments in Soil Science*, Elsevier Scientific Publishing Company, Amsterdam, 548 pp.
68. Zăvoianu, I. (1978), *Morfometria bazinelor hidrografice*, Editura Academiei R.S.R., București, 176 pp.
69. Zêzere, J. L. (2002), *Landslide susceptibility assessment considerating landslide typology. A case study in the north of Lisbon (Portugal)*, Natural Hazards and Earth System Sciences, vol. 2, European Geophysical Society, pp. 73-82
70. ****(2002) Ordinul nr. 223 din 28 mai 2002*, privind aprobarea *Metodologiei întocmirii studiilor pedologice şi agrochimice, a Sistemului național şi județean de monitorizare sol-teren pentru agricultură*, publicat în Monitorul Oficial, Partea I, nr. 598 din 13 august 2002, anexa nr. 4, Norme de conținut http://www.ngo.ro/legislatie
71. *** (2007) http://www.eea.europa.corine2000eu/themes/landuse
72. *** (2007) http://recensamnat.referinte.transindex.ro
73. *** (2008) http://www.apia.org.ro
74. *** (2008) http://www.icpa.ro
75. *** (2009) http://www7.ncdc.noaa.gov/climvis/CdoDispatcher
76. *** (2009) http://www.anif.ro/patrimoniu