BABEŞ – BOLYAI UNIVERSITY
FACULTY OF GEOGRAPHY

PhD Thesis

THE EFFECT OF PRECIPITATION ON THE MORPHODYNAMICS OF THE MOUNTAINOUS AND HILLY SPACE IN CLUJ COUNTY

Summary

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Chapter 1. INTRODUCTION

This paper is the result of the research conducted during 2010 - 2013 period, having as objectives the analysis of the distribution, intensity and frequency of rainfall, the current morphodynamics analysis for predicting the trends and developments by identifying areas of the county in which pluvial aggression occurs more intense and areas affected by erosion and mapping them, and thus proving to be useful both theoretically and practically.

The research activity was conducted in accordance with the proposed objective, through several stages, starting with the documentation stage when the existing data in the literature on the area of study were analyzed, completed by research in the field in order to grasp the dynamics of surface erosion geomorphological processes, gullying and torrential and delimitation of areas affected, followed by laboratory stage and ending by making cartographic and thematic maps regarding these processes.

The paper is structured in five chapters: the first chapter is an introduction, which includes the database, research methodology and historical research. The second chapter provides an analysis of the natural setting and includes general aspects of lithology and topographhy, climate issues, general issues on hydrography, vegetation and soils. The third chapter analyzes rainfall and its role in morphogenesis. The morphodynamics of the mountainous and hilly area of Cluj is analyzed in chapter four. The last chapter deals with pluvial aggression and erosion zoning in the studied region.

Meteorological data on rainfall used in this paper come from six weather stations located in all major relief units in Cluj county, during a climatic period between 1971-2000 (source: ANM Bucureşti). The meteorological stations in the county are located at different altitudes, and thus conditions in the several units of relief can be observed. Distribution of meteorological stations relief units is as follows: the interfluve - two stations (Cluj-Napoca and Turda), in lane valley - one station (Dej), the depression - one station (Huedin) and in the mountains two stations - Băişoara located on an interfluve, and Vlădeasa, located on mountain with the same name.

Chapter 2. THE NATURAL SETTING OF CLUJ COUNTY

Cluj County, with an area of 6,674 km², is located in the northwestern part of Romania, between parallels 47º28'44" North and 46º24'47" South, and meridians 23º39'22" West and 24º13'46" East.

In the West of Cluj county, the following subunits of Apuseni Mountains are found: Mountais Vlădeasa, Bătrâna, Gilău, Muntele Mare, Trascăului, Plopişului, Meseşului, and in the northern part subunits of the Someşan Plateau, and in the south-eastern part those of the Transilvania Plane (fig.1).

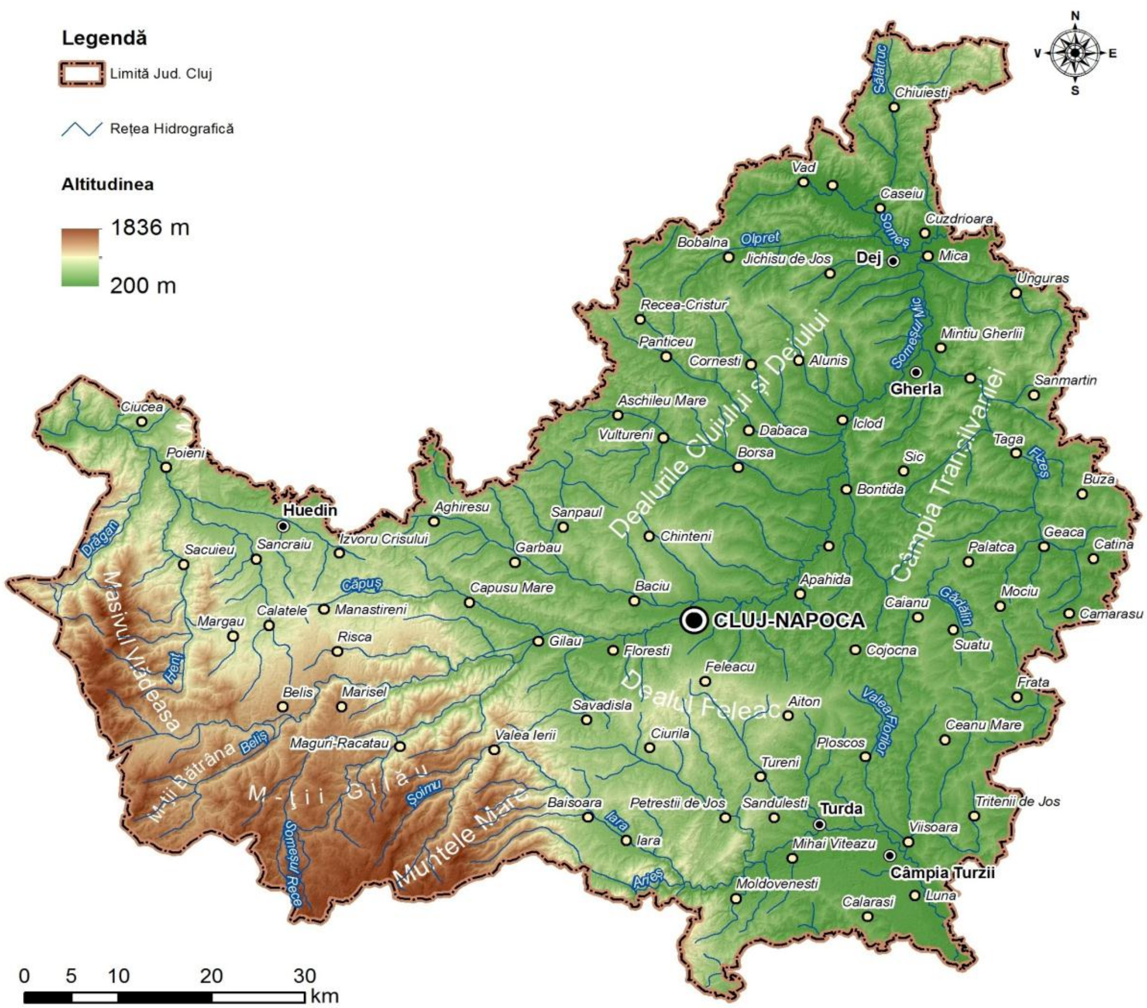

Fig. 1. Physical map of Cluj County

The north-eastern part of the county overlaps Somes Plateau (Cluj and Dej Hills, the southern extremity of Sălătruc Hills, south-western extremity of Ciceului Hills) and southern and southeast part overlap with Transylvania Plain (Someş Plain and the northwest of Mureş Plain).

The geological structure of Cluj County is characterized by a variety of geological formations from the Prehercinian to Quaternary deposits (fig. 2).

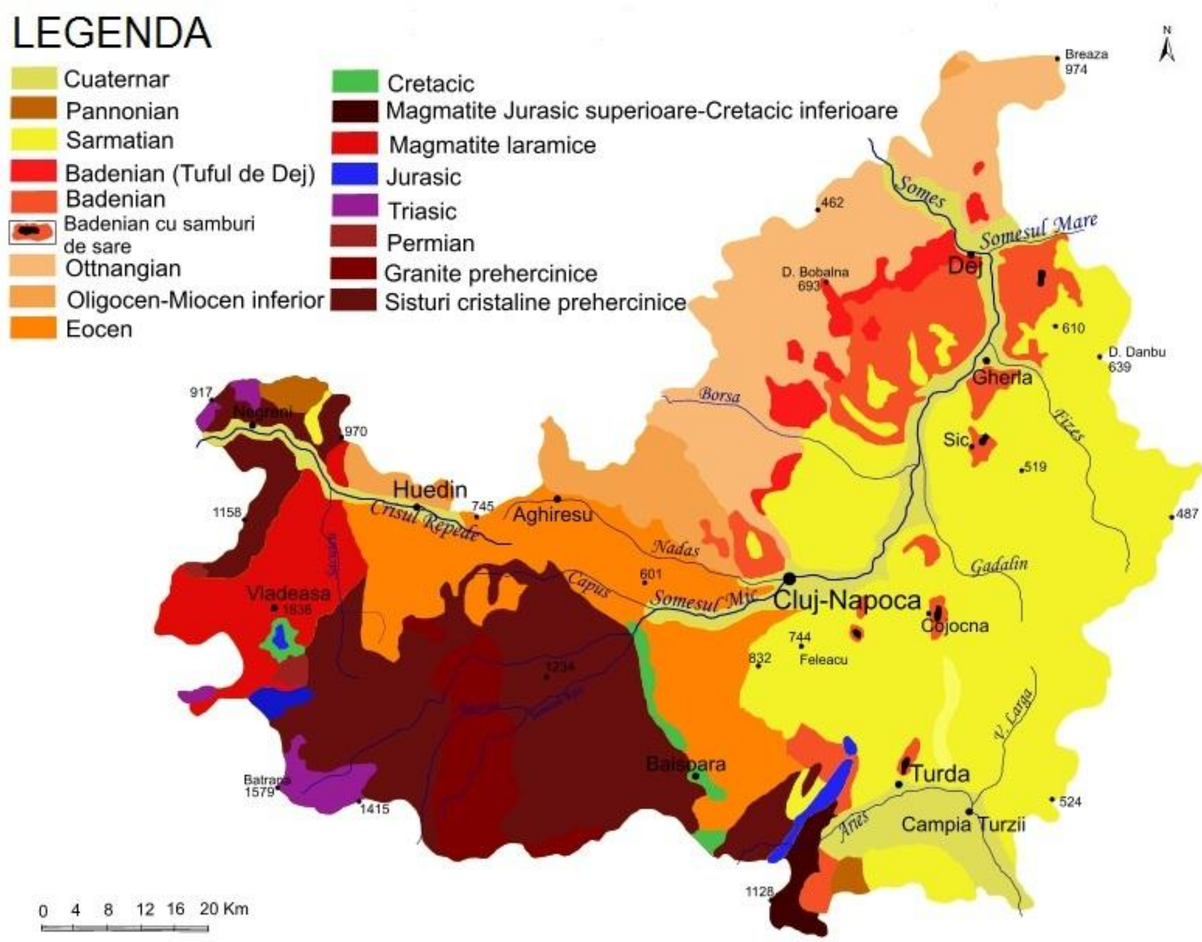

Fig. 2. Geologic map of Cluj county (according to Pop, 2007)

The mountains Gilău, Muntele Mare, Munţii Vlădeasa, Munţii Meseş şi Plopiş are composed of metamorphic formations, and granitic intrusions are found in Gilău Mountains and Muntele Mare, being a result of geological evolution. Mesozoic is represented predominantly in Trascău and Vlădeasa Mountains, and only isolated in the other mountain formations. Neozoic, by detrital formations, is characteristic to the hills regions.

Cluj County is located in a temperate continental climate with oceanic hues, which influences rainfall and geomorphological processes initiated by this.

Cluj county has numerous water resources represented by rivers, lakes and groundwater. The network of rivers belongs to the river basins of Someş, Crişul Repede and Arieş rivers (fig. 3).

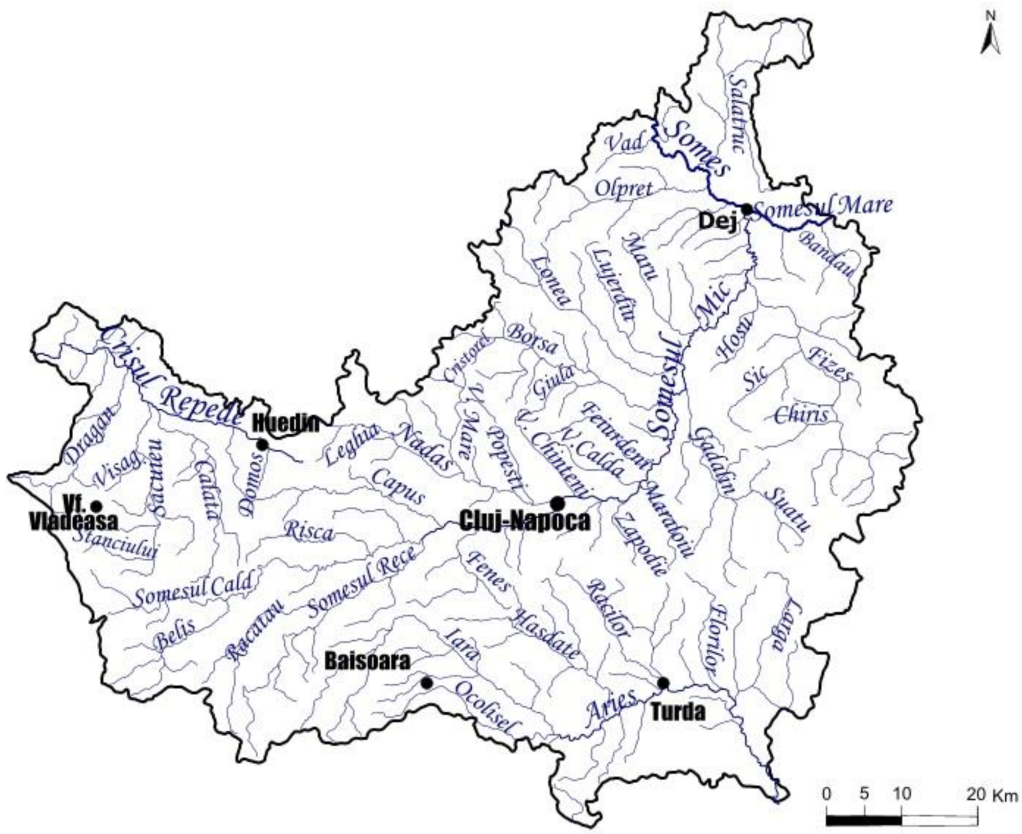

Fig. 3. The hydrographic network of Cluj County

The presence of vegetation protects the soil against erosion. The canopy takes part directly or indirectly in catching precipitation water. The higher the degree of ground covered with vegetation, the less intense the rainfall impact on the environment (Dragotă, 2006).

The vegetation of the Apuseni Mountains is dominated by natural forest vegetation represented by spruce, fir, larch, juniper on peaks, and below the coniferous forests limit, beech, hornbeam, oak, lime. The vegetation of the Transylvanian Plain (afferent to Cluj county) is the forest steppe and is found in the hills of Cojocna - Sic and Aiton - Viişoara at altitudes between 250-500 m. Forest vegetation is represented by oaks, sessile, hornbeam, turkey oak, maple, ash and the highest peaks in north, beech. The Somes Plateau Area has typical forest vegetation, the main vegetation formations consist of traces of pure beech (with predominance of beech beech or hornbeam) and pure sessile areas. The hills vegetation includes sessile, turkey oak, sycamore maple, field maple, hornbeam, beech, lime, ash, wild pear, and shrubs: hazel, dogwood, horn, hawthorn, privet. In river valleys, forests are composed of trees with soft wood: poplar, willow, alder (Pop, 2007).

Soils play an important role in differentiating the current relief modeling processes, also reflecting trought the profile peculiarities the conditions in which relief evolution took place in different periods (Bălteanu, 1983).

Chapter 3. RAINFALL AND ITS ROLE IN MORPHOGENESIS

Rainfall is an important climatic element characterized by a vast spatio-temporal variability, largely responsible for the onset and subsequent development of geomorphological processes. Energy contained by rainfall is divided into two, namely the kinetic energy of rainfall, that is their striking force with direct role in the destruction of aggregates on the surface of the soil and their potential energy, flow energy on slopes and river beds, with significant role in the detachment and transport of the parts of broken rock on its way (Tufescu, 1966).

For characterizing precipitations (amount, duration, intensity, frequency) data from weather stations in Cluj County, for the period 1971-2000 were used. Cluj County is situated in the north-western part of Romania, and the movement of air masses under the action of the main baric systems causes a predominance of western circulation, with advections of moist air (maritime polar) for the county. The mountain in the western part of the county are positioned perpendicular to the flow direction, thus the western slopes receive a significant amount of rainfall, while on the eastern slopes this amount is reduced due to the foehn effect.

The analysis of average annual rainfall quantities shows that they decrease from west to east, from the mountains to the lower areas of the plateau and the plains of the county. In Cluj and Dej Hills average anual quantities reach an annual average of 600-700 mm and isolated above 700mm, and in the Transylvanian Plain quantities fall around 500 mm and isolated over this value. In the mountain region, precipitation increases gradually with altitude, up to a maximum value of exceeding 1150 mm in the high mountain area at altitudes above 1800 m.

The distribution of average monthly precipitation amounts in comparison to the six meteorological stations in the study area can be seen in figure 4.

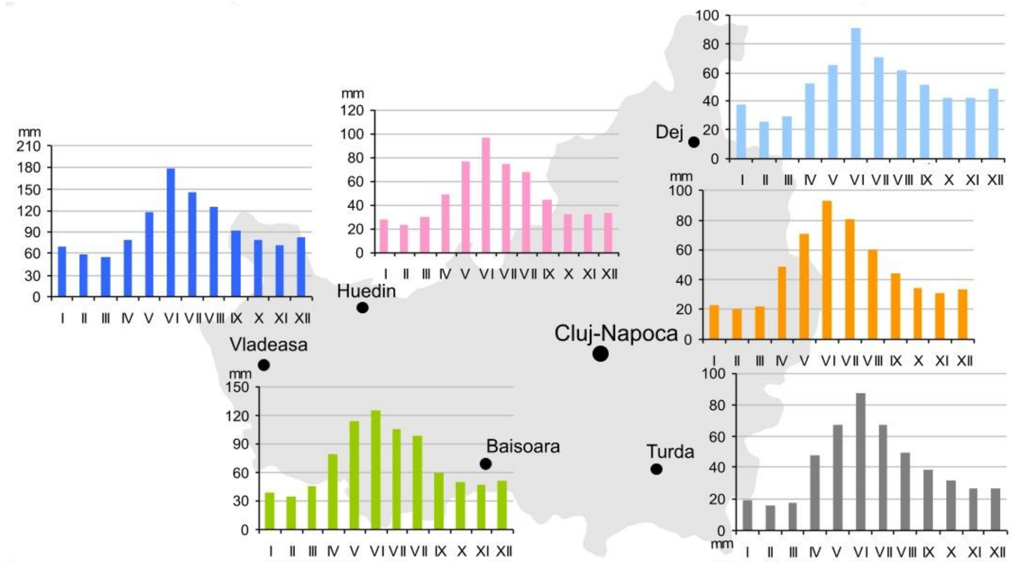

Fig. 4. The distribution of average monthly precipitation amounts for the period 1971-2000, in Cluj County

Processed after ANM archive (1971-2000)

In the warm half of the year, from April through September, the most significant quantities of precipitation of the year is registered. The months that have the highest percentage in the realization of this quantity are June, month of maximum rainfall, July and May. The seasonal distribution of precipitation can be observed in figure 5.

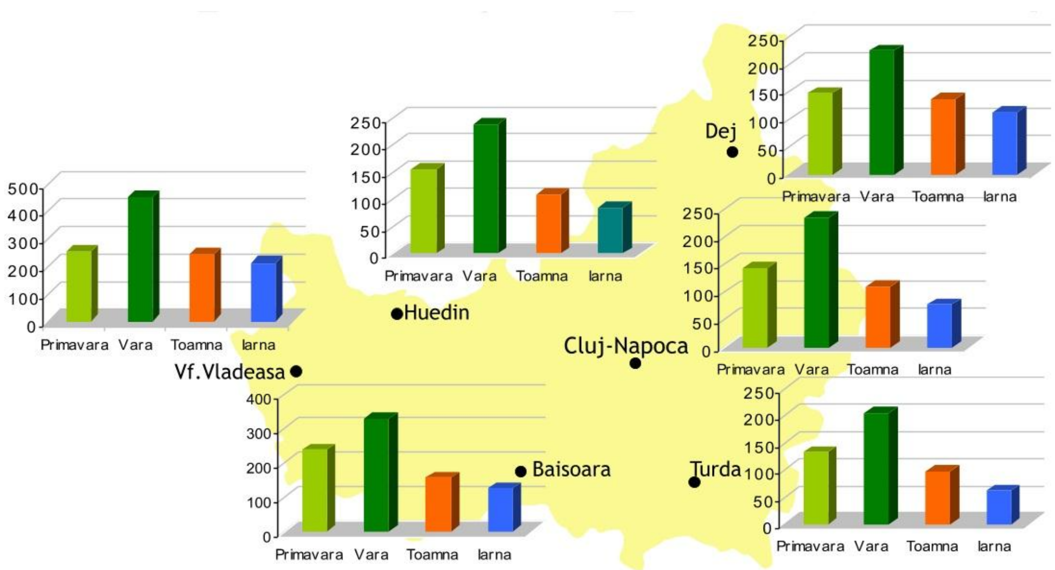

Fig. 5. The distribution of rainfall in the warm semester, during 1971-2000, in Cluj County

Processed after ANM archive (1971-2000)

In spring, due to high humidity and lower evaporation, flow is more intense, the same is true for the summer season, when an increase in the frequency of heavy rains is registered. Lower values of flow are recorded in autumn and winter season.

Erosion occurs with greater intensity in the warm semester of the year. On the southern slopes, which are sunny and dry, surface erosion due to heavy rains during the summer is manifested more intensely than in the northern slopes, which are moist and protected by the denser vegetation.

Maximum annual quantities of rainfall registered in 24 hours, from 1971 to 2000 are shown in figure 6. The largest recorded values during the 30 years analyzed period is highlighted in red. On the abscissa, the years of the period are listed, the first year denoted by 1 is 1971, and on the ordinate the corresponding precipitation for each year are listed. For the meteorological stations in the study area, the maximum quantities vary greatly from year to year, therefore the values recorded in the lowlands range from 17.1 mm at Huedin in 2000 (considered a dry year) and 68.1 mm recorded in 1973 (at Huedin). In the mountain region, the lowest values were 24.6 mm Băişoara in 1982 and the highest value of 88.2 mm in 1975 Vlădeasa.

It can be seen that the maximum of the largest recorded values of the period were made in the first decade (1971-1980). At Huedin, Dej, Vlădeasa and Turda they were done by 1975 and in Băişoara in 1979. The exception was the Cluj-Napoca station, where the maximum was recorded at the end of the second decade, in 1989.

Using the Hyfran program - by analyzing the data string, using the tests and laws of probability, the probability of exceeding certain thresholds of the maximum amount of rainfall in 24 hours was calculated. It appears that at least every 10 years, the annual maximum rainfall in 24 hours exceeds the 50mm threshold at all theweather stations except Turda, where the maximum annual amount of rainfall in 24 hours can exceed once every 10 years the 48.8mm threshold.

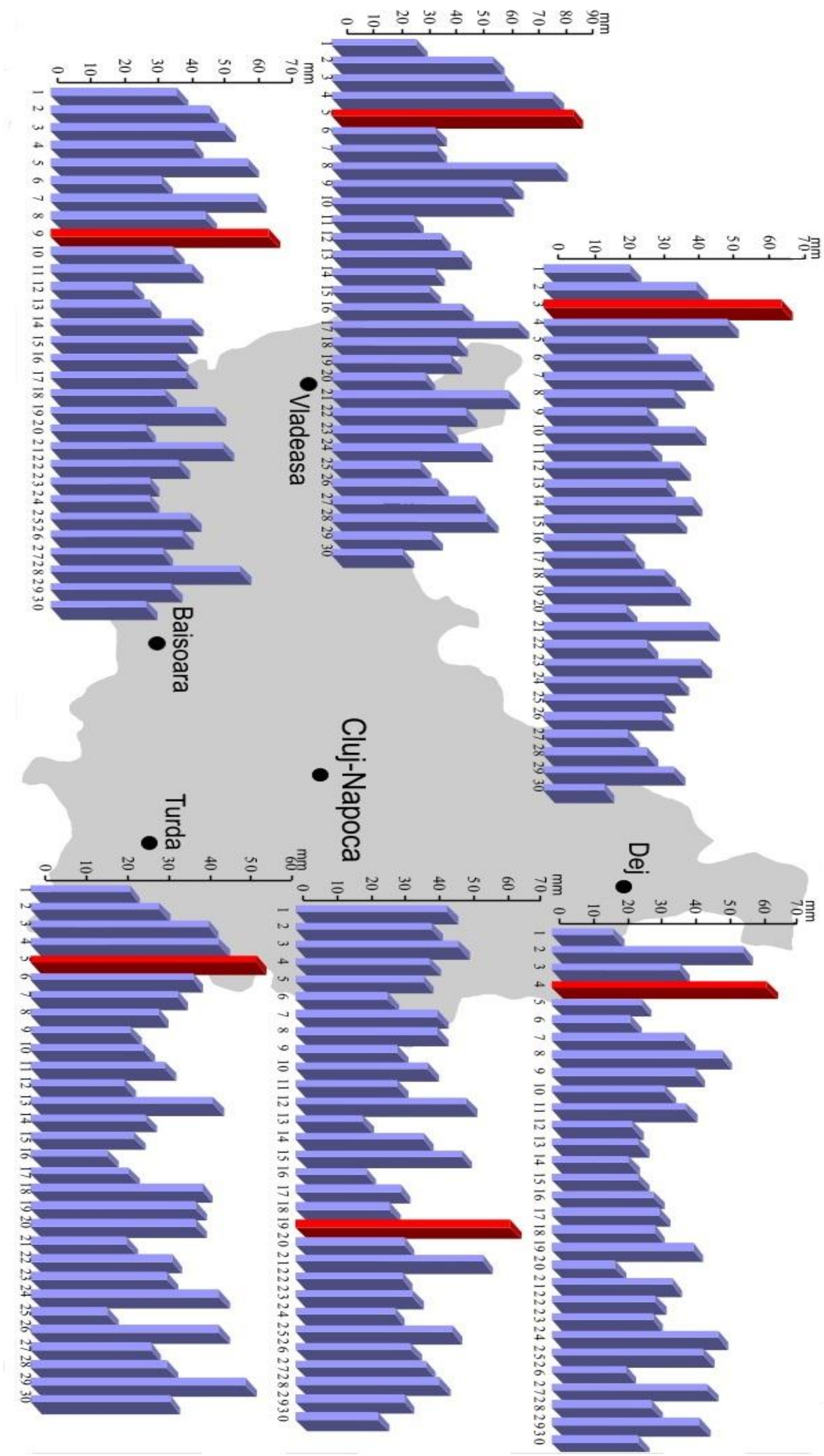

Fig.6. Maximum amounts in 24 hours between 1971 - 2000, in Cluj County

Processed after ANM archive (1971-2000)

A synoptic analysis was done for the cases of severe weather which led to the accumulation of large amounts of rainfall in a short time period at the weather stations, over the period analyzed. It is shown that a common feature of all the analyzed cases is the presence in the medium troposphere of thalweg depression generally related to the Icelandic depression and/or of some depression-type cut-off nuclei which influenced weather in the analyzed area.

At ground level, associated with the cut-off type nuclei of altitude, cyclonic fields with low pressure values (under 1010 - 1005hPa) were present in the interest area. At the 850hPa level (about 1500m) the presence of a warm dorsal with temperatures ranging from 12 to 17ºC was noted in the early period of the analyzed frame. The warm dorsal at the 850hPa level together with cold core from the middle troposphere (cut-off type) caused a pronounced mass instability and favored the onset of convective phenomena of a very high intensity in the analyzed area. Analyzed periods, during which large quantities of rainfall caused the runoff activation and which had an important role in shaping the landscape, generated changes which, in conditions considered to be average, would require much longer periods of time to unfold.

Excess quantities of precipitation cause intense processes of soil erosion, landslides, and floods (Bălteanu, 2006). In the period 1971-2000, the number of days in which there were significant amounts of precipitation, which reached and/or exceeded the 40mm/24h threshold can be seen in figure 7.

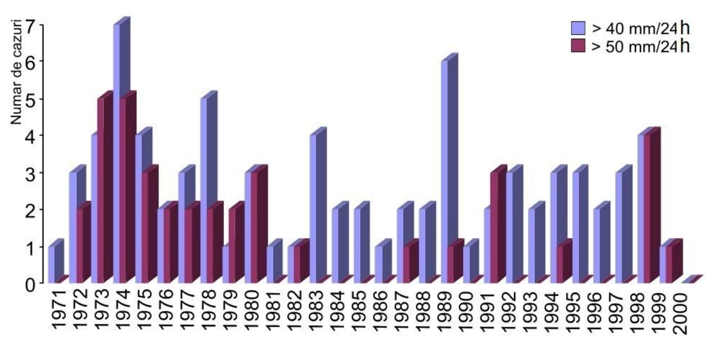

Fig. 7. The distribution of cases in which quantities of precipitation larger or equal to 40 and 50mm/24h have been registered Processed after ANM archive (1971-2000)

The number of cases (events) in which quantitatively significant precipitation were registered is 114, which took place in 99 separate days. It can be seen that in the first decade of the analyzed period abundent rainfall (50mm/24h) were very numerous, they represented 73% of the quantitatively significant rainfall.

The rains that fall over several days increases surface run-off and have an action of erosion on the slopes, increasing as water infiltration capacity decreases. The number of consecutive days with rain is indicative of the intensity of rain erosion processes and mass movement, because the amount and duration of rainfall contributes to the state of fragility of the systems (Goţiu, 2007).

For the weather stations in Cluj, the annual number of cases of consecutive days with rainfall was analyzed, from 2 days to 5 days, and they were represented in figure 8. The largest percentage is for cases with 2 consecutive days, followed by those with 3 days.

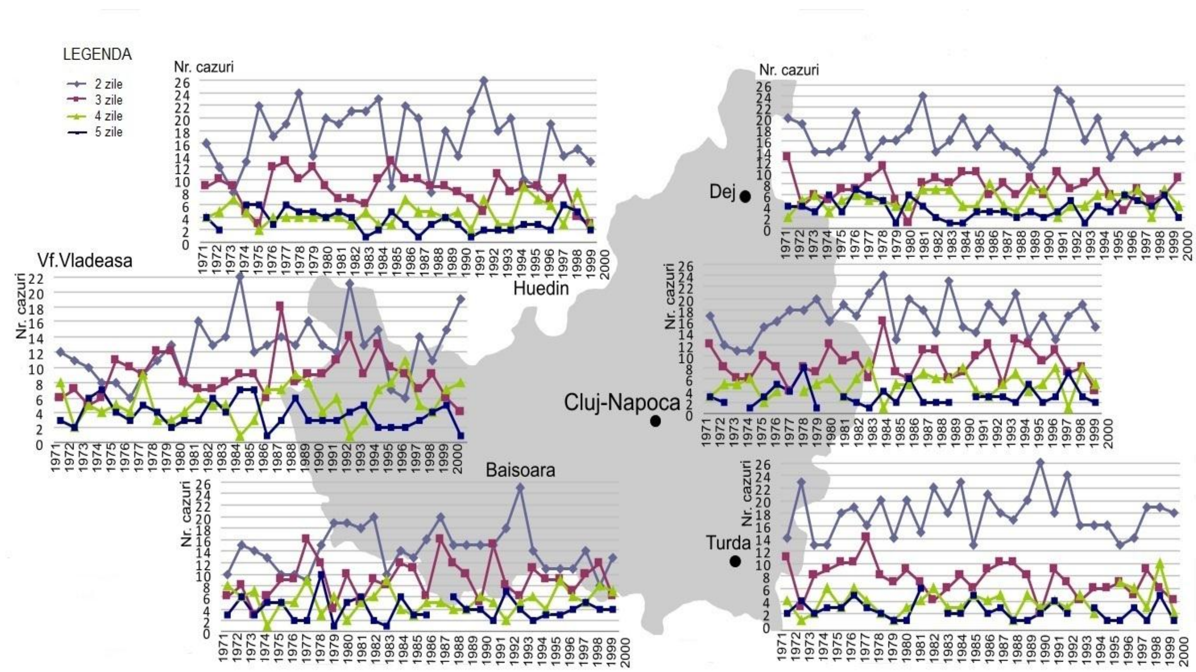

Fig. 8. The distribution of consecutive days with precipitation per year, during 1971-2000, in Cluj County
Processed after ANM archive (1971-2000)

The distribution on semesters of cases with consecutive days with rain at the weather stations in Cluj County can be seen in figure 9. The number of cases with 2, 3, 4, and 5 consecutive days with precipitation during the two semesters was analyzed by comparison. It can be seen that the differences between the number of cases of consecutive days with precipitation in the two semesters of the year is quite low.

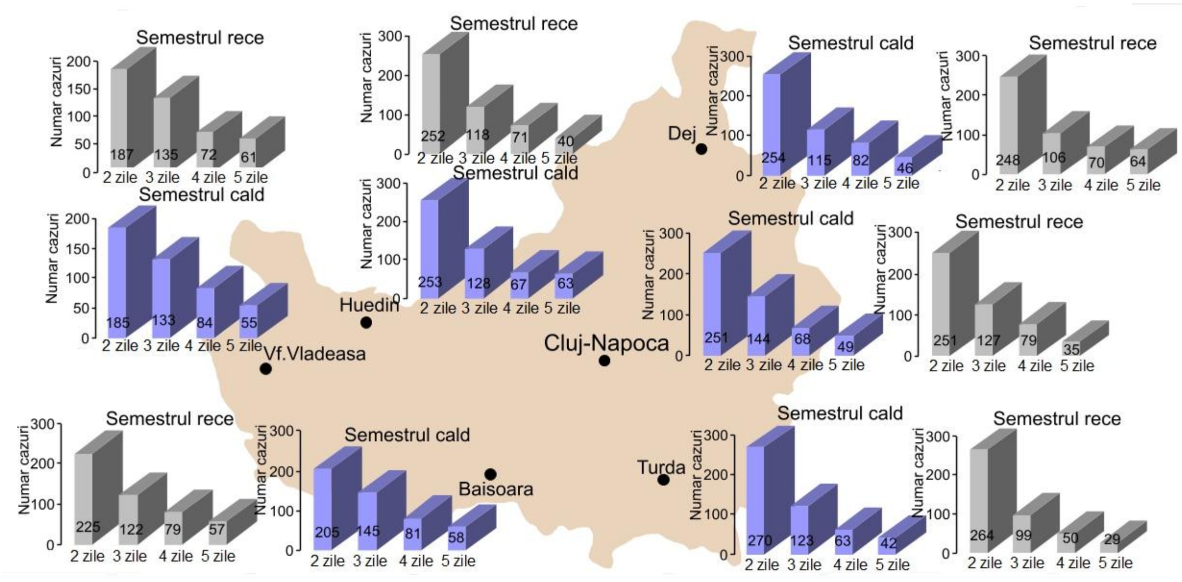

Fig. 9. The distribution of consecutive days with precipitation on semesters, during the period 1971-2000, in Cluj County
Processed after ANM archive (1971-2000)

Heavy rains are rains with high intensity and short duration falling on small areas, and are more common during the warm season. The water from torrential rainfall has force to dislodge and carry soil particles, thus soil erosion is very high during these rains. For Cluj county, monthly distribution of maximum intensity rainfalls was analyzed and it can be observed in figure 10. Most cases of the torrential rain during the year were recorded in June, representing 20% at Dej, 21% at Cluj-Napoca, 24% at Huedin, 25% at Băişoara, 29% at Turda, and 31% at Vlădeasa, from the annual number of cases**.**

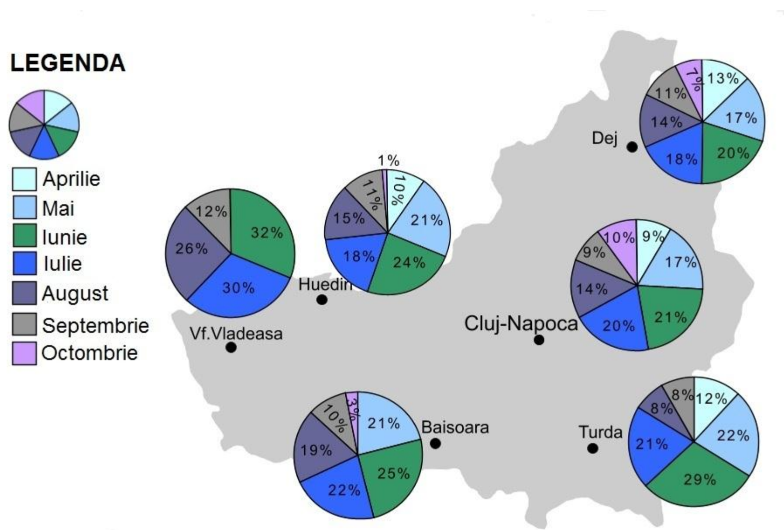

Fig. 10. Monthly percentage of maximum intensity of heavy rains in Cluj County
Processed after ANM archive (1971-2000)

Heavy rain with water drops with diameters of 3-7 mm and hail have an impact in rain erosion and, according to some authors, in the washing of the surface and runoff (Ielenicz, 2005). In the high mountain area, the average annual number of days with hail is 9.7 days at Vlădeasa and the for rest of the weather stations does not exceed two days. The total number of days in which hail fell in the analyzed period ranged from 27 cases at Huedin and 331 cases at Vlădeasa (fig. 11).

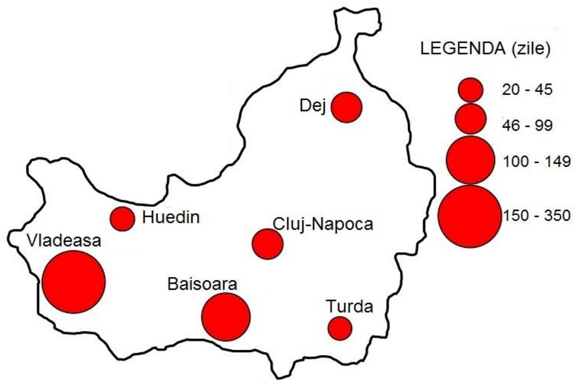

Fig. 11. The number of days with hail, during the period 1971-2000, in Cluj County

Processed after ANM archive (1971-2000)

Chapter. 4. THE MORPHODYNAMICS OF THE HILLY AND MOUNTAIN AREA IN CLUJ COUNTY

Subunits of the Apuseni Mountains and Transylvanian Depression compose the landscape of Cluj county, its level varying for 1600m (ie 1609m) between Vlădeasa Peak (1836m) and 227m at the exit of the Somes river from the county.

In Cluj county, the monoclinal structure of formations generated the cuesta relief (photo. 1), with the strata tilted from the mountains framw towards the lowlands, and the valleys system developed over this region belongs to the obsecvent and subsequent type (Posea, 1961).

Photo. 1. Top cuesta of the Pietrei Hill (Căpuşului Valey)

Between the structural and petrographic relief there is a direct connection, and the domination of the influence of the structure or nature of the rocks is primarily a matter of stage of evolution. Geological and geographical literature recorded many aspects of petrographic relief, from imposing the nature of the rock to the modeling mechanisms and evolutionary features. The trend to approach the relief formed on limestone is noteworthy, as reflection of the behavior of erosion. (Irimuş, 2003)

Orogen units have a wide petrographic variety, and the valleys have a sharp V cross section, with very inclined sides that have fairly regular slopes, commonly forming gorges - such as Cheile Turzii, Hăşdate Valley in Trascău Mountains (photo. 2), with numerous thresholds, and the largest waterfalls are found. The Răchiţele Waterfall (Vălul miresei) located on the Stanciului Valley in Vlădeasa can be seen in photo. 3.

Photo. 2. Cheile Turzii, on Hăşdate Valey, in Trascăului Mountains

Photo. 3. Răchiţele Waterfall

Karst topography develops on soluble rocks (limestone, salt, gypsum). It is located on the Somes Plateau (Eocene limestone), Turda, Cojocna, Ocna Dej (the salt karst is located where salt appears to date). Karst topography developed on Gypsum has a low prevalence, being reported near Cheile Turzii. Sandstone is rough, but also permeable, allowing the development of a massive relief that evolves from physical disintegration. Landslides and torrential bodies find favorable conditions for development on clayey and marly sandstone. Limestone relief is the result of processes of fragmentation of the limestone massives and blocks, developed in the interfluves and slopes (photo 4). Steep limestone often fit the periphery of calcareous plateaus.

Photo. 4. Relief developed on limestone (com Gârbău)

Photo.5. Red clay (Rădaia, com.Baciu)

Clay (photo. 5), a result of cementation or consolidation of pelites (very fine grained materials), is a rock avid for water when dry, waterproof when it is water saturated, and by swelling it expands, becomes plastic and slides downhill; the most characteristic feature of the morphology developed on clays is given by landslides and mudflows (Rădoane, 2001).

Sand is a detritus rock with high permeability which allows rainfall water to infiltrate easily, thus greatly reducing surface runoff.

The process of erosion is influenced by the characteristics of the landscape, mainly by the slope inclination and length. The inclination of the slopes makes erosion manifest differently, thus, for more pronounced inclination the flow is faster, the percentage of water infiltrated in the soil decreases and the water's power of erosion increases. The slopes' exposure influence the type of processes that take place at their level (photo. 6).

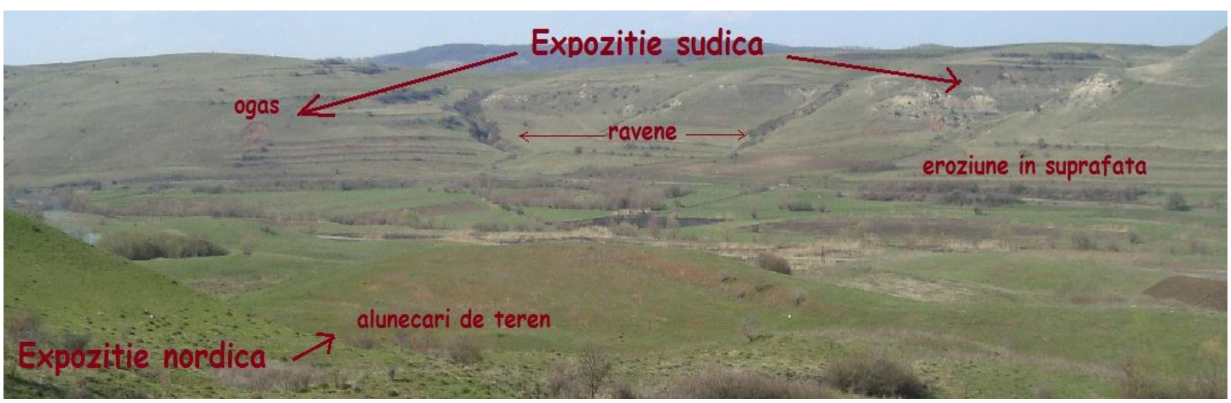

Photo. 6. Geomorphological processes carried out on slopes with southern and northern exposition, on the Nadăş Valley

On the slopes with northern exposure, landslides are predominant, and on the slopes with southern exposition erosion occurs more intense, and is conducted both on the surface and in the deep.

Drains plays a decisive role in transporting materials both on the slopes and in the riverbeds. For the slopes, the physiognomy (byslope and length), together with leakage, plays a very important role in the transport and accumulation of materials. Sediment transport is an important process because it controls their dynamics and thus the physiognomy of the slope (Goţiu, Surdeanu, 2008). The areas affected by erosion at different stages provide silt in rivers. The stronger the erosion, the greater the amount of silt (Rădoane, 2001). In Cluj County, in the mountains area, alluvial production does not exceed 0.5 tonnes/ha/year, and an increase of the quantities from the west to the east of the county is noted. In the Cluj and Dej Hills and Cojocna - Sic Hills the highest amount of silt is accumulated, which is 2.5 - 5.0 tons/ha/year.

Chapter 5. PLUVIAL AGGRESSION AND THE ZONING OF EROSION

Rating pluvial aggressiveness on substrate was determined using indexes. The Fournier Index (FI), Modified Fournier Index (MFI), and Angot index were determined.

The Fournier Index (FI) is based on the correlation between rainfall and the measured amount of sediments. Because it is based on easily accessible input data (the amount of precipitation in the wettest month of the year and the annual amount of precipitation) it has enjoyed great success. The formula for calculating this index is:

$$IF = P_m^2/P$$

P_m = the amount of precipitation in the wettest month of the year

P = the annual amount of precipitation

Pluvial aggressiveness manifested differently for the six weather stations in Cluj County in the period 1971-2000. Pluvial aggression computed using the Fournier Index is low and very low in the hills and plateaus region, low in Gilău Mountains and Muntele Mare and moderated in Vlădeasa Mountains.

The percentage of different classes of pluvial aggressiveness can be seen in figure 12.

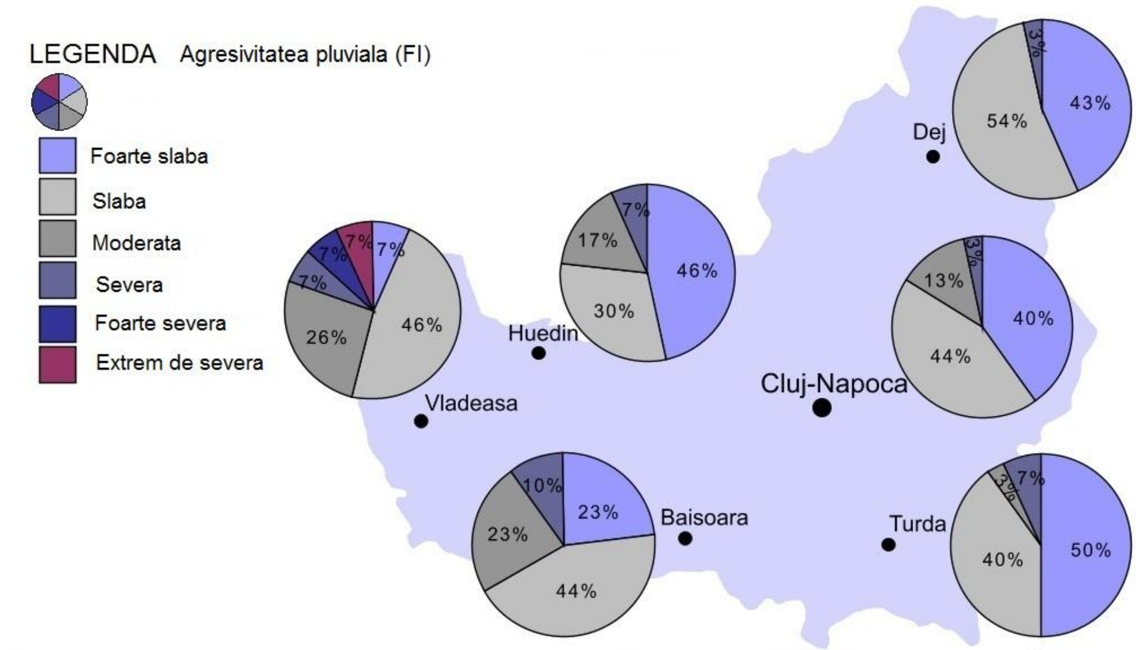

Fig. 12. The percentage of pluvial aggression classes, after Fourier FI (Fournier, 1960), for the period 1971-2000

It was found that for the meteorological stations in the county of Cluj, in the analyzed period, the predominant pluvial aggression was low and very low, so at Cluj-Napoca (83.7%), at Turda weather station (90.1%), at Huedin (76.8%), at Dej (96.6%).

In the mountain region, at Băişoara, the percentage of years in which pluvial aggression was very low and low was 67.7%, and at Vlădeasa it was 52.6%.

A modified version of the Fournier Index (FI) was introduced by Arnoldus (1980) for FAO, in the study of degraded land, Modified Fournier Index (MFI) with the following formula:

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

p_i = average amount of rainfall for the month i (mm)
P = average annual amount of precipitation

Pluvial aggression classes based in FMI

Class	MFI (mm)	Pluvial aggression
1.	< 60	Very low
2.	60 - 90	Low
3.	90 – 120	Moderate
4.	120 – 160	High
5.	> 160	Very High

In the study area, the average values of this indicator are between 63.3 mm at Turda and 131.6 mm at Vlădeasa (fig. 13).

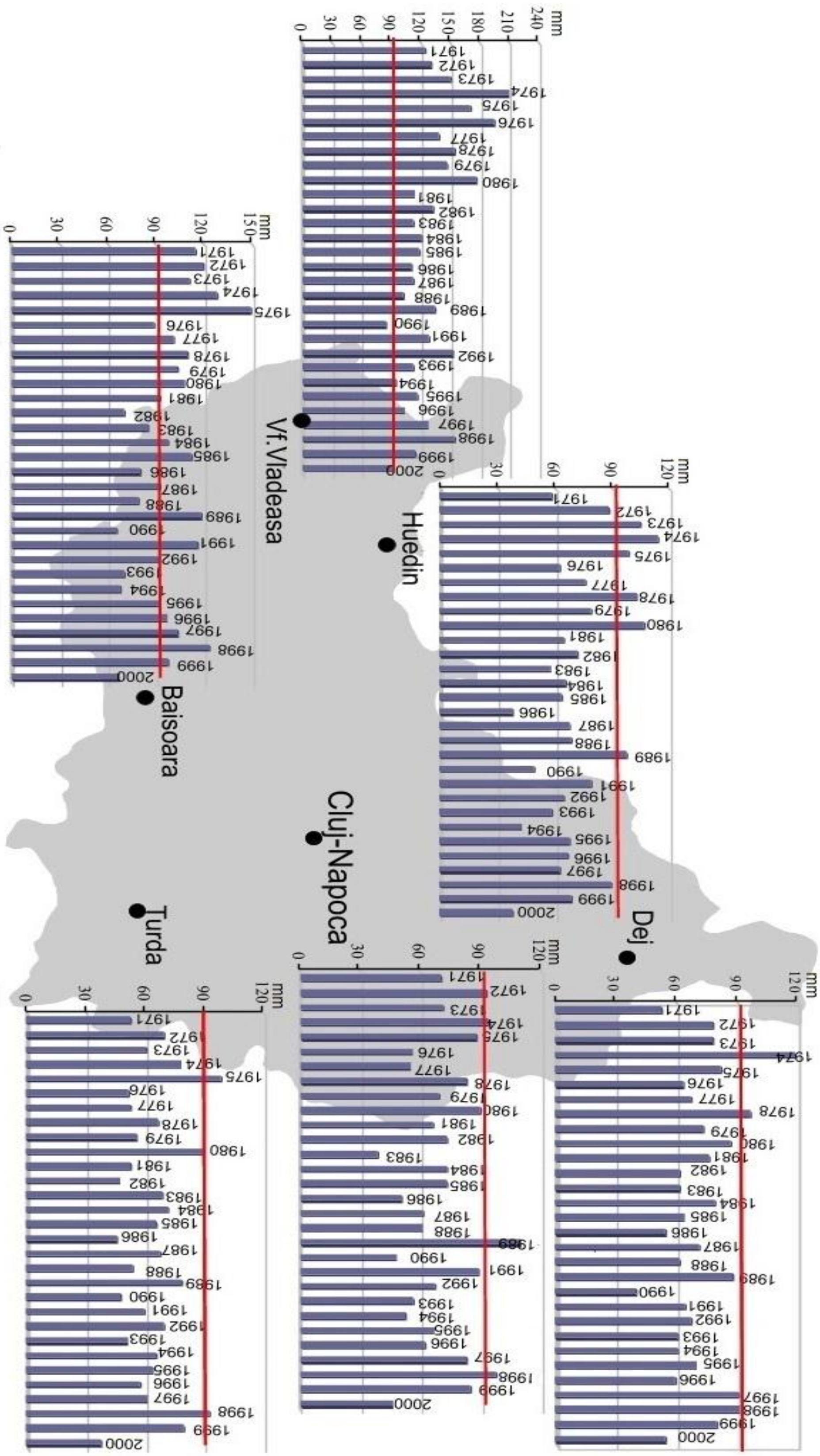

Fig.13. Modified Fourier Index MFI (Fournier, 1960, Arnaldous, 1980), for the period 1971-2000

According to the pluvial aggressiveness classes based on MFI, it resulted a low aggression for the Transylvania Plain and Plateau, moderate aggression in the mountains area from Gilău-Muntele Mare, and high aggression for the Vlădeasa Mountains.

Triggering geomorphological processes of erosion and slope can have as determinant factor either a long period of precipitation, either a high intensity of precipitation, which lead to the accumulation of a large volume of water that flows down the slopes as run-off, favoring the production of torrential and runoff processes. The periods of deficit or surplus in terms of rainfall during a year were highlighted by using the Angot index. It is used to create a demarcation between dry and rainy months. It is a ratio between the average daily amount of precipitation in a month and the annual average quantity. It is given by the formula: $K = p/P$

$p = q/n$ şi $P = Q/365$

q = medium daily amount of precipitation per month

n = monthly number of days

Q = average multianual quantity

Depending on the values of this index (below par or above par), classes of susceptibility for triggering slope processes, for linear erosion or for flooding were derived.

During a year, above par values of the index are recorded, predominantly in the months of the warm semester, when all the conditions for triggering slope processes and linear erosion are met.

If the values of the Angot index are between 1.0 - 1.5, a low and very low susceptibility to the onset of these processes can be highlighted. For values between 1.5 - 2.0 this predisposition is average. When the values of the Angot index exceed 2.0 there are conditions for triggering processes, and at values above 2.5 there are favorable conditions for triggering slope processes and linear erosion. During the cold semester, the Angot index values are below par, these months being considered dry.

For weather stations in Cluj County, the Angot index values were calculated for the period 1971 - 2000, to identify the months of the year in which the necessary conditions for the onset of linear erosion were met.

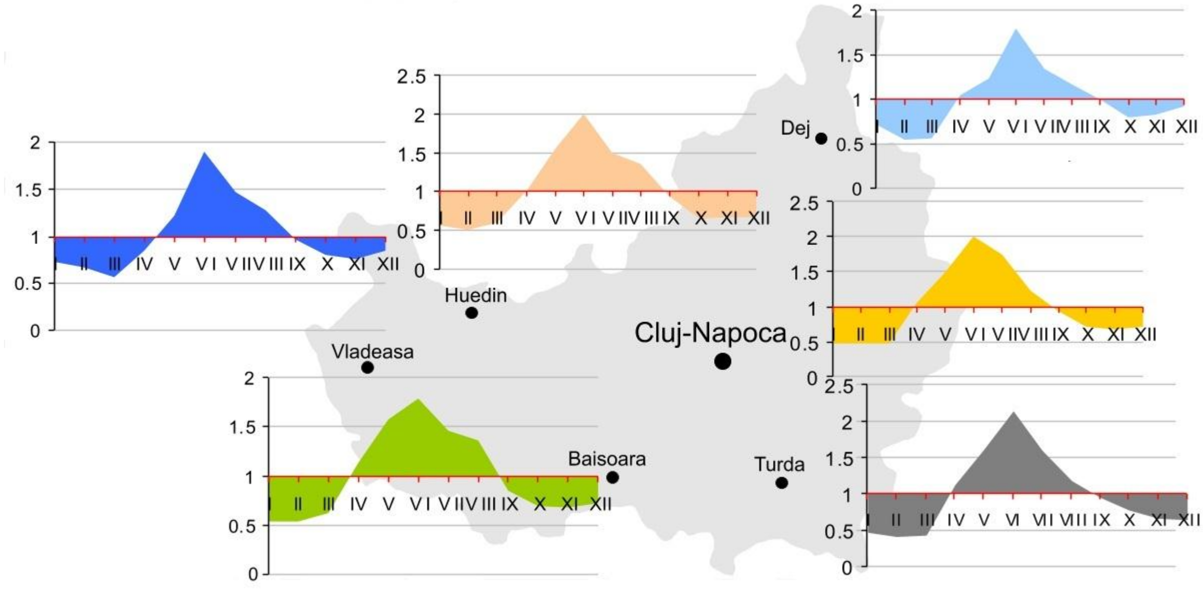

Fig. 14. Angot Index value, in the period 1971-2000, in Cluj county

Figure 14 shows that, for the entire analyzed period (1971-2000), the average monthly values above the 2.0 threshold (when there are trigger conditions for slope processes) that were recorded in June, in Cluj-Napoca (2.01) and Turda (2.13), and values above 2.5 were not recorded at any weather station.

Particular importance is attributed to quantitatively significant precipitation fallen in the winter season, which, if followed by high precipitation in March, have led some authors (Szobo, 2003; Arghius 2010) to consider that the conditions for the activation or reactivation of landslides are met. A relationship between the excess amount of rainfall during the winter and a large amount of rainfall in March, over the annual average over the month, was used to identify risk periods that may trigger landslides.

The situations where rainfall in Cluj County in March exceeded the average values and which followed after some winters with excess precipitation were analyzed for the decades between 1972 - 2000 and represented in Figure 15.

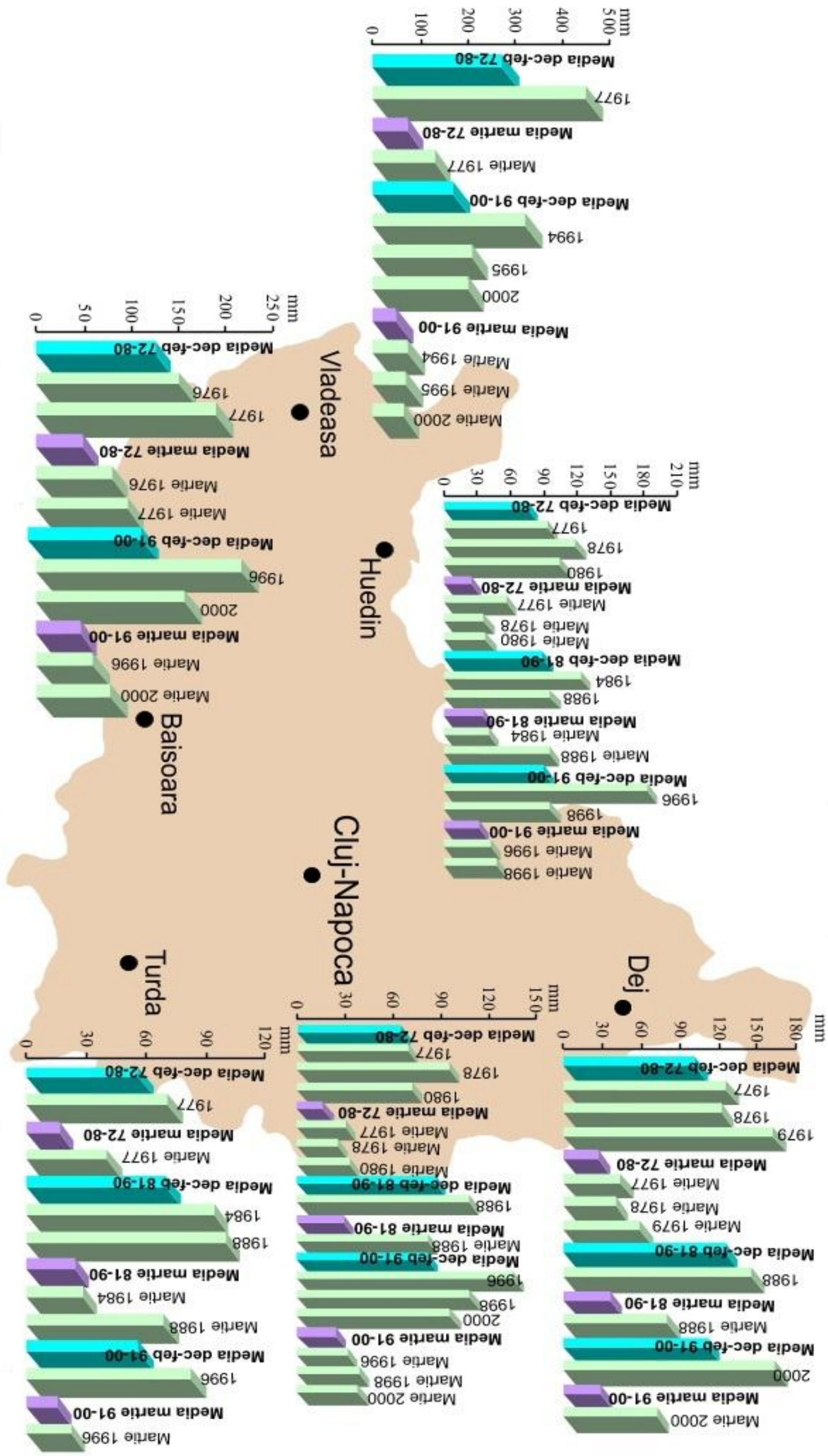

Fig. 15. The highest amounts of precipitation in the winter season/March (1972-2000)

Quantitatively significant precipitation fall in the warm semester of the year. Critical erosion season is the period of the warm semester when the amount of precipitation registers some of the highest values and has the highest frequency. The effects of the fallen precipitation, especially the torrential ones, over the substrate consist of an erosion in the form of stream drains, smaller or larger, which cover the entire surface of the slope, initially causing uniform erosion (surface erosion) throughout the slope. Move away from the watershed, the streams unite and trigger in depth erosion with specific forms: gutters, gullies and torrents.

To analyze the critical season erosion in Cluj county, the average rainfall data accumulated from April to July for each of atthe weather stations in the county was used to begin with. The average annual rainfall vaues and the average rainfall values for the warm semester (April to September) were represented, a period coincides with the period of plant vegetation (fig. 16). It was found that the mean of the precipitation values in the warm season represented between 63.4 and 72.2 % of the annual average, and the rainfall values between April and July (erosion critical season) were between 45.2 - 54.4 % of the annual average.

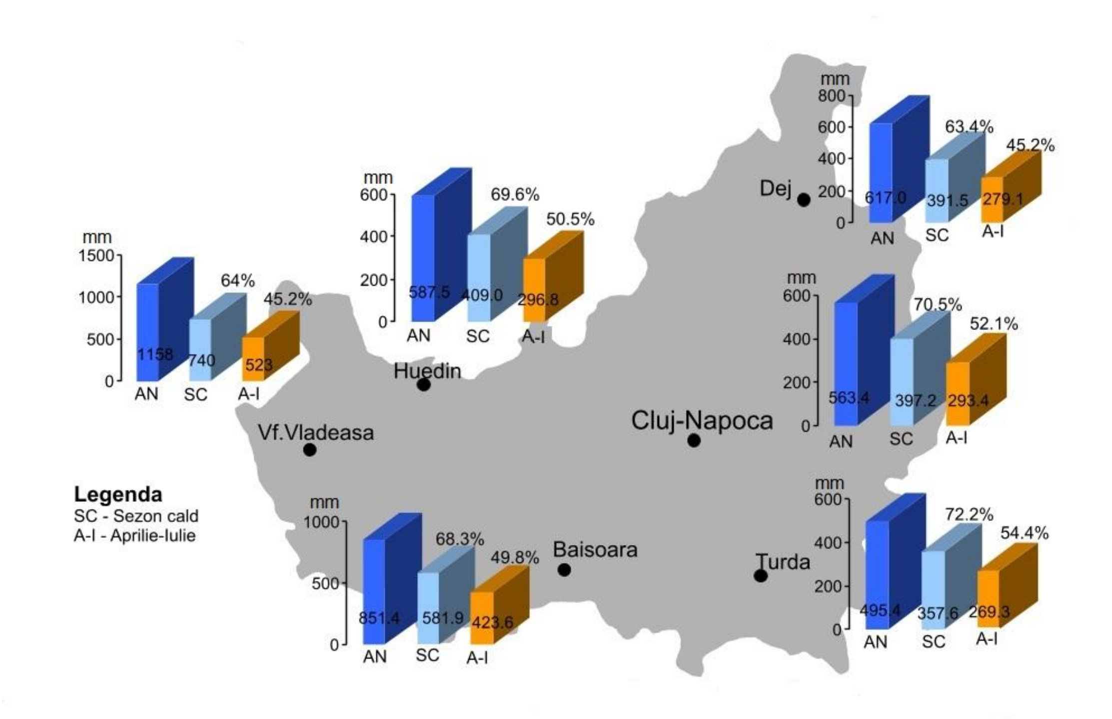

Fig.16. The critical erosion season, in Cluj county, during 1971-2000

Erosion zoning

Rain erosion and surface erosion change the main physical and chemical properties of the soil. The regionalization and geomorphological processes map for Cluj county can be seen in Figure 17.

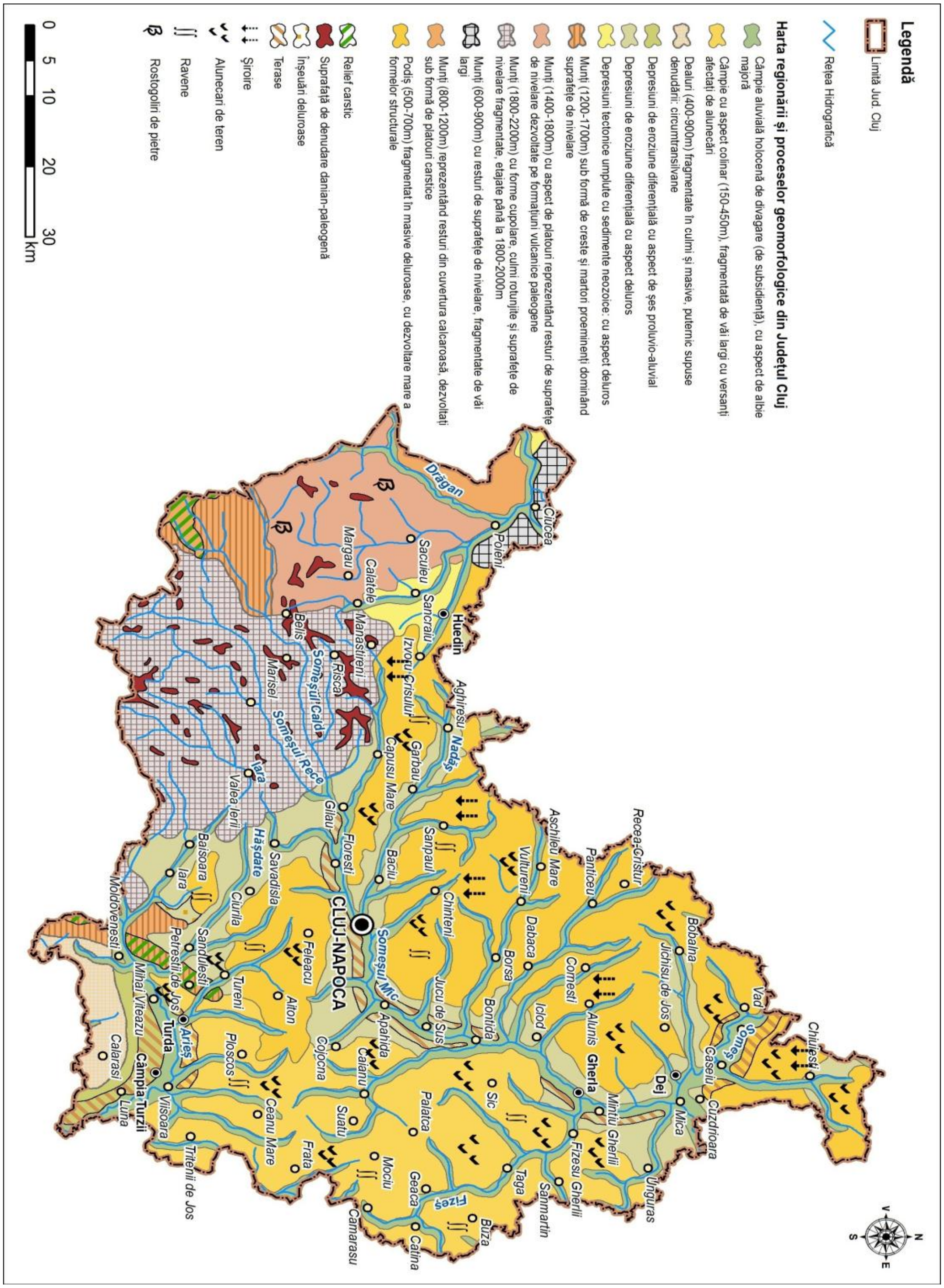

Fig.17. The regionalization and geomorphological processes map for Cluj county

In the mountain region, rolling stones are prevalent, while in units of Somes Plateau and Transylvanian Plain ravination, landslides and runoff are prevalent.

Estimating surface erosion rates based on USLE model

Erosion of the soil is estimated using a formula which includes the pluvial erosion factor (R), the ground erosion factor (K), and two dimensionless factors, the relief factor (LS) and the vegetation factor (K) (Mihăilescu et all, 2004).

The equation was established to predict the average annual soil losses on cultivated land under certain conditions, such that the losses be kept to a minimum (Rădoane, 2001).

In Romania, based on the universal equation for erosion, the values of the parameters determining the amount of the average losses of soil in the climatic and relief specific conditions to each of the areas were established. Specific annual average soil loss was calculated on experimental plots and drain fields, in the laboratory for soil conservation in the ICPA, over a period of 12 years, with application to the climatic conditions of Romania, based on the following formula: $E = K\ S\ C\ C_s\ L_s$;

where E = the amount of sediment resulting from the erosion of the surface (loss of soil), as an annual average (tones/ha/an);

K = rainfall aggressiveness coefficient (erosion indicator), obtained as the multiplication of $H \cdot i_{15}$ (H – the amount of rainfall throughout the entire rain, i_{15} the intensity of the torrential core with a 15 minute duration);

S = erosion coefficient;

C = coefficient expressing the crops influence on erosion (indicato of the protection offered by crops);

C_s = coefficient for the influence of the anti-erosion measures on soil erosion (indicator of the effect of the anti-erosion measures), (Motoc et. all, 1975, Dârja, 2000).

L_s = topographic factor, whose value increases with the slope length (L = length of slope on homogenous units of relief (m)), and slope inclination (i = slope gradient on homogeneous units of relief (%));

The slope length was calculated using GIS from DEM, using the formula proposed by Mitasova et all in 1996, (quoted by Bilaşco et all, 2009), POW([accumulation]*20/22.1,0.6) *POW(sin[slope] *0.017)/0.09,1,3 unde

[accumulation] – accumulation due to water erosion

20 –cell resolution

1,3, 0.017, 0,6 – experimental coefficients

[slope] – slope

The map for the slope length (Ls) is shown in Figure 18. The values of the coefficient between 0-5 m represents 62.4% of the county surface in the extensive plains areas of the main rivers, Huedin Depression, lower basin of Aries, the south-west part of the Transylvanian Plain and the south region of the Cluj and Dej Hills.

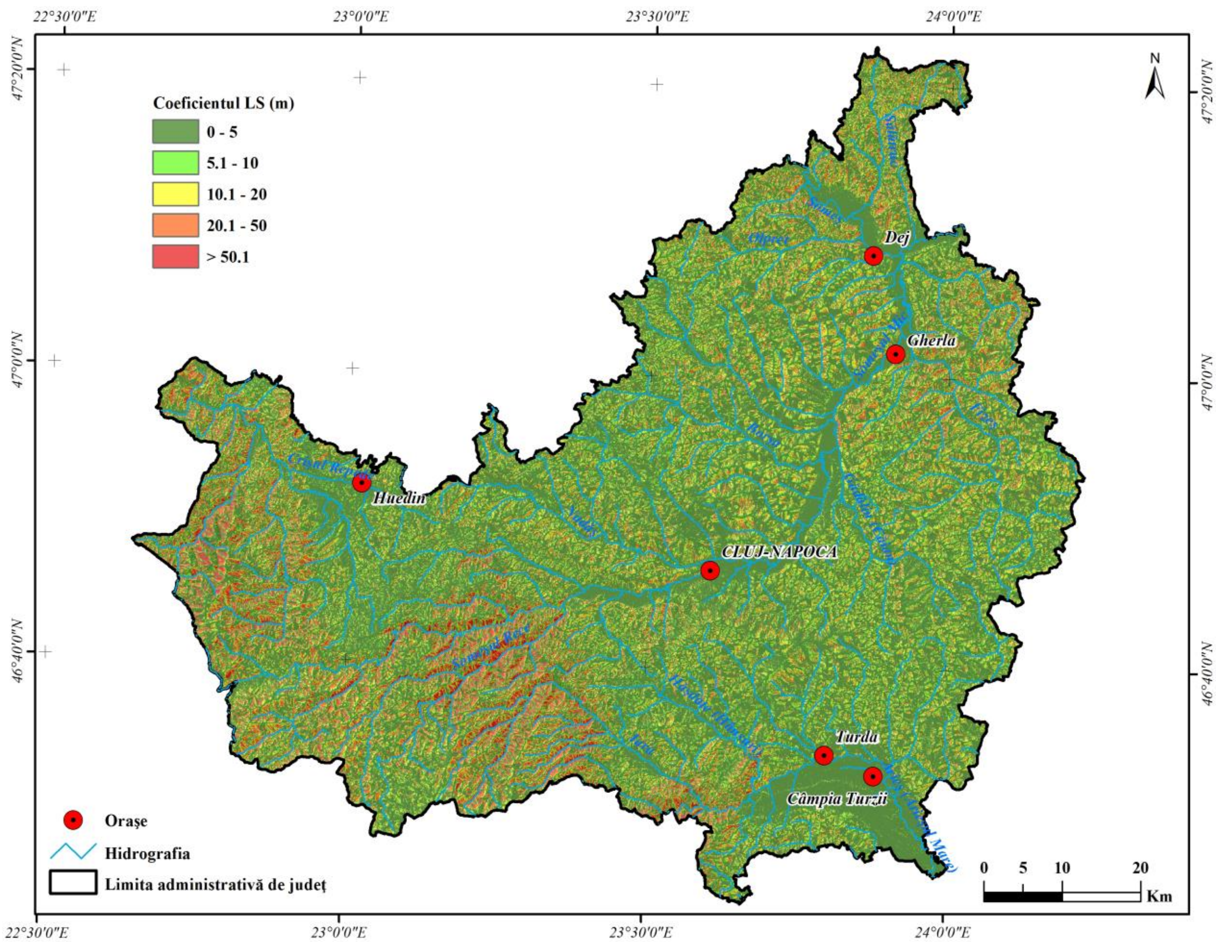

Fig.18. Slope length (in homogeneous slope units)

The coefficient values between 5.1 - 10 m, representing 12.2% of the area, is reflected in the Transylvanian Plain, Cluj and Dej Hills and areas of erosion in the Apuseni Mountains. Coefficient values between 10 - 20 m represent 12.4% of the area (in the lower basin of the main valleys in the Transylvanian Plain and Somes Plateau) and those between 20.1 - 50 m (9.7%) are located on the slopes of the valleys in the Apuseni Mountains, Transylvanian Plain and Somes Plateau. The highest values (> 50 m) represent only 3.3%, in the basins of Somesul Rece, Crisul Repede and Iara, and in the areas with cuesta relief from the Somes Plateau.

The coefficient K can be defined as the ratio of the annual average loss per area unit and the index of erosion. Annual average loss value is determined using observations made on flow plots specially landscaped. The erosion indicator is calculated with elements drawn from torrential rains pluviograms that cause erosion (Motoc et. all, 1975).

The coefficient of pluvial (climatic) aggressiveness K is shown in figure 19.

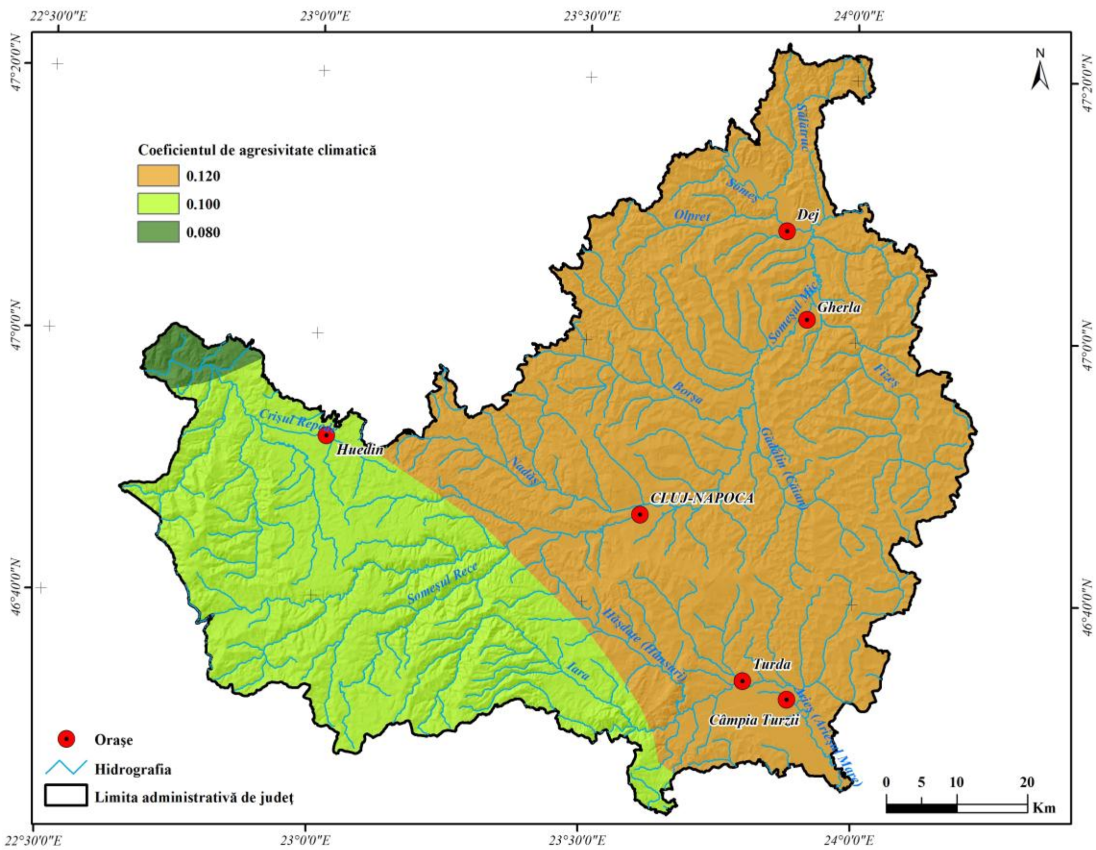

Fig.19. The coefficient of climatic aggression

For Cluj county, the coefficient of climate (pluvial) aggression is 0.10 in the mountain area, 0.12 for the plateau and the plains of the county and 0.08 in the north-west of the county, in the Plopişului Mountains and Negreni Plateau.

The correction coefficient, depending on soil erodibility (S), is influenced by a number of soil attributes (texture, structure, permeability, organic matter content) and its representation in the county can be seen in Figure 20.

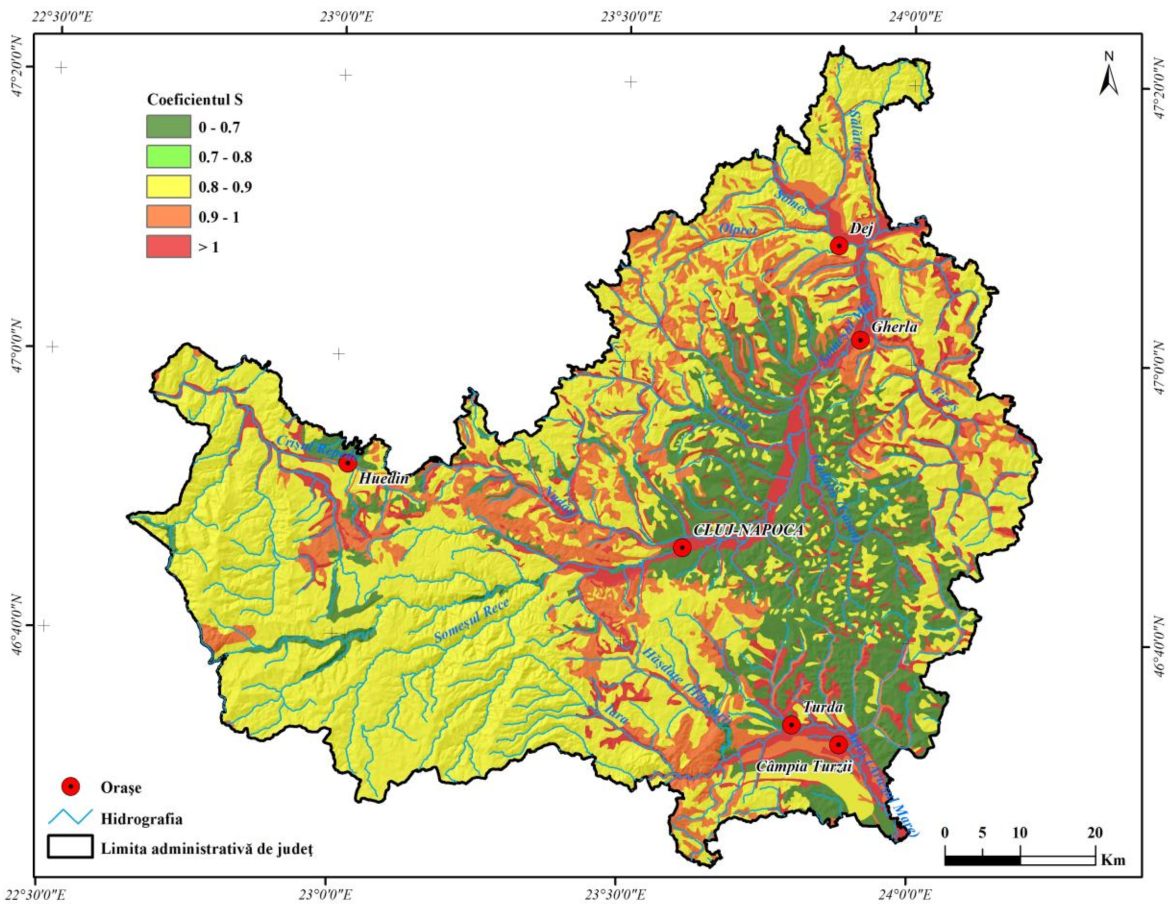

Fig.20. The correction coefficient, depending on soil erodibility

Values between 0 - 0.7 of this coefficient, representing 17.4% (1165 km2) of the county, are found in the western half of the Transylvanian Plain, the central-southern part of the Somes Plateau, on soils with high content of humus. Values between 0.7 - 0.8 with an area of 1624 km2 (24.4%) of the county, and those between 0.8 - 0.9 are found in an area of 2044 km2 (30.6%), situated in the mountain areas, the Fizeş basin, Transylvanian Plain and the northern and western parts of the Somes Plateau. Huedin Depression, Căpuşului Hills, the Olpret and Fizeş basins and the lower basin of Arieş have a correction factor, depending on soil erodibility, between 0.3 - 1.0 (1022 km2). The highest values (> 1) occupy an area of 810 km2 (12.1%) located in the valleys and river valleys, on alluvial and sandy soils.

The coefficient (C) expressing the crops influence on erosion (indicator of protection provided by crops) is estimated based on vegetation type and mode of use of land, depending on the type of management and the type of crops. The USLE model, used for erosion analysis on agricultural land, was subsequently adapted for other uses of land. The map showing land use was adapted from the Corine Land Cover Database 2000 database. The correction coefficient values based on the vegetation cover vary between 0 - 0.005 and 0.8 - 1.5 (fig. 21).

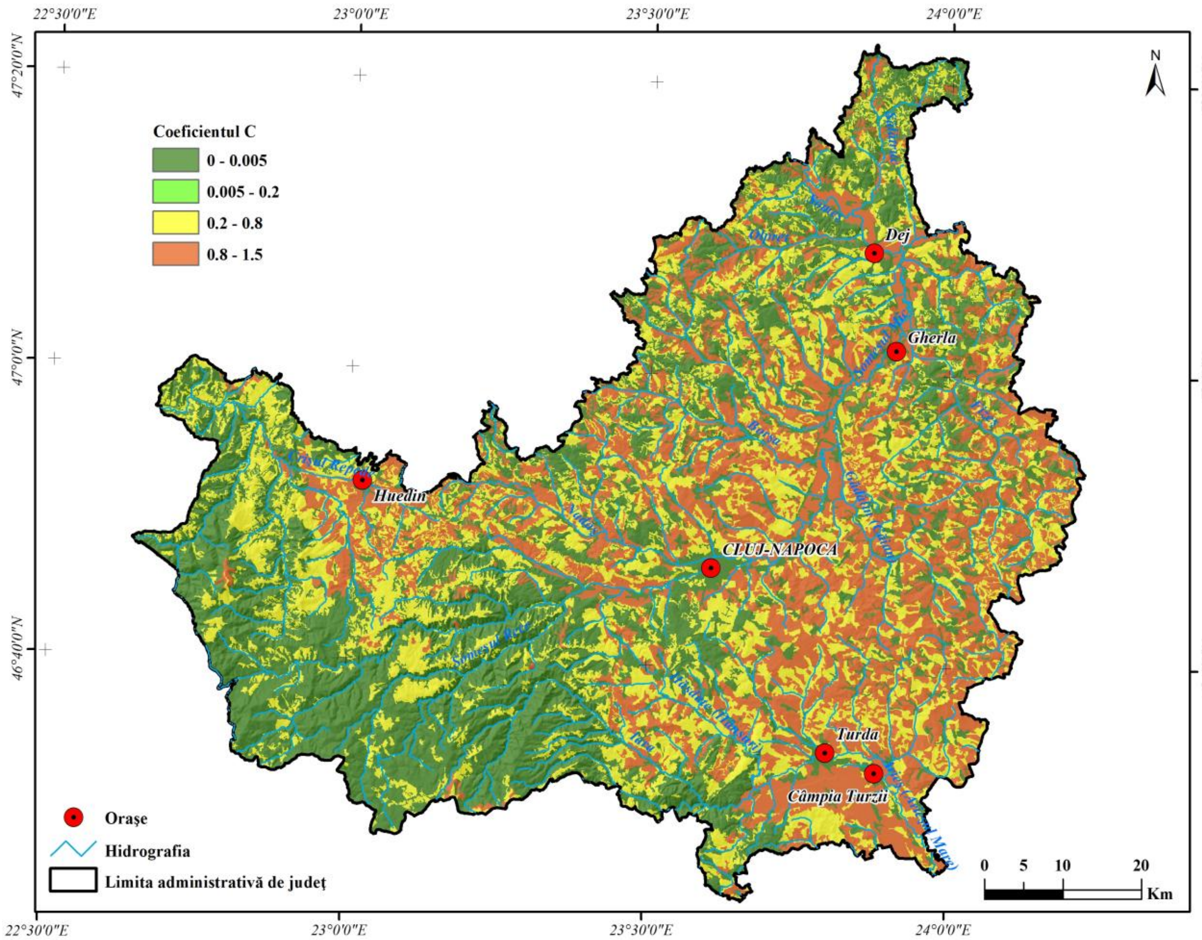

Fig.21. The correction coefficient depending on the type of vegetation and the type of land use

Erodibility, ranging between 0 - 0.005 , is registered in an area of 2671 km2, representing 40 % of the county, mostly in coniferous forests, hardwood forest, or mixture in the mountain region, in the north-east and south-west of Cluj and Dej Hills, in Saălătrucului Hills and the north-eastern part Transylvanian Plain. Erodibility between 0.005 - 0.2 is specific to natural grasslands and pastures, and occupies an area of 1545.5 km2 (29%) of the county. Erodibility values between 0.2 - 0.8 have a percentage of 8.3 % (554.6 km2) in the county, being specific to crop lands, mixed with natural vegetation (lower basin of Arieş, Transylvania Plain and Someş Plateau). For irrigated croplands, erodibility values are between 0.8 - 1.5 (22.5%), representing 1550 km2 in the Transylvnia Plain, Cluj and Dej Hills, the meadows of Arieş and Someş rivers and Huedin Depression.

Based on the formula: E = K S C C_s L_s the average annual soil erosion rate was calculated using GIS techniques (the Raster Calculator function of the Spatial Analyst module), the obtained values were between 0.0 - 0.1 and over 4 tons/ha/year. The obtained map (Figure 22) revealed the following features of the erosion in the study area.

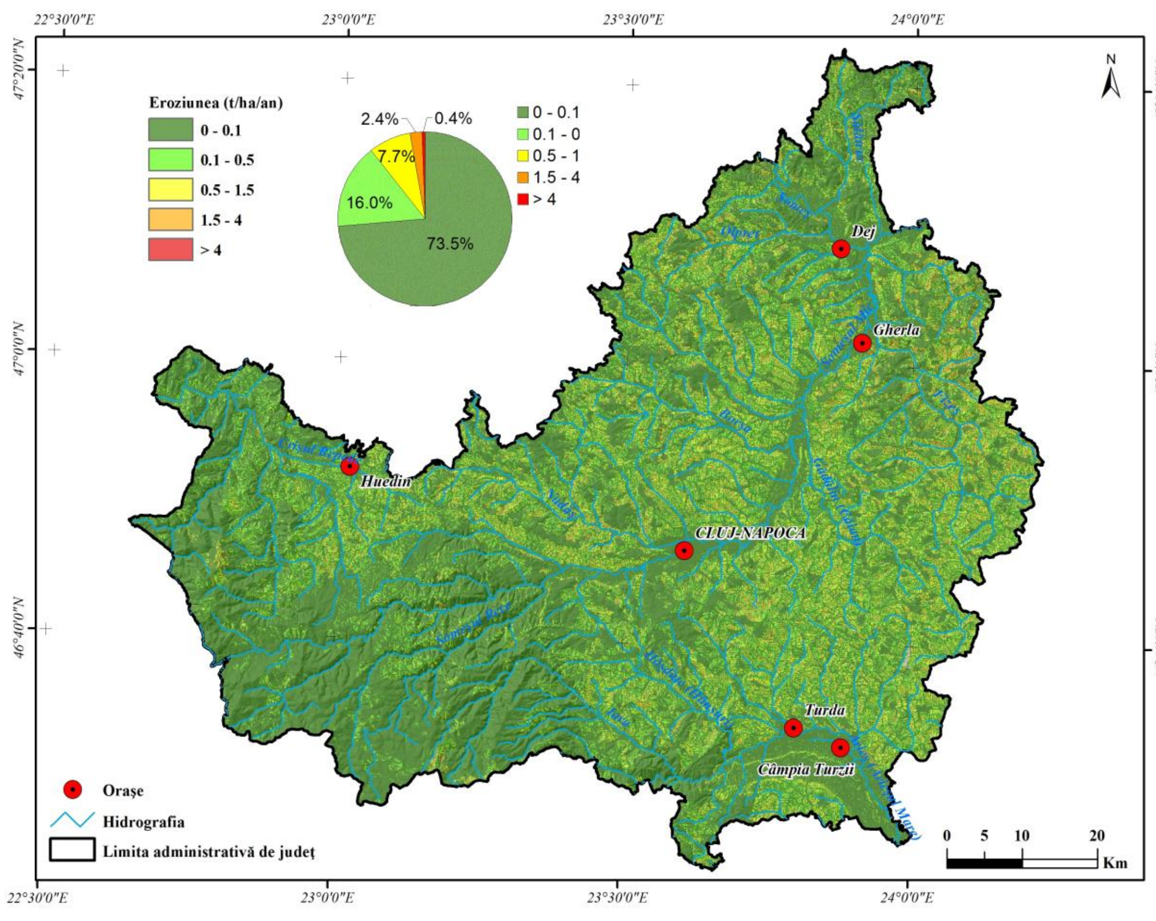

Fig.22. Spatial distribution of the annual surface erosion rate, according to USLE

Thus, in Cluj County, the areas without erosion or with insignificant erosion (less than 1.5 tons/ha/year) have a percentage of 97.1%, and 89.4% of the area is characterizes by a potential erosion under 0.5 tonnes/ha/year. Areas where there is low erosion potential (1.5 - 4.0 tones/ha/year) occupy 2.5% of the surface, and moderate erosion occurs in 0.4% of the county area. From the analysis of surface erosion map, it is noted that most of the Cluj county surface (97.1%) has the tolerable erosion values (below 1.5 tonnes/ha/year), highlighting good degree of vegetation cover (forests, shrubs) and dominance of slopes with low inclination, less susceptible to erosion. These low values of erosion are found predominantly in the forests areas from mountains and Someş Plateau.

Erosion values between 1.5 - 4 tons/ha/year can be found on 2.5% of the county surface on the slopes with agricultural uses from the Someş Plateau and Transylvanian Plain, and an average erosion (> 4 tonnes/ha/year) is manifested on agricultural lands, on steep slopes, and on the areas of the Borşa, Fizeş and Gădălin Valleys.

To reduce soil losses that occur due to surface erosion, and to achieve high economic efficiency, it is recommended that the system of cultivation on contours, on slopes up to 8-10% be applied, and conservation and the gentle terracing of slopes can limit erosion.

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