DEPARTMENT OF PHYSICAL AND TECHNICAL GEOGRAPHY
FACULTY OF GEOGRAPHY BABES-BOLYAI UNIVERSITY

Applied geomorphology research on road infrastructure. Case Study Transylvania highway

Summary of Thesis

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Contents

Keywords

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GPR

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1. Motivation, aim and importance of the study

In 2004 when work began, "Transylvania Highway" was considered the largest infrastructure project in Europe. The project involves the construction of 415 km of highway of 26 meters wide with four lanes platform. Together with the highway it was planned the construction of about 900 km of access road. Consequently the volume of excavation was etimated at over 90 million m^3, while the volume of enrochament was estimated to over 50 million m^3 (see for example, www.cnadnr.ro). The relocation of this soil volume was designed to be based on a strict schedule to avoid the soil erosion and silt mobility. However, to an itinerant analysis along the highway one can see several areals characterized by acute geomorphologic instability.

Geomorphological hazard expressed near infrastructure may induce risks. This hazard has a great probability of occurrence in the areals characterized by geomorphologic instability, fragility manifested by the geomorphologic processes which could be (or not) anthropogenically induced (Panizza, 1996). In the context described above, the geomorphologic hazard is represented by erosive and denudational processes manifested in the riverbed and slopes. The numerical analyze of these processes represent a kernel for the study of the post-construction impact.

The aim of this thesis is to evaluate the impact induced by the construction of a road from the perspective of the geomorphologic approach. This objective involves the identification of a methodology able to provide responses on very subtle forms of manifestation into the geomorphologic processes.

The first specific objective of the present work is to assess the natural conditions of the studied environment by analyzing the geomorphologic pre-existing natural factors in which the anthropogenic activity is done.

The second of our objectives is to analyze the alluvial mobility into a basin affected by the highway construction. The approach of this objective was done by using the conventional methodology of physical geography (Ichim et al., 1996) (Rădoane & Rădoane, 2007). To identify the spatial and temporal distribution of these target processes we used numerical models and simulations of the geomorphologic environment (Kirkby, 1980) (Coulthard, 2001) (Coulthard et al., 2007) (Hancock et al., 2010).

The third specific objective is to analyze the geomorphological processes that occur on the slope system affected by the engineering works on the highway. This objective involves both geotechnical and geophysical approaches (Băncilă et al., 1980) (Surdeanu, 1998) (Jol, 2009). The erosion processes were discussed by means of mathematical modeling and technology of the geographic systems (Wischemeier & Smith, 1978) (Renard et al., 1994) (Cristescu, 1978) (ESRI, 2010).

"A highway is forever. It is a legacy ", says Mix M., Director of Projects at Bechtel Company (Doan, 2007). Accepting this as a premise of this study, we would consider to assess the impact of this "inheritance" on the geomorphologic environment, and implicitly on the community development.

2. The history of applied geomorphology in Romania

To identify the distribution on areas of economic development, the history of applied geomorphology in Romania was divided into parts based on socio-economic activities related to geomorphologic issues. The periodization corresponds to different stages of contemporary epoch in the history of the national economy.

It begins with the foundation of the Institute of Geography of the Romanian Academy with branches in Iasi and Cluj-Napoca. Geomorphological researches are classified in several main directions: rational organization of agriculture, documentation necessary to engineering and construction (hydraulic structures in Bistrita, the Iron Gates, studies for new communication routes, etc.), the mapping of new reserves of raw materials, the erosion control and the study of the landscape as a tourism object. In 1990 was launched the Association of Geomorphologists in Romania, aiming, among others, to emancipate the geomorphology as an applied science in the economic environment. Besides the above-mentioned topics of study, in this period comes a new trend, respectively the study of geomorphological hazard and risks processes. The decade of the 90 was declared “The International Decade of Natural Disaster” (Rădoane & Rădoane, 2004). Geomorphology becomes an applied science officially recognized by international decision-making bodies and now it represents an integrated science that generates responses according to social requirements (Grecu, 2009).

2.2. Applied geomorphology into urbanism and regional planning

The applied geomorphology assertion in this context began with the systematic expansion of urban areas in Romania. In this context, between 1950 and 1970 were undertaken a series of studies coordinated by the Institute of Geography. Also, during this period appear the first works where is stated the torque of terms "applied geomorphology" (Martiniuc & Băcăuanu, 1963).

In addition, mapping becomes the most productive method of geomorphological studies (Posea & Smith, 1967) (Gregory, 1972) (Martiniuc & Hârjoabă, 1975). The landscape suitability for urban expansion and the exploitation of morphology resources was studied by in the framework of the potential socio-economic development (Mac & Râpeanu, 1995) (Mac et al., 1995) (Mac & Sweet, 1997). R. Petrea analyzed the geomorphological characteristics that contribute to regional development of small towns in Western Hills (Petrea, 1998). In the same vein, we mention the regional geomorphological studies undertaken in the Haţegului Country (Goţiu & Surdeanu, 2002) or in Cluj County (Surdeanu et al., 2006) (Surdeanu et al., 2006), which attempted to decipher the trigger causes of the geomorphological processes and also their spatial distribution.

2.3. Geomorphology applied in agriculture and land improvements

Different studies for land improvement done in terms of geomorphology refer to a number of causes and solutions regarding the soil erosion and torrentiality, the alluvial dynamics in the geomorphological systems, the flood control and the riverbed processes. The role of applied geomorphology also stated in irrigation and drainage works or in studies on slope stability. If we invoke the interdisciplinary character of the applied geomorphology, we can mention many works whose authors were not geomorphologists into the strict sense. Thus M. Motoc studied the process of soil erosion on agricultural land proposing solutions to control it (Motoc, 1963) (Moţoc et al., 1975). Munteanu has done works on torrential planning and on the role of trees in the anti-erosive processes (Munteanu, 1953) (Munteanu et al., 1970). Băliou V. proposes solutions against the development of the erosive processes after studying different arrangements of the agricultural land (Baloiu, 1965) (Baloiu & Ionescu, 1986). C. Arghiriade does research on plant protection capability against land degradation (Arghiriade, 1968). Ouatu C. and Ionita I. bring their contributions to the knowledge of some processes including the land degradation. Here we may note the study of soil erosion in Tutova hills (Ionita & Ouatu, 1985). Studies on the ravines development and distribution were made by Rădoane M., Rădoane N., Ichim I. and V. Surdeanu, trying to identificate the regionalization morphology and the dynamics of ravines bodies (Rădoane et al., 1988) (Rădoane et al., 1995). Later, the authors proposed several mathematical methods for the analysis of these processes (Rădoane et al., 1994) (Rădoane et al., 1997). Denudational processes were studied by Surdeanu V. His works were collected into a comprehensive collection of methods and case studies (Surdeanu, 1990) (Surdeanu, 1992) (Surdeanu, 1997) (Surdeanu, 1998). In 1999 appears the book *Ravines,* which represent a detailed display of specific research methods with examples through case studies (Rădoane et al., 1999). In 2000 in Iasi appears a work of applied geomorphology under the direction of I. Ionita representing a handbook on land degradation into hilly area (Ionita, 2000). Also in 2000 another work appears under the same author on the gulling of Barlad Plateau (Ionita, 2000). The human impact on the land use was studied by Oncu M. and St. Bilasco.

2.4. Geomorphology applied in hydrology and hydrotechnical improvements

In 1950 Romania adopted a national plan to increase the electrical power capacity by exploiting the hydroenergy. Thus into this period began the construction work on the Bicaz dam. In 1959 started the integrated management on water hydrographic basins. Romania was among the first countries in the world where water management was done on the river basin as a natural unit (Oprişan et al., 2011). After putting into service the dams built on rivers, the geomorphological interest in Romania turned to the impact of the riverbed and slopes dynamics upstream or downstream the dam. In this sense were undertaken studies on the dynamics of the landscape affected by dams (Rădoane, 1983) (Ichim & Rădoane, 1986). In this period also appeared several studies on clogging lakes (Rosca et al., 1980). V. Surdeanu studied the stability of slopes and landslides role into clogging reservoirs (Surdeanu, 1986). Studies on human impact on riverbed evolution have done (Petre et al., 2006) (Rădoane & Rădoane, 2005) (Rădoane et al., 2008).

2.5. Geomorphology applied to study the risks and hazard processes

Study of the geomorphological hazards and risks is a dominant trend in applied geomorphology today. The hazard analysis and mapping the geomorphological risk areas yet been appeared during the assertion of applied geomorphology as a science. In 1978 Coteţ P. launched a new map with great importance in the studies of geography, respectively the Map of Risks (Cotet, 1978). In 1985 Surdeanu V. presented a method of mapping the landslide risk by using the tracking of such sites (Surdeanu, 1985).

2.6. Geomorphology applied in transport and communication ways

Within the urban expansion period of 1960-1970 the romanian geomorphologists become interested on the issue of the relationship between landscape and communication routes. In 1966 all working groups were united under The Engineering Institute of Auto, Naval and Air Transport (IPTANA) and reviewed the design of road, water and air.

3. Methodology and techniques applied in the thesis

3.1. Introduction

The applied geomorphology is an aggregate of methods and techniques used to implement the specific solutions, especially in resource management, hazard reduction (Gouda, 2001), spatial planning and environmental engineering (Brunsden, 2002).

3.2. Cartographic method on terrain and laboratory

The technique used in this case was an iterative one, respectively monitoring the mass movement processes that may affect the highway construction. Monitoring was done at a fixed time step.

Firstly, we registered one representative case of mass movement processes, interesting due to volume, area and location.

The next phase of the methodology was mapping the area affected by the landslide. The mapping was done at a scale that allows the recording of all morphological forms and elements. A topographic survey was used for a strict localization of elements in the landslide. The technique of geolocation allows the identification of the precise topographic and morphometric characteristics of these elements in a system of coordinates established by the operator. Among the morphological elements, we included the line separation, sliding body perimeter, basins perimeter and human artifacts (high voltage poles, constructed prism of highway). Differential GPS measurements were used to determine the absolute quotas by linking the measurements to the national references grid points. The used technical steps are those described by (Schofield & Breach, 2007). Topographic measurements of morphometric variables were applied as is described in (Surdeanu, 1998, Chrzanowski et al., 1986). The method is well adapted to the dynamic conditions of the landslide. To calculate the three-dimensional model of the landslide body we raised points throughout the affected area, aiming the morphological elements: monticuli, depressions, cracks, torrents.

3.3. Statistical analysis of time series

The investigation of natural phenomena cannot be done without analyzing specific sets of parameters that defines the phenomenon. This includes time series (as are rainfall data) or spatial data sets. Often the data collection involves involuntary errors or noises due to equipment with which data collection is carried out. In mathematical terms this are called noises or trends and should be removed from the data series. The method of analysis used in the present work to investigate the series is Detrended Fluctuation Analysis (DFA) (Peng et al., 1994). In addition, we used statistical investigation done by traditional methods commonly used in geography (Ichim et al., 1996).

3.4. Granulometric analysis of fluvial deposits

The particle distribution on riverbed deposits was performed according to the techniques presented in international and national literature. Samples were collected using the volumetric method (Mosley & Tindle, 1985). Samples were processed in the laboratory and the data were statistically analyzed. Since this study requires only the spatial distribution of sediment classes of grain size within the river basin, the analysis focused on the percentage distribution of such classes Φ on Wentworth scale (Wentworth, 1922). Samples were dried in an oven at a temperature of 105 ° for 24 hours, according to STAS 1913-1-82 (Manea et al., 2003). Sieving was done initially with a set of screens for classes Φ: -4 to -3, and ulteriorly with a battery of sieves and equipment to achieve vibrant sifting for class fractions Φ -2, -1 , 0, 1, 2, 3, 4, 5, 6.

3.5. Stratigraphic and geotechnical analysis of diluvial deposits

We used the natural ground openings from withit and outside of the studied perimeter. From these outcrops we registered the lithological succession of layers, the thickness of lithostratigraphic units and the absolute location where they outcrop. In addition, in the sliding body was carried a borehole by using a hand drill for soil and substrate sampling. The aim of these two methods is the characterization of the horizons from the diluvial deposit and the detection of a possible layer with a maximum of saturation. The method is required to calibrate and validate the Ground Penetrating Radar variables (GPR).

3.5.1. The stratigraphic column

The outcrop is located at about the same altitude as the rate of detachment slip. The natural opening is dihedral and is located inside the shaped body with a tilt of the torrential channel of about 50 degrees. In the outcrop, it was observed the inclination of strata from east to west, according to the general inclination and direction of the whole slope. Layers with a thickness not exceeding 20-30 cm were considered as intercalations in the bedrock. Altimetric measurements were performed by using total station laser beam. The topographic measurements determined the absolute location where appear packets of fine sand, marl and sandstone and the relative thickness of these layers.

3.5.2. The drilling

Drilling was carried out by using a manual drill kits. For advancement in depth, we used two specially designed digging for clays and wet sand. These two digs usually extract disturbed lithological samples. To extract undisturbed samples, we used a hoe with tubular piston, or a piston spout. Undisturbed samples unbiased and sealed were taken at a depth of 1m.

3.6. Geophysical methods of investigation by electromagnetic waves

3.6.1. The description of the GPR method

This section also summarized the theoretical basis of measurements with GPR. In the present study we used a set of antennas with a frequency of 50 MHz. With this frequency and in specific lithological conditions *i.e*. without high attenuation layers, one can detect objects hidden at about 0.5 m to a maximum depth of 20 m. The extreme depth of about 40 m have been reported in literature, but needs excellent lithological conditions as clean and dry sand, gravel (Smith & Jol, 1995) or sandstone (Jol et al., 2003). The antennas were positioned in a configuration of "parallel endfire" (Jol & Bristow, 2003).

3.6.2. The application in terrain of GPR method

Firstly we made the environmental evaluation of the area under investigation to verify the feasibility of this method. Following the analyzes of the landslide morphology, we determined the topological profiles subjected to the geophysical investigations. Within the analysis process we taken into account the localization of high voltage lines that are an important generator of electromagnetic noise. To detect the sliding surfaces and piezometric levels we proposed four profiles lines, each of 600 m.

3.7. The numerical modeling of terrain

The numerical modeling of terrain is required for a qualitative and quantitative description of the landforms. The analysis is done in the light of the terrain static equilibrium by using a series of geomorphometric indices (slope, hypsometric, exhibition and fragmentation) and on dynamic balance by using statistical and geostatistical analysis of the three-dimensional space under the influence of temporal rate. The numerical model of terrain was calculated by using GIS technology on platform developed by ESRI ArcGIS (ESRI, 2010). Elevation data we used to calculate the isohypses of topographical plans.

3.8. The landscape evolution model

In this chapter, we have presented the main reasons related to the objectives of the study that led to choose the CAESAR model, as described by the code developer (Coulthard, 2001).

The investigated area

CAESAR model development is based on studies acquired in the temperate zone. The river basins under investigation are included in the small and medium size classes. The model is suitable for simulations on simple meandering riverbeds.

Geomorphological process representation

The model simulates the riverbed and slopes processes to an accuracy that involves the deposit granulometry and the stratigraphy of the sediment. It also models the riverbed topography.

Temporal and spatial resolution

CAESAR can model time sequences from a storm or flood (i.e. hours or days) up to 10,000 years, beyond which the subject remains open to be validated. It also can model riverbed sections of about 1-4 km up to river basins.

Work interface

CAESAR model has a graphical interface for general use. Cooperate easily with ArcGIS platform that facilitates the mapping transfer and elevation data for ulterior geographic analysis.

CAESAR is a two-dimensional model that simulates river flows and sediment transport. The description of the model has been the subject of numerous scientific articles and debates, among which may be mentioned (Coulthard, 1999), (Coulthard, 2001), (van de Wiel et al., 2007), (Hancock et al., 2010).

4.Technical characteristics of Transylvania highway

The Transylvania highway project is of major importance into the national economic development. The project promises more aid for integration the Romanian economy into the European economy, these economic benefits extending over long periods. It also becomes an important section in the European highway network and in Romanian road structure. Since 2014 this project was included in the Trans-European network and could be financed by the TEN-T program.

Highway project includes a 4-lane platform with a projected length of 415 km. It starts in the northeast of Brasov, at an altitude of 600 m and ends in Plain Crisana, near Oradea at 130m altitude.

For engineering reasons, the project was divided into several sections listed below:

Section 1A, Brasov - Fagaras - 48.81 kilometers

Section 1B, Fagaras - Sighisoara - 53.37 kilometers

Section 1C, Sighisoara - Ogra - 58 km

Section 2A, Ogra - Campia Turzii - 37.19 kilometers

Section 2B, Campia Turzii - Cluj West - 52.55 kilometers

Section 3A, Cluj West - Mihăileşti - 25.5 kilometers

Section 3B, Mihăileşti - Suplacu de Barcau - 75.48 kilometers

Section 3C, Suplacu de Barcau - Bors - 64.5 kilometers

The highway has an average platform width of 26 m. The carriageways are separated by physical tools and have a width of 7.5 m each. For connecting the highway with adjacent roads, the engineers have provided 16 interchanges, 94 bridges and 58 overpasses. For the construction of the infrastructure they were planned the excavations of a volume of about 90 million cubic meters (http://www.cnadnr.ro/).

In the present work, we have studied the geomorphological processes associated with Section 2B Campia Turzii - Cluj West. The main reason is that only this sector is fully functional.

5. Factors that influence the proper functioning of a road

5.1. The geological factor

5.1.1. Description of geological factor

The area under investigation is located in the western part of the sedimentary basin placed at the contact between the Apuseni Mountains and Transylvanian Depression. The geological evolution and the structure of the sedimentary basin directly influence the infrastructure design, *i.e.* by extending radially (civilian neighborhoods) or linear (highway). The anthropogenic deposits occur in the studied territory from two sources. The most important source of sediment is the highway neighborhood where the excavated material was deposited near the infrastructure platform, thus following the linear character of the road. The second source is the limestone quarry from the north of the Săndulești village. From the geotectonic point of view, Transylvanian Basin sedimentation completed in Pliocene by forming sedimentary layers during diapire wrinkling stress. The highway route is cvasiperpendicular across Turda Depression and Campia Turzii anticline-syncline system (Săndulescu, 1984), (Mutihac et al., 2007). Analyzing the map of crustal movements, we can see that this highway vicinity intersects an area with a spacing activity between -1 and 1 m per year. The linear infrastructure of the highway also intersects the active crustal fault line known as Transylvania fault, which is located at the contact between two vertical tectonic microplates with antagonistic dynamics (Zugrăvescu et al., 1998). The importance of this tectonic configuration is due especially to its influence on the river dynamics in this area.

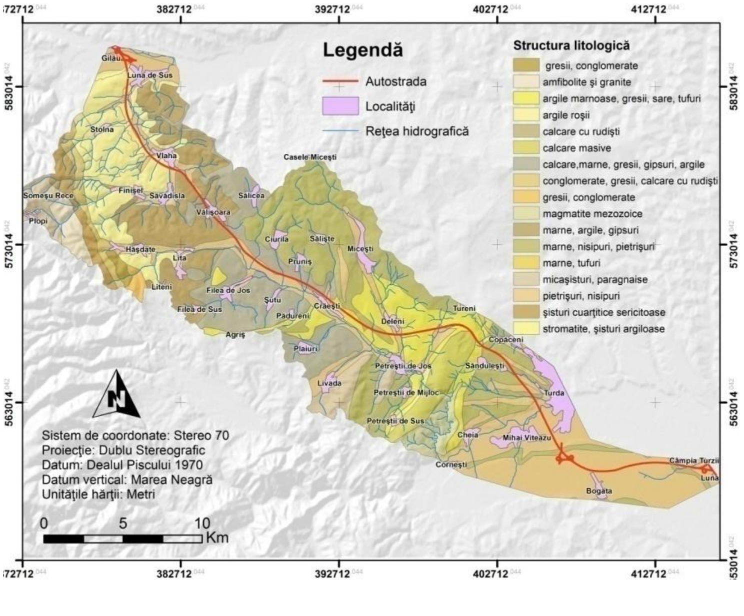


Figure 1 Lithological structure of the investigated area (Codarcea & Răileanu, 1967)(Răileanu & Saulea, 1967)

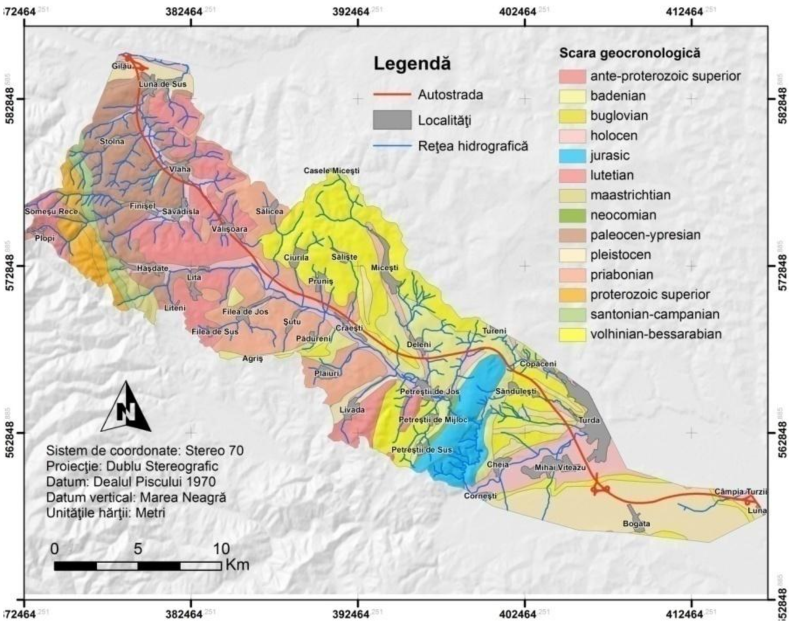


Figure 2 The geochronological distribution of geological structures (Răileanu & Saulea, 1967) (Codarcea & Răileanu, 1967)

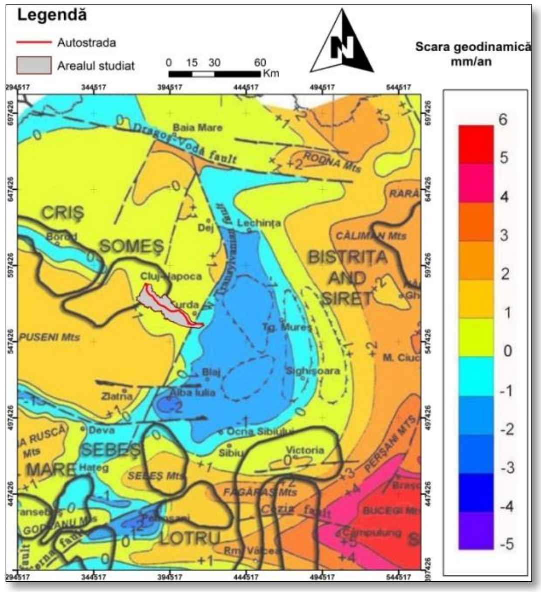


Figure 3 Extract from the map of current vertical tectonic movements (Zugrăvescu et al., 1998)

5.1.2. The importance of the geological factor

From the geotechnical point of view, the geological evolution, and more specifically, the lithostratigraphic units, put sometimes at severe tests the infrastructure design through their physical and chemical properties. The upper sedimentary package (2-30m) of the studied area constitutes the foundation in which is anchored the infrastructure project. The rockfill viaduct pillars and the foundations transmit the motorway vibrations to the ground layers included in the sedimentary foundation.

A sustainable construction needs the knowing in detail of the sedimentary package properties. In this case, the main geomorphological phenomena that affect the highway structure are mass movements, soil erosion and sediment transport into the slope-riverbed system.

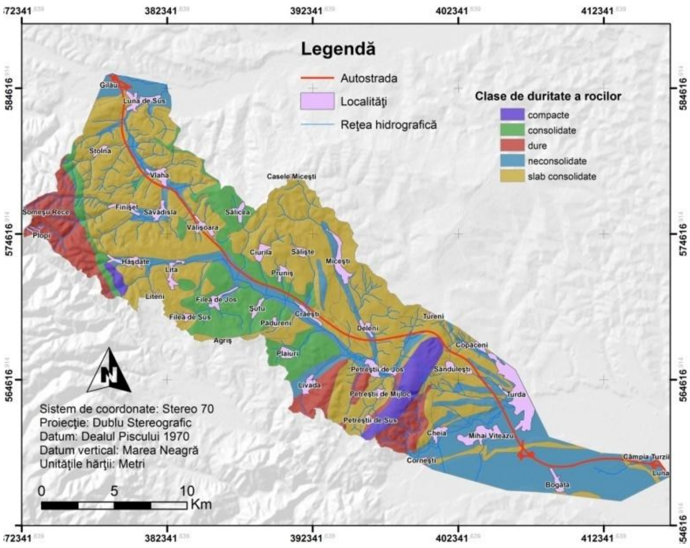


Figure 4 Spatial distribution depending on the hardness of the rocks

5.2. The landscape factor

5.2.1. The morphology

We can see from maps that the highway, in most of its length, across longitudinally the Hasdate - Vlaha Depression. This depression has a hilly appearance with a hypsometric a gap between 300 and 500 meters. The road junction in Gilău is located on the alluvial terrace in the Somesul Mic - Gilau Corridor. In the southeast of the Hasdate basin, the route is built over the Culmea Hasdate. By passing the Aries valley, the highway route across one extremity of the Ludus Hills. The landscape looks generally hilly with broad valleys and slopes affected by geomorphological processes as mass movements. In Aries valley the highway has two road junctions built on alluvial terraces with a generally aspect of lowland (Campia Turzii Depression).

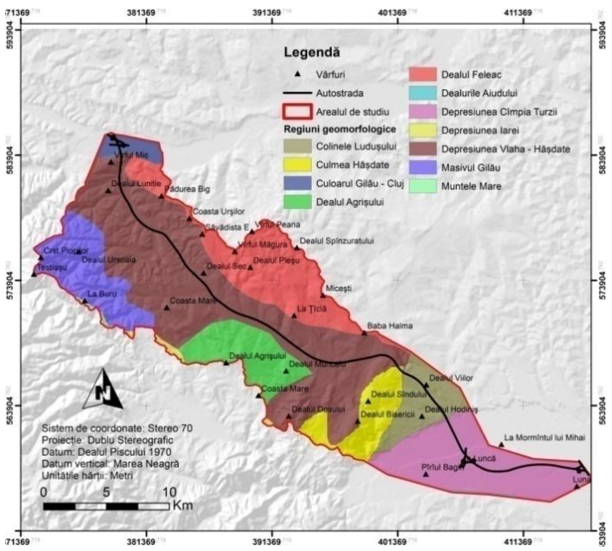


Figure 5 The geomorphological regionalization (Posea & Badea, 1984)

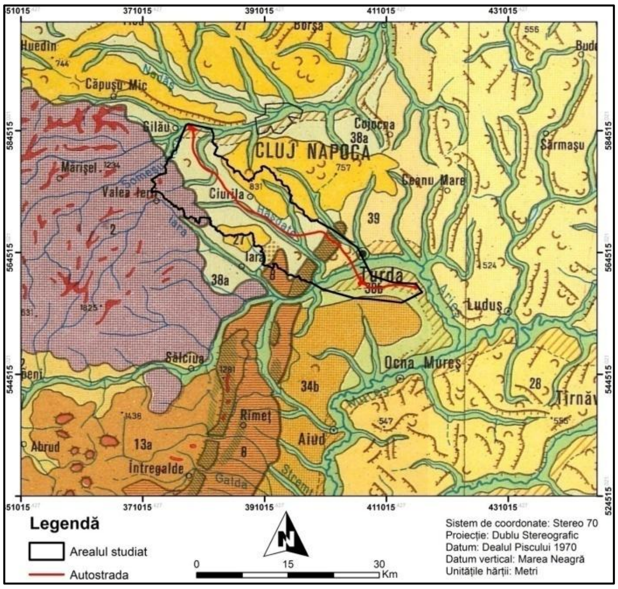


Figure 6 Extract from the geomorphological map (Badea et al., 1976)

The highway route intersects forms of relief with a morphology closely related to the lithostratigraphical structure. The morphography of the slopes, interfluves and thalwegs is the result of the lithology influence in the genesis of relief. An important role is played by the rock strength, leading to selective erosion and giving specific forms to the relief.

5.2.2. Morphometric characteristics of the landscape

The morphometry of the relief was calculated on the numerical model of the terrain by giving quantitative information on the relief. By analyzing the hypsometry of the terrain, we observe that the highway has a route who generally sat on low quotas with an average altitude of 400 meters. These values are encountered on the lower terraces of the river, in the Campia Turzii - Vlaha - Hasdate depressions and in the Gilau – Cluj corridor. The highest quotas are found in the interfluves of these three depressions. The terrain declivity distribution in this area shows a majority of slopes between 3 and 17 degrees. The highway is built in this panel of slopes, an exception being near the Tureni Gorges, where the slopes are found to be up to 31 degrees.

The terrain declivity directly influences the geomorphological processes way of expressions on slopes. The class of slopes between 3 and 6 degrees was reported to induce a high frequency of erosion and proluvio-coluvio-diluvial accumulation. For slopes between 6 and 17 degrees was found to highly occur other processes, such as landslides (Surdeanu, 1998).

The slope exposure is a factor that influences the retention of humidity in the superficial deposits. Duration of sun exposure and angle of sunlight incidence affect the evaporation regime and the duration of snow cover. Soil frost regime is also dictated by the amount of solar heat received by edaphic layer. The highway intersects the south-facing slopes in the Hasdate basin and mainly the northern facing in the Feneş basin.

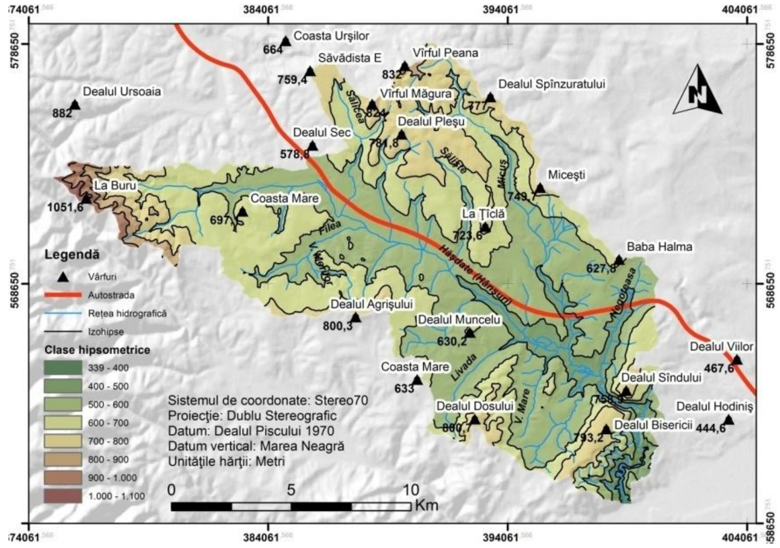


Figure 7 The hypsometry of the Hășdate basin.

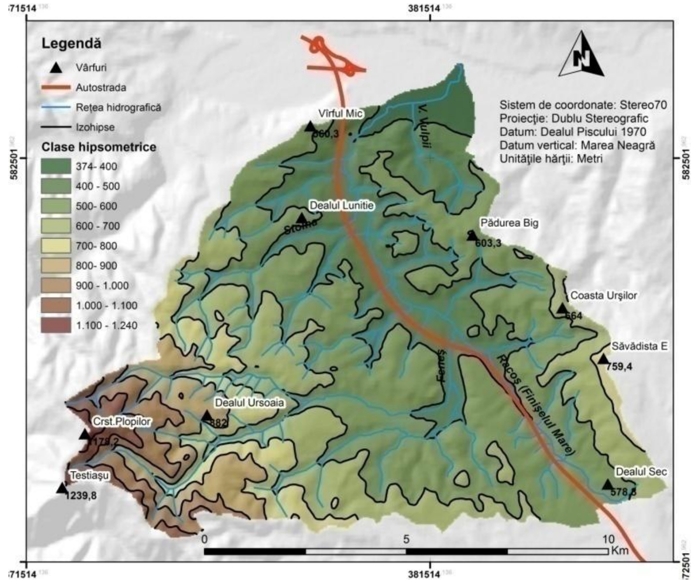


Figure 8 The Hypsometry of the Feneș basin.

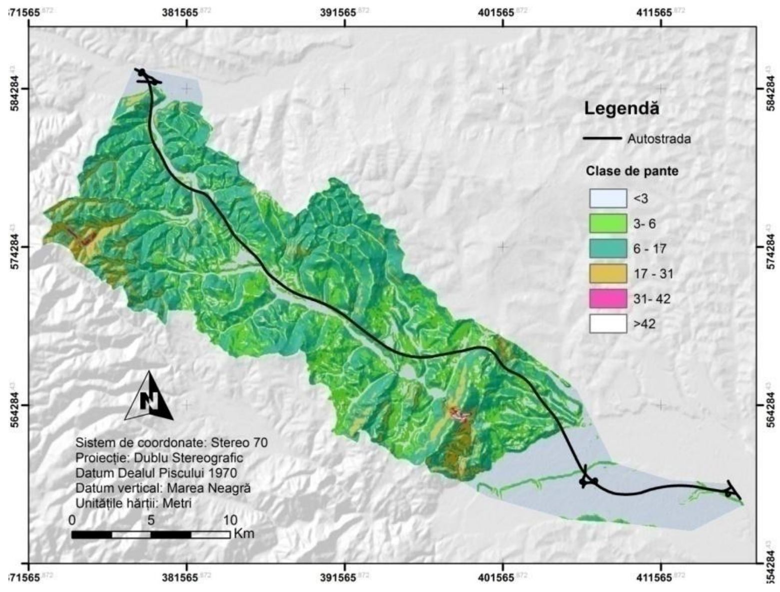


Figure 9 The slopes distribution.

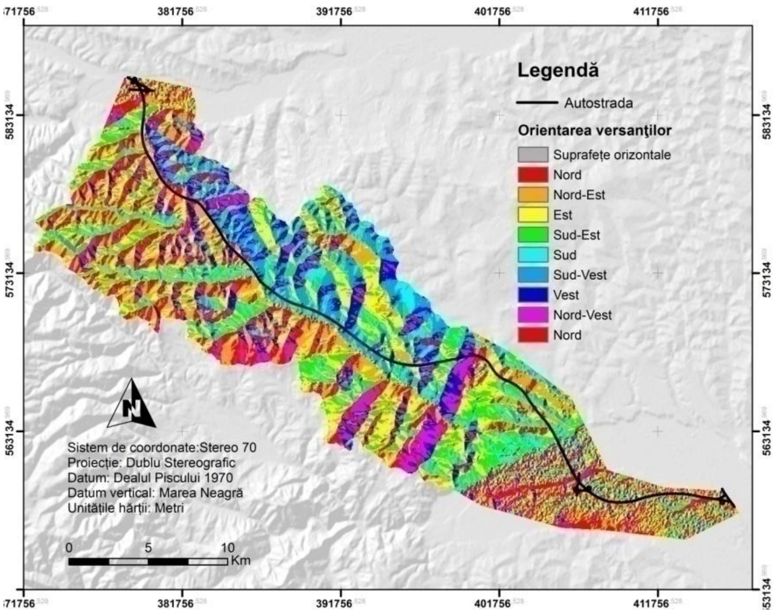


Figure 10 The exposure of the slopes

5.3. The climatological factor

To understand the genesis and spatial variability of the climatic conditions is necessary to make an integrated geographic analysis. The first physico-geographical aspect to be underlined is the integration of the investigated area into the macro-unit space as is the Transylvanian Depression. It has a relatively wet climate (Moldovan et al., 2002). Among the main geographic factors generators of climate, topography remains a major factor in the spatial distribution of climatic phenomena in Romania (Moldovan, 1999).

5.3.1. The airflow

In the Transylvanian depression spreads out three types of air masses: polar maritime (60%), tropical maritime (30%) and continental arctic (10%). The polar maritime air is transported in Transylvanian depression by the subpolar and North Atlantic anticyclones, through the Somes Valley, while the tropical maritime air is brought through the Mures corridor by the Mediterranean cyclones (Holobâcă, 2010).

5.3.2. The air temperature

From the thermal point of view the investigated territory is crossed by 8°C isotherms in the east and the 4°C in the West. The isotherms of January are -3°C and -4°C while for July, the warmest month, the isotherms are 14°C and 18°C. The amplitude of the annual average ranges between the 21°C and 22°C isotherms (Bogdan & Frumușelu, 2002). An important role in thermal regime is held by the period of freezing. Thus for this area, the freezing duration is between 120 and 150 days. In addition, the temperature of the soil has an average of 23 ℃ to -5 ℃ in July and respectively in January (Croitoru, 2007) (Badea et al., 1983).

5.3.3. Precipitations

The precipitation values are specific to the Transylvanian Basin, placed in the western part of the contact between the Apuseni Mountains and Transylvanian Plain. The multiannual average amount of precipitation ranges at about 600 mm (Belozerov, 1972). CAESAR model requires as input data a time series of rainfall at a time step of one hour. There is no availability of hourly rainfall data for the Hasdate Basin, so we used a method described in literature and widely applied in the modeling of some natural phenomena (Schaefer & Baker, 2002) (Pierini & Telesca, 2010) (Cheval et al., 2011) (Yang et al., 2010) (Parajka et al., 2005). In order to analyze the precipitation typology, we investigated the total monthly precipitation data for a period of 30 years, between 1971 and 2000 from the pluviometric stations in Turda, Cluj-Napoca and Băişoara. The rainfall data series for Petreştii de Jos were available on only two years, between January 2007 and December 2008. The reason why these data were also taken into account is that their analysis allows the calibration of the median data for the whole Hasdate basin. Fărcaş I. also studied the correlation between the data from stations in Cluj-Napoca and Turda to extend the monthly data and the annual average rainfall in order to compare them with those of the 1896-1955 period, finding that from climatologically point of view there are no large differences.

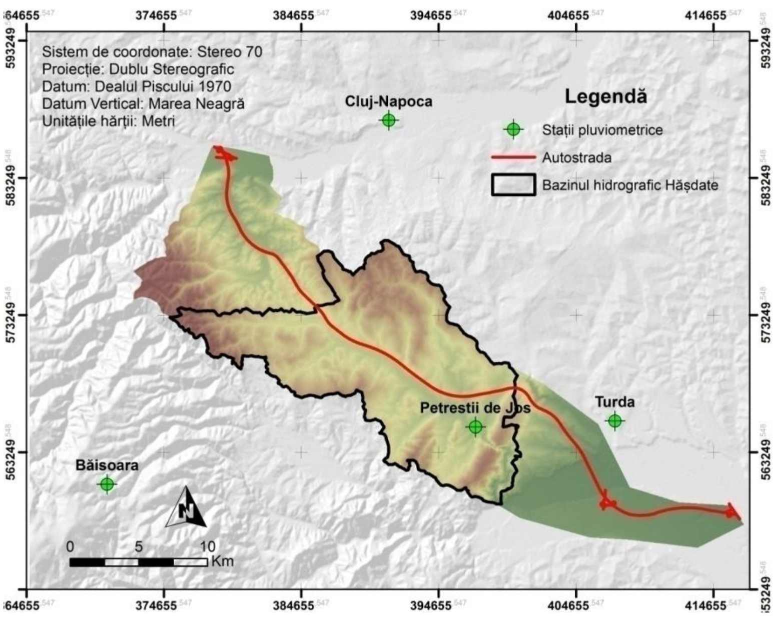


Figure 11 Spatial distribution of pluviometric stations

The time series required by the CAESAR program was obtained for a period of 17 years from actual data measured in Cluj-Napoca and Turda, calibrated to the amount of precipitation from Petreştii de Jos and Băişoara.

5.3.4. Hourly precipitation series

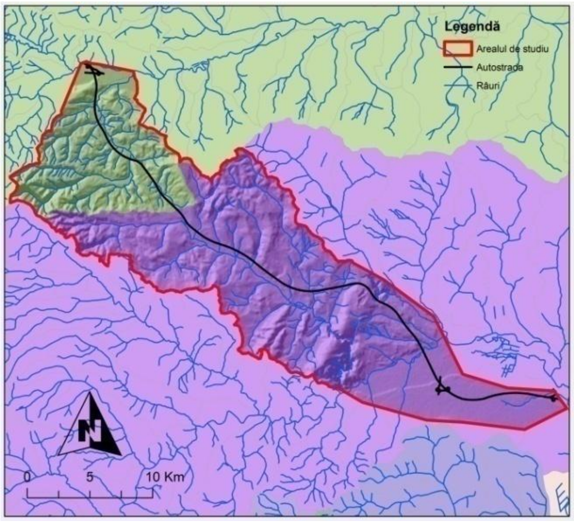
For a realistic simulation is required a realistic set of input data. Input data for precipitation should be sufficient (to cover several years from a climate perspective) and have to describe as possible correctly in statistical terms the entire investigated area. The processing of the precipitation data to achieve the right format needed for running CAESAR program was performed by using a simple code, created by us in the C language. We obtained a data set of 150,000 with zero slope, based on characteristics of the actual rainfall measured in the four meteorological stations considered for this area.

5.3.5. Climatic issues with importance in the occurrence of geomorphological processes

Liquid precipitations are primarily important both in terms of quantity and in the temporal distribution. A classification of territorial vulnerability in Transylvanian Depression by analyzing the torrential rain intensity shows that the highway across a region with low vulnerability class. Evapotranspiration is another derivative element from the climate system, representing the sum of the amounts of water evaporated from the soil and exuded by plants within an areal. According to the studies made by Sandu I., the spatial distribution of average annual evapotranspiration in the highway vicinity is ranked within 500-650 mm (Sandu et al., 2008). Rainfall erosion is a common parameter in soil erosion studies. This parameter best describes the climate aggressiveness regionally manifested by the silt mobility in a river basin. To estimate the erosion in the area of interest we used the method proposed by Diodato N (Diodato, 2005). The analysis of hourly rainfall values for 2010 from the highway neighboring allowed to calculate the value for 2010 to 51,6 MJ mm $ha^{-1}h^{-1}$.

5.4. The hydrological factor

The highway route is divided between two major basins units, respectively the Mures River and the Somes River basin. In order to strengthen the note of symmetry we may note that two of the road junctions of highway are built in the depressionary corridors of the two rivers, Aries and Somesul Mic respectively.



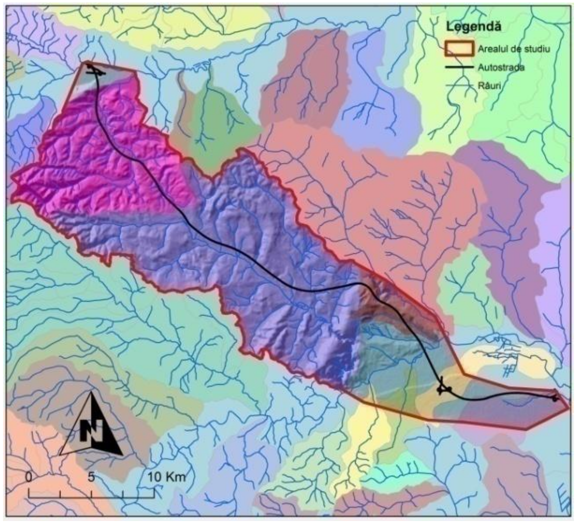


Figure 12 The spatial extension area in Mureş and Somes basins.

Figure 13 The spatial extension in Hasdate and Feneş river basins.

The highway longitudinally across the two river basins. Feneş basin has an area of 105 km^2 and a length of 29 km. Feneş River is affluent of River Somesul Mic, the point of confluence being downstream the junction of the highway with the Somes Mic riverbed. Hasdate basin has an area of 215 km^2 and a length of 31 km. Hasdate River is affluent of Aries River on the confluence point located upstream of the intersection of the highway with the Aries riverbed.

5.5. The biopedologic factor

In this chapter we presented the main characteristics of soils encountered in the area adjacent to the highway.

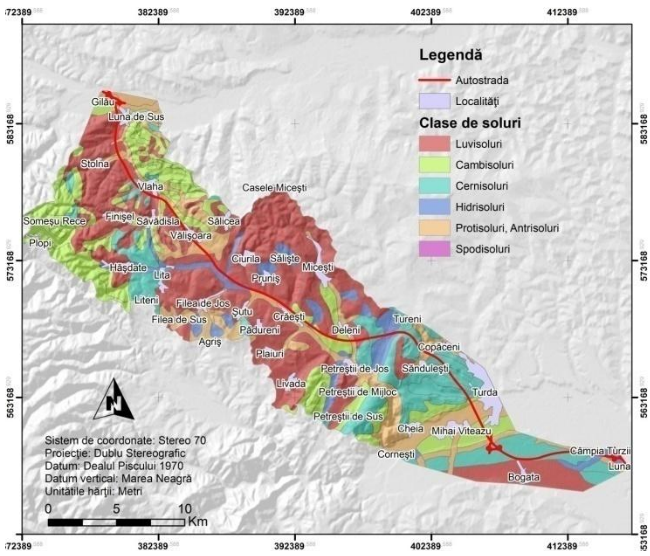


Figure 14 Spatial distribution of soil classes (Florea, 1988)

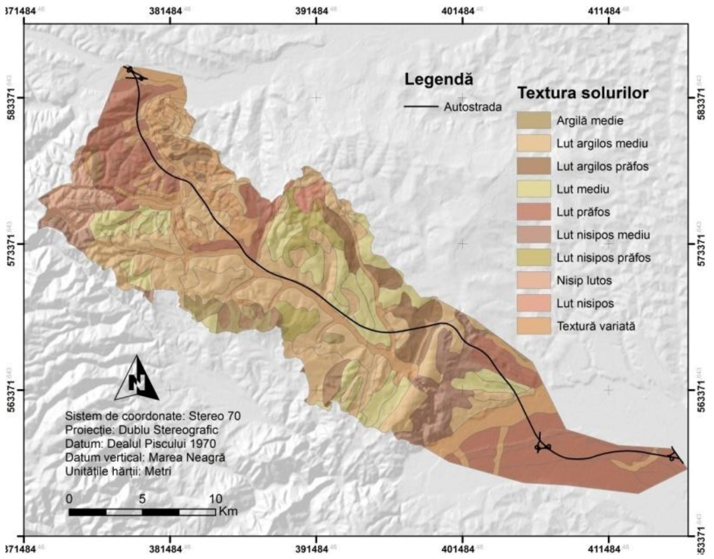


Figure 15 Spatial distribution of soil texture classes

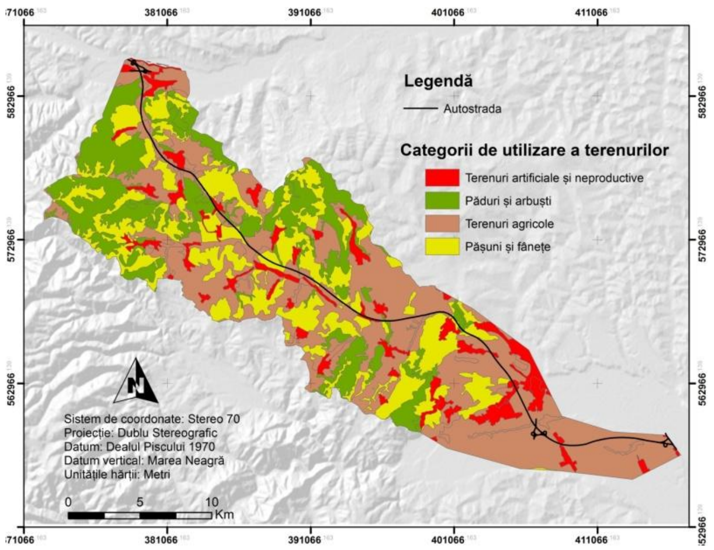


Figure 16 Spatial distribution of land use categories (EEA, 2006)

6.The analysis of the highway influence on the geomorphological river system dynamics by using numerical simulation. Hasdate basin case study

The first phase of the study was to simulate the landscape development under predetermined conditions by using the numerical model of terrain without highway. The second phase was the simulation of the relief evolution under the same conditions but with the physical parameters of the motorway implemented in the numerical model of terrain. During this phase we introduced into the system the leakage flows coming from the highway road surface, collected by drains and discharged into the river valley on the left side of Hasdate basin. We identified six points of collecting debts which were raised topographically to be implemented in the CAESAR model. These debts represent the amount of precipitation collected on the highway and discharged into the river system. The data input for CAESAR model is a time series with the time step identical to that of rainfall.

6.1. Parameters and algorithms involved in CAESAR model

6.1.1. Topography and the numerical model of terrain

The numerical model of terrain is the topographic basis on which CAESAR model simulates the slope and riverbed processes. Topographic surface representation can be done in four basic modes: grid, profiles, izohipses and triangular irregular network (Carter, 1988). For this study, we used a model of terrain formed by regular rectangular grid of cells, with a resolution of 25 meters. This resolution is a compromise between the minimum size of a cell and the processing time of CAESAR model. We used a topographic model with the best accuracy of the elevation values. To produce the numerical model of terrain used in this study we scanned, geo-referenced and digitized the topographical plans printed at 1:5000 scale. From these plans we extracted the isohipses, the elevation values and the hydrographic network. The topographic surface was calculated by using the ArcGIS platform with the Topo to Raster method (ESRI, 2010). The topography was examined for accuracy by using the corresponding geodetic points from ANCPI (National Agency for Cadastre and Real Estate Publicity) and the quotas calculated by the RTK GPS method (Real-Time Kinematic).

6.1.2. The numerical model of terrain with the highway infrastructure

We used the CAD and GIS technologies for doing the three-dimensional representation of cut and fill construction type on the sector of highway that crosses the Hasdate basin. Topographic surveys were made on the whole highway section with a differential GPS RTK system. The elevation points were processed to build a three-dimensional model by triangulation. We used a two-dimensional line to break the slope at the level of the highway-running surface. The numerical model of terrain was exported to a grid network for GIS processing. With the help of GIS technology we made the initial correction of the numerical model without highway by using the mosaic process, resulting in a numerical model of terrain with the highway infrastructure represented by the elevation values.

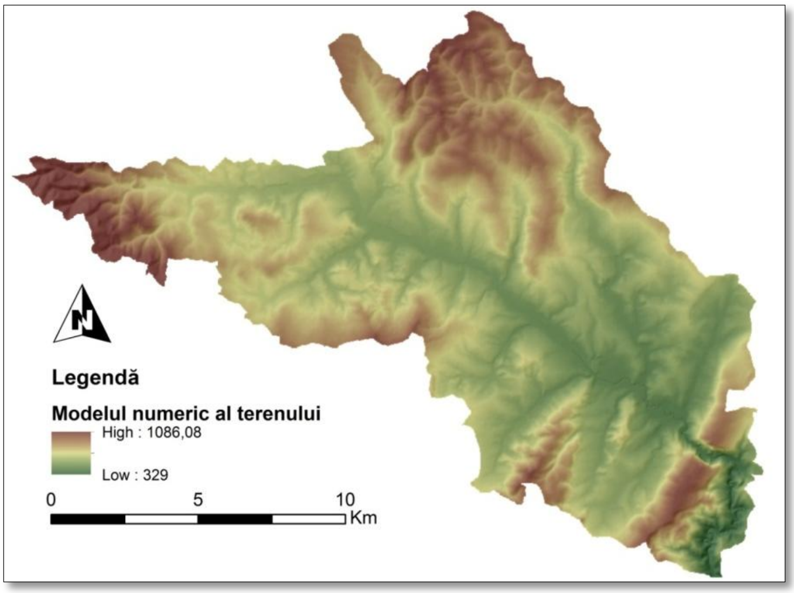


Figure 17 The numerical model of terrain for the Hășdate basin

6.1.3. The numerical model of the bedrock

The CAESAR model requires a numerical model of bedrock that acts as substrate limit for all geomorphological processes thus the soil erosion cannot pass this depth. This model was created as the difference between the initial surface of the terrain model and one with an elevation established by the operator. The rough substrate elevation that would slow or even stop the soil erosion was determined during field campaigns. For the terrain model with the highway we furthermore considered as bedrock the highway infrastructure because the perimeter of highway is not subjected to erosion.

6.1.4. Distribution of granulometric fractions in the river basin

Taking into account that the sampling points were few, was necessary to redistribute the granulometric fractions on the basin surface. The active layer where erosion is initiated has initially a uniform particle size, setted by the operator following the laboratory measurements. For a redistribution of factions in a manner close to a natural one, CAESAR model made a running until a pavement layer was obtained and the sedimentograph was balanced. This new spatial distribution of granulometric deposits is used further as input data in the model.

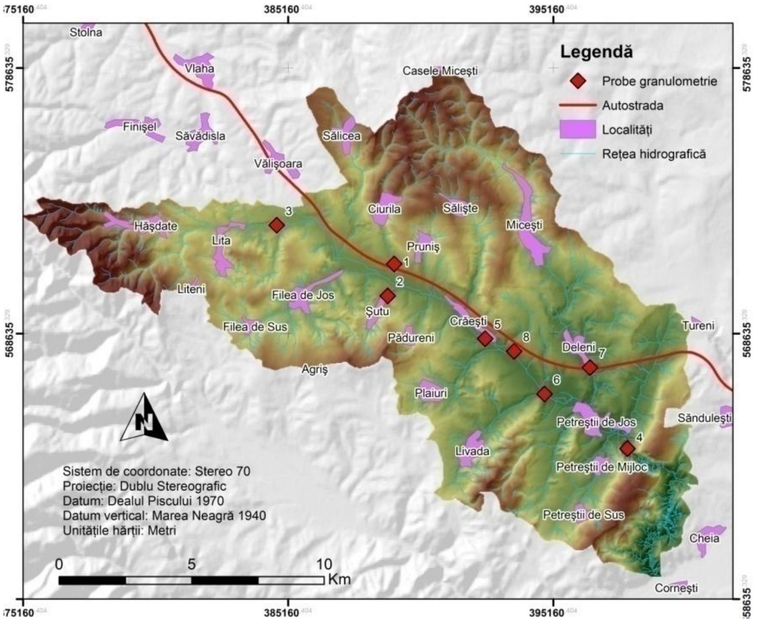


Figure 18 The geolocation of the granulometric sampling points in the Hasdate basin

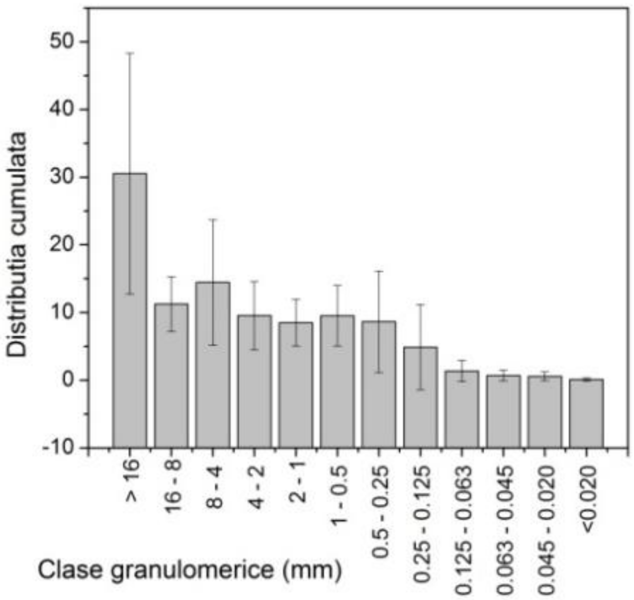


Figure 19 The granulometric distribution of the samples in Hășdate basin

6.1.5. The regression rate of the flood hydrograph

Parameter *m* as an input parameter for the model represents the regression rate of a flood peak in the basin. Its calculation could be completed in two ways. The first and most reliable is the analysis of data from a flood hydrograph of the basin. For basins that have no hydrometric stations, the calculation is done by using the topographic index of the river basin.

Within this study, we used the values registered at the flood from Petreştii de Jos on 22.06.2010. Fitting the cumulative distribution of these values with a hyperbolic function led to obtaining the value for the parameter *m*, which in this case was 0.014.

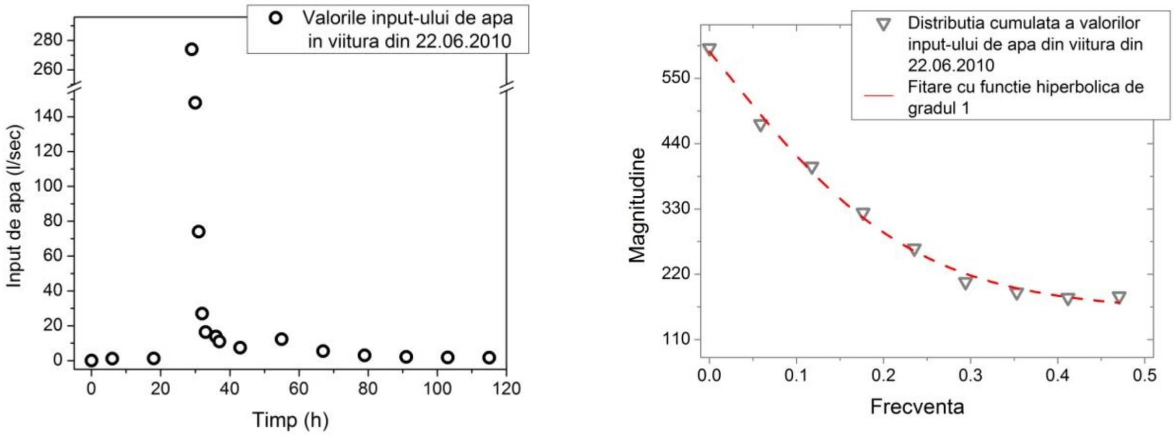


Figure 20 The regression rate of values given by the hydrograph for the 22.06.2010 flood in Hasdate basin.

6.1.6. The algorithm for calculating the flow

The algorithm used in this model to calculate the quantity of water and sediment in the riverbed or on the surface is well described in the literature (van de Wiel et al., 2007), (Coulthard et al., 2007), therefore we pointed out here only general aspects.

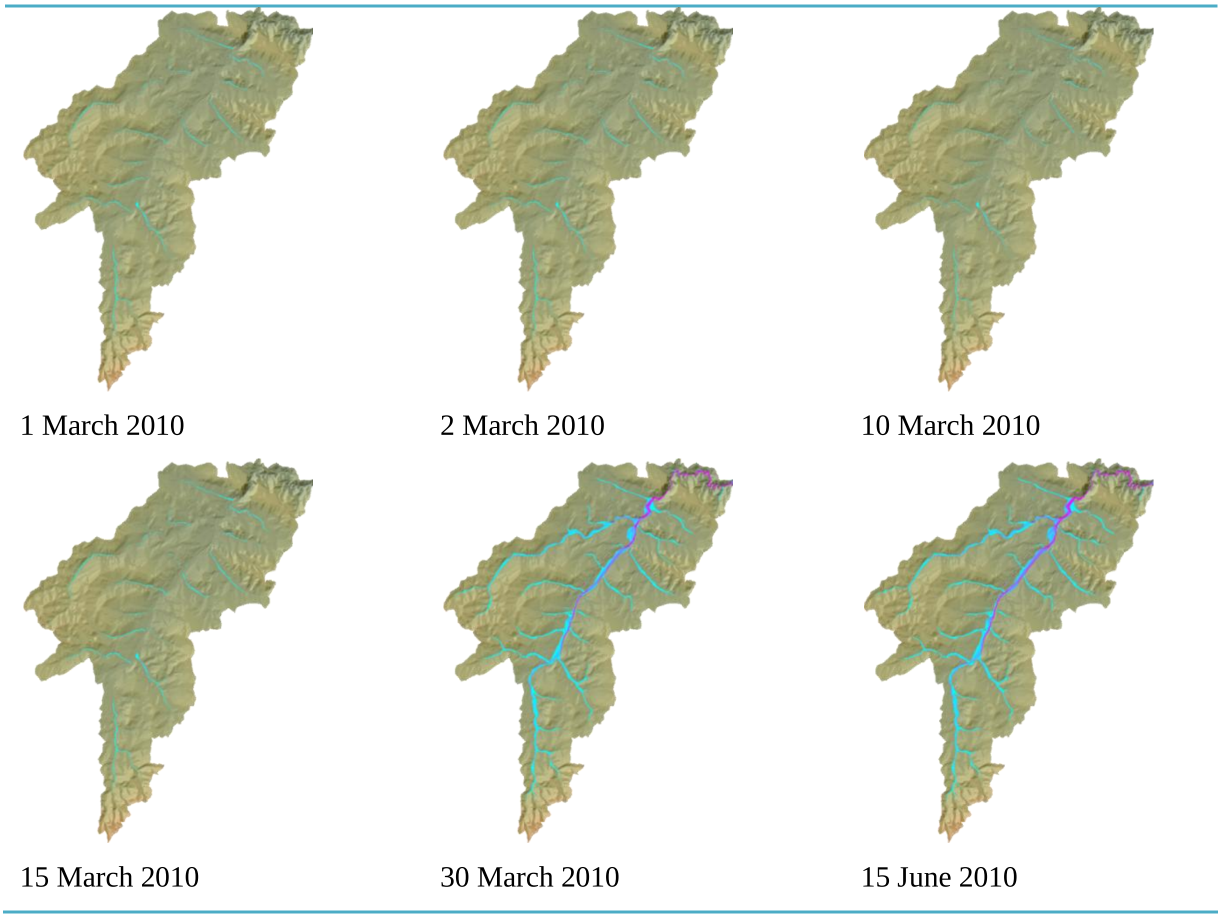


Figure 21 Sequences in the simulation of the landscape evolution in Hasdate basin.

6.2. Results obtained from simulation

The results of the CAESAR model simulation consists of the time series at a predetermined time step of 24 hours. From the resulting parameters of the simulation, we chose for analysis the debits of sediment mobilized in the basin.

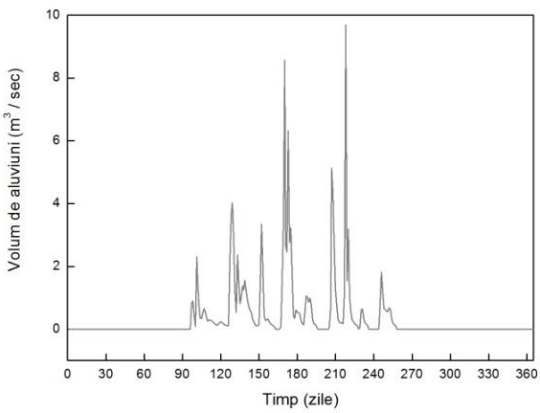


Figure 22 The values for the sediment flow calculated on Hasdate basin (no highway)

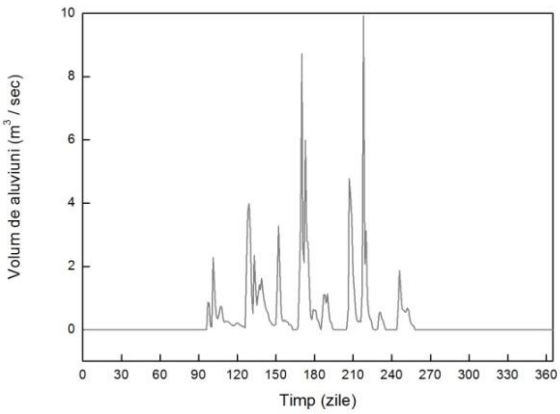


Figure 23 The values for the sediment flow calculated on Hasdate basin (with highway)

Differences between the two simulations show that the acceleration and attenuation of the sediment transport within the river basin is not based on quantitative variation in precipitation on the basin. Differences arise due to changes at the level of topographical surface variation and on liquid flow redistribution on the left side of the Hasdate valley.

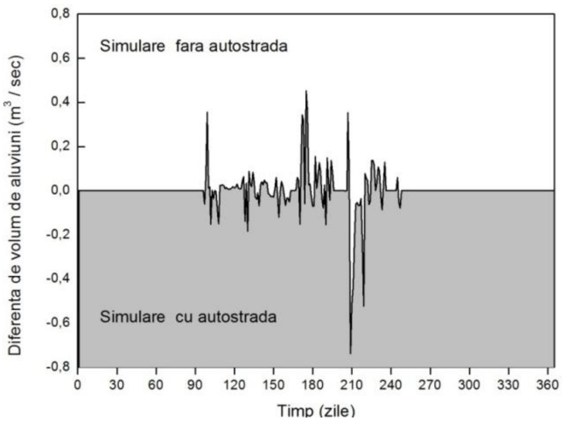


Figure 24 Differences in sediment flow between the two simulations (up – without highway, down – with highway)

The distribution maps indicate the areas with erosive processes and the reorganization of these processes on the left side of the Hasdate valley, near the highway infrastructure. From the pictures we can see details on the distribution of the storage areas which act as sources of sediment. One can notice a clogging perimeter near the highway infrastructure, which is identified in terrain by clogging the protection gutters of the highway.

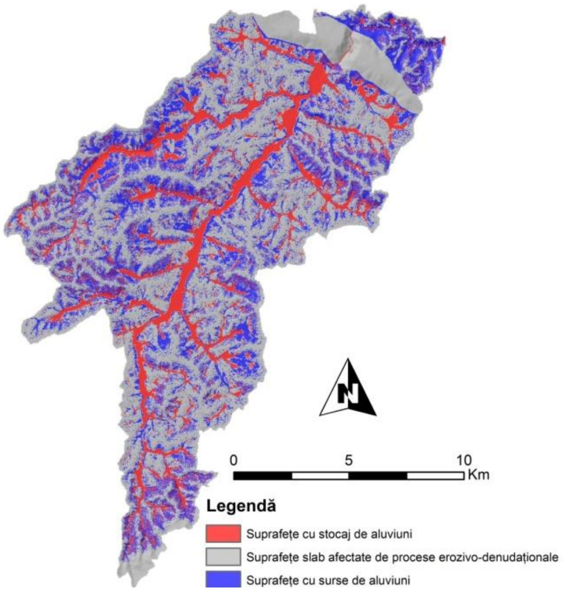


Figure 25 Distribution of areas affected by erosion processes. Numerical model including the highway.

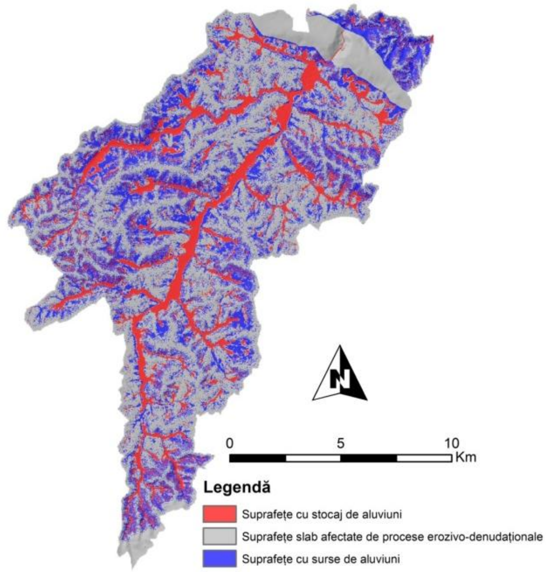


Figure 26 Distribution of areas affected by erosion processes. Numerical model without the highway.

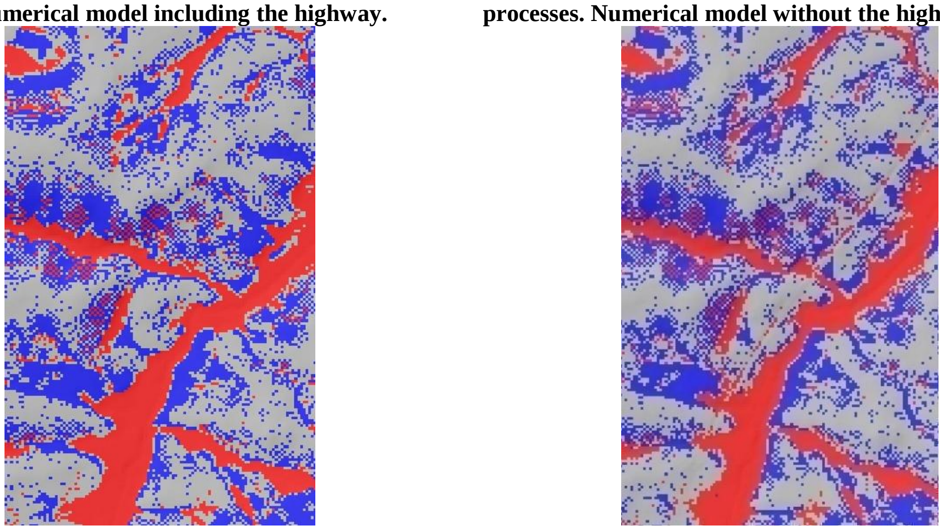


Figure 27 Images of details on the areas affected by erosion processes. Left without highway, right with highway.

7.Analysis of the highway influence on the dynamic geomorphological slope system. Mass movement processes in the Hasdate basin

The highway route across a territory which in terms of lithology is characterized by poorly consolidated rocks, that are plastically deformable, slide and flows on slopes. The active manifestation of the diluvial processes is relatively low. Most landslides on the highway related area are translational and superficial. Among the most important causes of releasing the landslide are the vibrations that occur during excavation of the yard in vicinity of the road. However, during the investigations performed in terrain we identified a landslide that has become a particular subject in this thesis.

7.1. The landslide from Craesti

7.1.1. Site location and description

The landslide is located in the northwest of the Craesti village on the left side of the Hasdate valley. The distance between the landslide forehead and the land requirement of the highway is about 5 m. According to the study of the diluvial deposit, in the lithologic composition are present clays, sands and sandstone concretions. In the vicinity of the sliding body we identified natural openings in the torrential bodies. Into this openings, where first occurres layers of sandstones and sands, we raised topographic quotas. Following these quotas we concluded that the layers of sandstones and sands are monoclinic, in accordance with the slope inclination. Furthermore, it was established that they are located at a depth of 3-4 meters from the ground. By using specific methods we have outlined the landslide mapping.

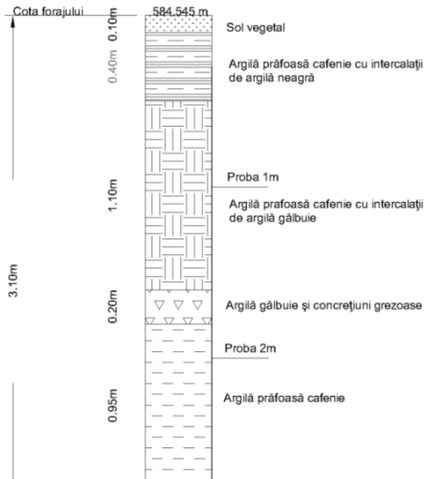


Figure 28 Drilling the diluvial warehouse from Craesti

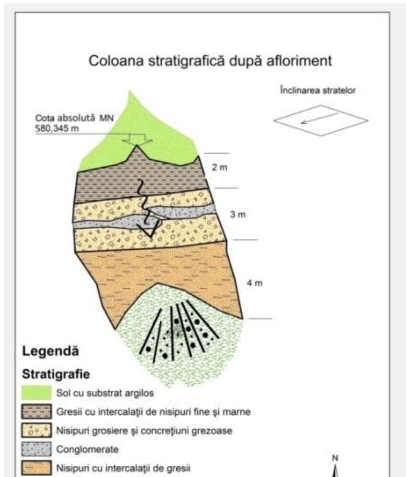


Figure 29 Stratigraphic column after the outcrop for the landslide near Craesti

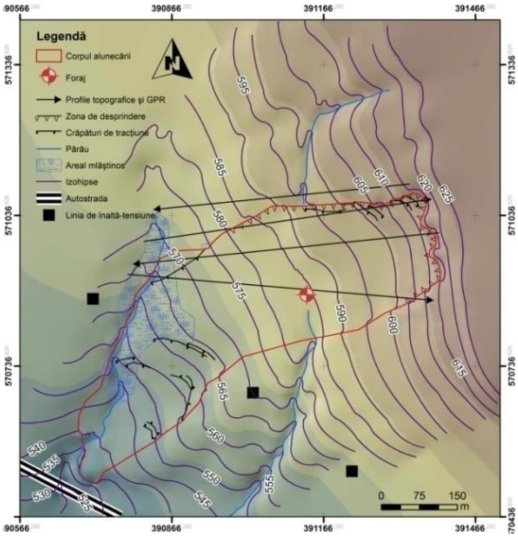


Figure 30 The outline of the landslide near Craesti

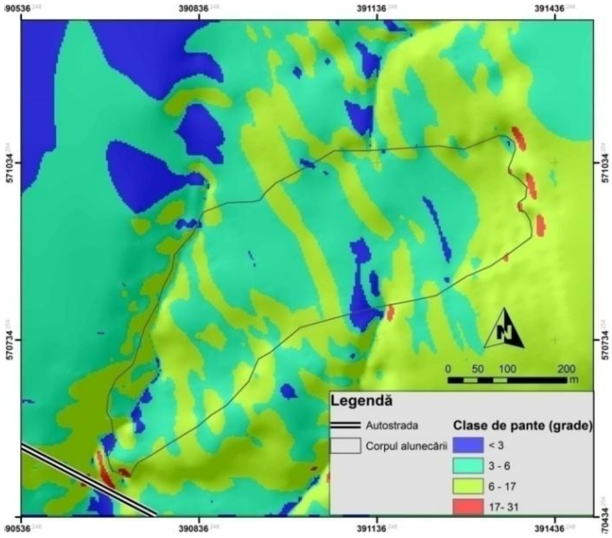


Figure 31 The slopes distribution in the landslide near Crăești

7.1.2. The physico-mechanical description of the diluvial deposits

Manifestations and dynamics of the landslide system largely depend on the physical properties of the substrate. They tend to change with the entry of the system into a dynamic phase. The knowledge of these variables contributes significantly to the accuracy of the results in the analysis of system dynamics of slopes.

The granulometric fraction is the represented by particle with characteristic size dimension for gravel, sand, dust and clay:

Table 1 The granulometric fractions STAS (1243-88, 1983).

Gravel	2-70 mm
Sand	0,05-2 mm
Dust	0,005-0,05 mm
Clay	< 0,005 mm

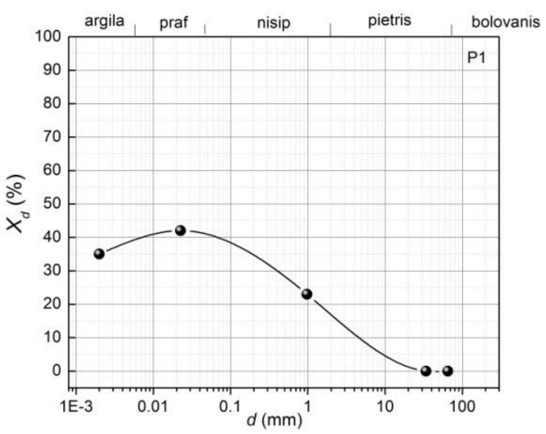


Figure 32 The granulometric histogram and frequency curve for sample 1

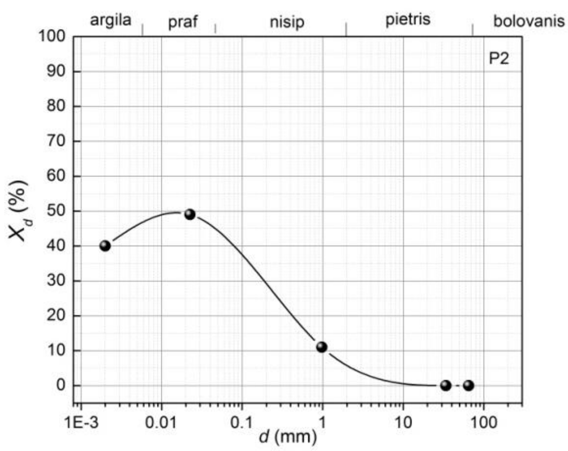
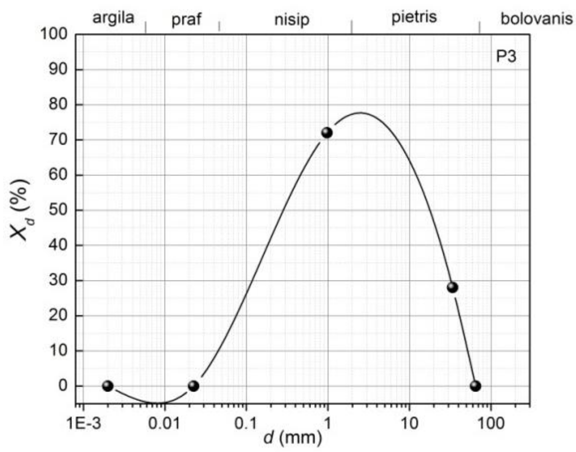


Figure 33 The granulometric histogram and frequency curve for sample 2



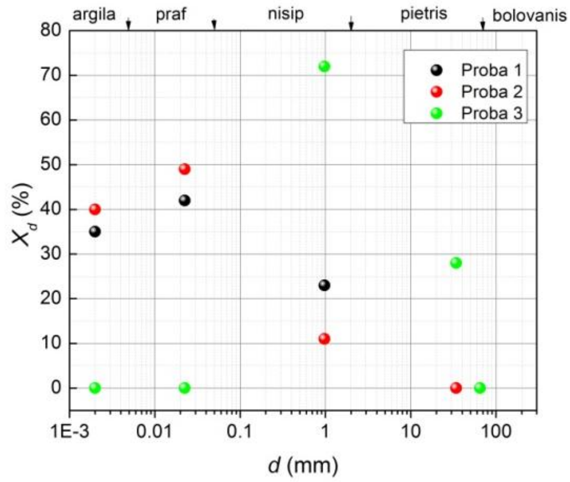


Figure 34 The granulometric histogram and frequency curve for sample 3

Figure 35 The granulometric histogram and frequency curve for all samples

Unevenness coefficient is the ratio between the diameter of the granularity with a weight of 60% of the composition and the diameter of the granularity with the weight of 10% in the same composition.

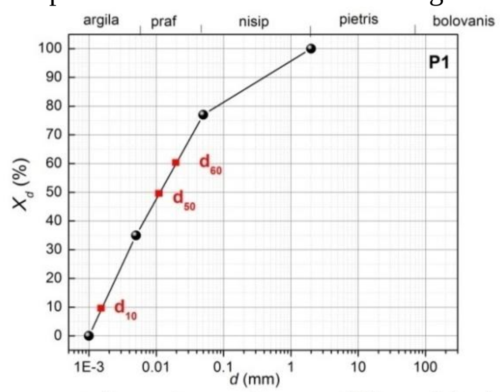


Figure 36 The granulometric curve for sample 1

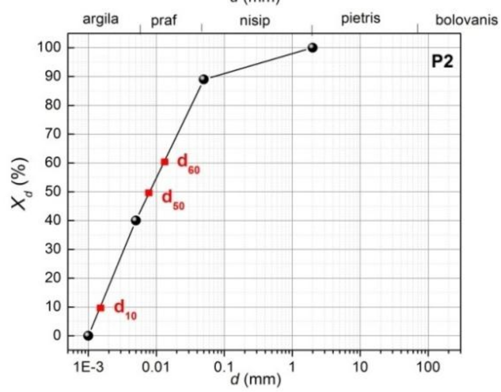


Figure 37 The granulometric curve for sample 2

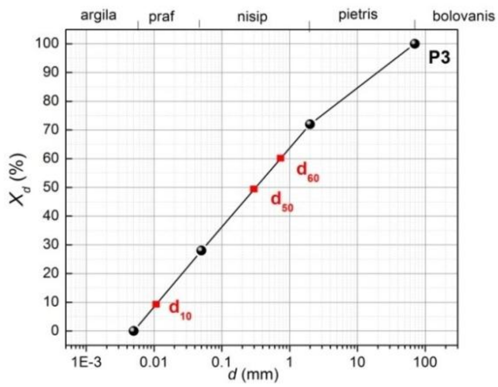


Figure 38 The granulometric curve for sample 3

According to granulometric curves this samples are included in class of soils with the medium uniformity (5 <U <15). They have the following values:

Table 2 The unevenness coefficient of samples

Sample 1	12,5
Sample 2	8
Sample 3	5,6

The natural humidity represents the wetting share of the diluvial material. To the samples we calculated the following percentages:

Table 3 The natural humidity percent

Sample 1	36,7 %
Sample 2	35,12 %
Sample 3	32 %

By means of these values we calculated the humidity content. Samples have the following degrees of saturation:

Table 4 The degree of saturation

Sample 1	0,98
Sample 2	0,94
Sample 3	0,96

We can see that the investigates soil deposit is saturated, with values of $S_r > 0{,}9$.
The limits of plasticity or the Atterberg plasticity limits are expresses the state of the matrix deposits. For the analyzed samples we established the following values:

Table 5 The limits of plasticity

	$\boldsymbol{W_L}$	$\boldsymbol{W_P}$
Sample 1	48,39 %	31,69 %
Sample 2	47,97 %	29,07 %
Sample 3	The fraction $< 0{,}5$ is not sufficient to perform this analysis	

The investigated diluvial deposit is included in the class of silty clays with medium plasticity: : $35\% < w_L < 50\%$. Based on these values we calculated the size of the interval of plasticity.

The plasticity index represents the value of the humidity interval in which the diluvial deposit behaves like plastic. The ranges of plastic behavior of the samples, calculated by basing on plasticity limits are:

Table 6 The plasticity index

Sample 1	16,70 %
Sample 2	18,90 %

By analyzing the plasticity index, the diluvial deposit falls within the class of silty clays with middle plasticity $15\ \% < I_P < 35\ \%$.

The consistency index represents the actual natural physical state of the clay deposits. Applying the above formula returned the following values:

Table 7 The consistency index

Sample 1	0,70
Sample 2	0,68

According to this index, the samples fall within the class of consistent plastic materials with $0{,}51 < I_c < 0{,}75$.

Weight density of the samples skeleton is the ratio between the weight of solid particles and the volume of the investigated material skeletal. For this case, we used the specific gravity values recommended by S. Manea, according to which these values do not differ significantly from a soil to other (Manea et al., 2003).

For gravitational acceleration we used the 10 $\frac{m}{s^2}$. Based on these values we calculated the following specific densities:

Table 8 Weight volume and density of the skeleton

	$\boldsymbol{\rho_s}$	$\boldsymbol{\gamma_s}$
Sample 1	2,7	27
Sample 2	2,7	27
Sample 3	2,65	26,5

Volume weight in natural state is the ratio of total sample weight and its volume. The samples have the following values:

Table 9 Volume weight in natural state

Sample 1	18,33
Sample 2	18,16
Sample 3	18,56

Dry volume weight is the weight of dry sample relative to the total volume of the sample. Dry density is the ratio of dry sample weight and total volume of the sample. Following the laboratory measurements we calculated the following volumetric weight:

Table 10 Dry volume weight

	$\boldsymbol{\gamma_d}$
Sample 1	13,41
Sample 2	13,44
Sample 3	14,06

Porosity is the percentage of pores to the total volume. We calculated the following values:

Table 11 Porosity

	n
Sample 1	50
Sample 2	50
Sample 3	46

The colloidal activity index or the Skempton's index of activity, defines the activity of the clay deposits in relation with water. The granulometric curve analysis returned the following values for colloidal activity:

Table 12 The colloidal activity index

Sample 1	1,11
Sample 2	1,11
Sample 3	fraction composition of 0,002 mm does not exists

According to these results, the clays from the diluvial deposit are a medium colloidal activity ($0{,}76 < I_A < 1{,}25$).

7.2. Investigation of the slide plane by using GPR

7.2.1. Setting the values for the used parameters

For the processing of the initial data sent and received by antennas is necessary to set the values for different lithological conditions. These values are entered into the system before starting the measurements.

The propagation speed of electromagnetic waves. In this study we used the empirically obtained values reported in the scientific literature or communicated personally. After the lithological analysis of drilling, confronted with the reported values, we established the use of a propagation velocity of 0.06 m /ns (Davis & Annan, 1989) (Jol & Bristow, 2003). This speed is characteristic to a clayish lithology and saturated sand, both of them being found in the investigated area.

The emission interval of the electromagnetic wave. Another default value is the time window. This is the period of time when the electromagnetic wave is emitted into an impulse and defines the total length of a trace. A.P. Annan argues that the time must be set so that the depth of penetration to exceed one third of the expected length of the investigated environment or searched object (Annan, 2001). For the case study presented here, we used a value of 433.3 ns, which is consistent with the values specified in the literature or used in practice (Annan, 2001) (O. Sass personal communication).

The interval of sampling. This variable sets the sampling frequency of a trace. In this case we used a sampling rate of 800 MHz.

The step of metrical measurement. The GPR system configuration and the terrain morphology imposed the use of equidistant metric step. This step represents the distance between the tracks recorded on a profile. For this application we used the step of 0.5 m, which is consistent with the two recommendations above.

7.2.2. Processing and interpretation of data

Editing and filtering

This stage resembles mostly with the processing of the seismic reflection data. A first step in data processing is to edit or correct the header file. It contains information about the parameters involved in the measurement, the profile names and other information that helps to organize the GPR data. The second stage is to process by filtration the data acquired in terrain. The majority of measurements performed on sedimentary substrate require a basic filtration (Jol & Bristow, 2003). For the processing stage, we used the ReflexW program (Sandmeier, 1993).

7.2.3. Interpreting the radargrams

After the radargrams interpretation we established that the saturated sand layer maintains an equidistant level 0 from the ground. This layer is found between 3 and 4 meters.

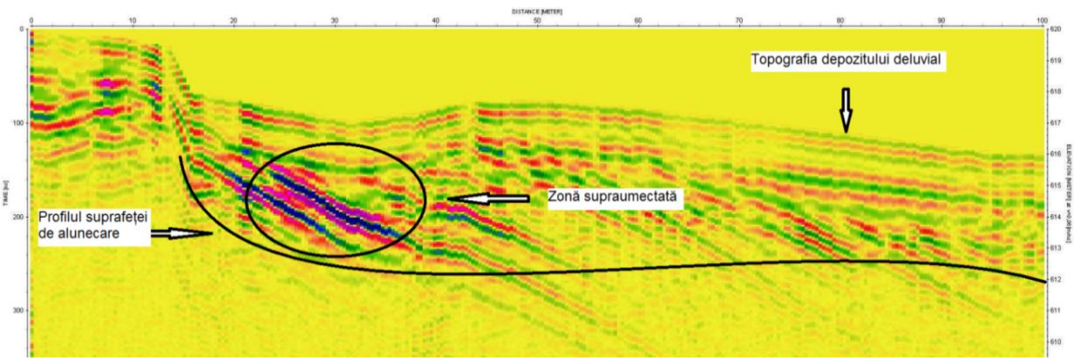


Figure 42 Radargram including the area of detachment of the landslide from Crăeşti

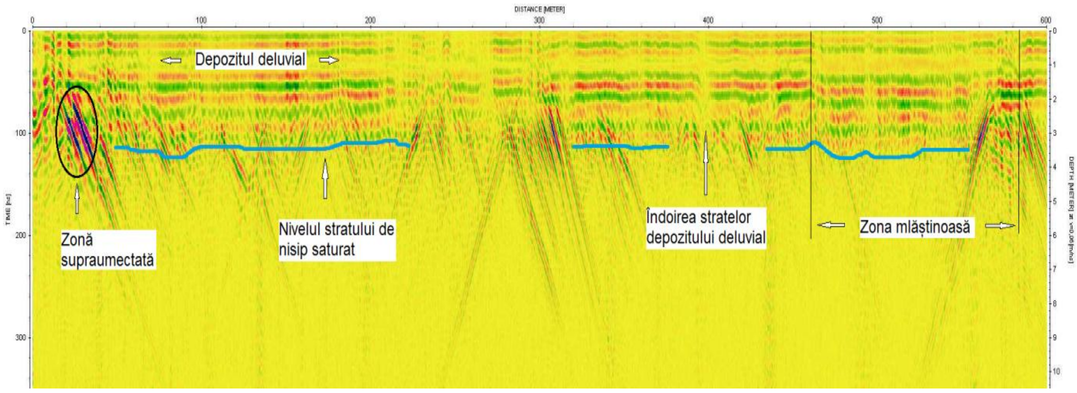


Figure 43 Interpreting a georadar profile on the landslide from Crăeşti

By interpolating between the georadar profiles we can consider that the sliding surface of this mass movement is in accordance with the terrain surface.

7.3. The slope stability analysis

The landslide was analyzed from the perspective of the affected slope stability or safety factor. For this analysis we performed a study of tensile shear strength of diluvial deposit. Maximum shear strength is influenced by the possibility of draining water from the diluvial deposit. In the light of this fact, two types of behavior of the diluvial deposits are known: On short-term, the deposit deforms into a constant volume without drainage; on the long term, the deposit is drained and its behavior is dictated by the skeleton of material without the interstitial overpressure of water.

The resistance analysis was done on the straight-line characteristic to the deposit and depending on the parameters of the tensile shear strength. The characteristic straight-line of the deposit expresses the shear condition by the Mohr-Coulomb equation. In this case the we carried out an analysis on a long-term behavior by calculating the effective parameters of tensile shear strength. This method involves the draining of the sample during laboratory tests and reducing the value of water pressure in pores to 0 (Popa & Farcas, 2004). The analysis conducts to the effective parameters:

Table 13 The effective parameters of the tensile shear strength

	internal friction angle (φ)	cohesion (c)
Sample 1	13	8
Sample 2	13	8
Sample 3	19	0

The safety factor is the ratio between the forces that cause the movement of the diluvial deposit and the resistance forces that stand against the movement (Surdeanu, 1998).

Gravity is the main force that tends to reduce the horizontal morphology of terrain. Against it are opposed the cohesion and friction forces. The stability of a slope depends greatly on the state of equilibrium between the two parties (De Blasio, 2011).

Thus,

$$F_s = \frac{\text{The resistive forces}}{\text{The driving forces}}$$

F_s> 1 means that the system is stable and F_s< 1 means that the system is unstable.

The factors that influence the value of the safety factor differ in their nature:

- Type of rock involved in the geomorphological process
- The stratigraphy of the diluvial deposit
- The weight distribution within the landslide deposits
- The infiltration rate of water into the lithological structure
- Vegetation and land use on the sliding body
- The influence of the impulsive forces outside the system that disturbs the slope equilibrium

The safety factor was calculated by using the (Milligan et al., 2005) method:

$$F_s = \frac{\text{tg}\varphi}{\text{tg}\beta}\left[1 - \frac{\gamma_w}{\gamma}\frac{(1 + \text{tg}^2\beta)}{(1 + \text{tg}\alpha\text{tg}\beta)}\right]$$

here:

F_s is the safety factor

γ is the volumetric weight of the deposits

γ_w is the volumetric weigth of water

$\text{tg}\beta$ is the slope of the diluvial deposit

$\text{tg}\alpha$ is the slope of the hydrostatic level

Within this study we have considered that $\alpha = \beta$ so the safety factor formula became:

$$F_s = \frac{\text{tg}\varphi}{\text{tg}\beta}\left[1 - \frac{\gamma_w}{\gamma}\right]$$

To calculate the safety factor value we took into account the results from the morphometrical and geotechnical analysis: the internal friction angle was $\varphi = 15$; the angle formed by the diluvial deposit arrangement and the horizontal line was $\beta = 6$; the volumetric weight of water is $\gamma_w = 9,8$; the volumetric weight of the deposits was $\gamma = 18,35$.

The study established thatF_s = 1,27 resulting in a stable condition. From the above assessment it can be seen that the value of the safety factor does not depend on the depth of the slip plane and the condition of stability is preserved as long as $\beta < \varphi$.

7.4. The geomorphology of the landslide

The Craesti landslide system was measured in terrain by topographic and geophysical variables, through the slip was detailed geomorphologically mapped and analyzed in the laboratory.

Morphometric variables measured in the terrain are:

- The maximum length measured from the cornice to the top of the landslide separation is 871 m
- The maximum width measured at the widest area of the sliding body is 254 m.
- The thickness of the landslide was determined after geotechnical and geophysical measurements at an average of 3.5 m.
- The sliding perimeter is 2020 m
- Landslide surface is 183 582 m^2.
- The volume was calculated according to the relation of Surdeanu V. (Surdeanu, 1998) and has a value of 774 319 m^3.

The morphological analysis established that the landslide has manifested in two sequences.

The first sequence has an anthropogenic causation. During the construction works to the highway raises the base of local hydrographic network by storing the waste dumps of soil in the riverbed. Ensuring the drainage was made by inadequate drainage pipe thus at the first heavy rainfall it was interrupted. It was followed by a period when the ground surface upstream of the highway infrastructure has turned into a swamp, the groundwater in the area making swamps.

In spring-summer season heavy rainfall occurred in Hasdate basin and the over wetted diluvial deposit exceeded the steady state and turned into a mudflow that pushed into the protection with stepped gabions furnished on the riverbed. This process has completely barred the highway drainage infrastructure arranged underneath.

The second sequence took place following the undermining of the left side base of the stream. Mudflows allowed the transport of diluvial sediments into the riverbed. The state of slope stability was affected by entering into a phase of translational slide. The diluvial deposit slip occurred on a relatively short distance up to 5 m and the cornice of detachment slide has an average height of 2 m.

At the time of the measurements the deposit was in an meta-equilibrium, established through sequential topographic measurements. The disorganized poor drainage on slopes may further impose new conditions thus adjusting the system structure and the equilibrium safety factor.

8. General conclusions

The present thesis is intended to be a study of applied geomorphology to analyze the impact of road infrastructure on the dynamic geomorphological systems. We presented two case studies for slope and riverbed processes, representative in the investigated area.

Initiation of detailed geomorphological studies were made after a review of the physical factors that affect local the proper functioning of the highway. The land classification systems revealed geographical area with factors of high impact on geomorphological processes generated even anthropogenically or natural.

The geological background of the area imposes, by the physical properties of rocks, conditions to the manifestations of the geomorphological phenomena. It was shown that tilting the degree of orientation of strata or compaction of layers within the stratigraphic packages drastically affects the slope stability. The grain size of the diluvial deposits and their spatial distribution influence the structure and dynamics of the groundwater in these deposits.

The geomorphological and geographical regionalization analysis highlights the conditioning in the system of slope – riverbed by the hypsometric gap and gradient.

The hydrographic network is an important factor in the dynamics of alluvial material displaced by erosion processes.

The climatic factor proved to be the "engine" of the geomorphological processes on slopes. The rainfall directly affects the geomorphological phenomena by amplitude and intensity.

We showed that in this area the biopedologic factor is closely related to human factor. Man influences the evolution of edaphic layer by controlling vegetation and land use. The soil is of great importance in the dynamic of the geomorphological system, in particular in terms of physicochemical properties.

The methodology employed in conducting the case studies presented above is a collection of techniques and methods with issues of originality for the applied geomorphology studies in Romania. We used numerical modeling and computational simulation to study the fluvial processes and soil erosion. Numerical and mathematical modeling was used to investigate the altimetric data, series of precipitation, geotechnical and geophysical data. GIS technology enables the spatial distribution representation of the areas under investigation. It should be noted that most of the data used in the statistical and mathematical models were collected during terrain campaigns.

The effect of the highway infrastructure in the geomorphological dynamic in Hasdate basin was simulated by means of CAESAR model. This model provides data that characterize the influence of environmental changes, showing that during a year may appear changes in the river basin, still too subtle for being measured locally.

The slope processes were studied for a landslide, considered representative for the highway area of influence. The morphometric variables were analyzed to characterize the slide system and slope stability. We discussed the anthropogenic influence on geomorphological versant system.

Among the aspects of originality we can emphasize:

- The using of CAESAR landscape evolution model to simulate the impact induced by the road infrastructure projects in the river basin
- The investigation of the structural architecture of diluvial deposits by means of GPR technique for the first time in applied geomorphology studies in Romania.

Integral bibliography

1. Abu Hammad, A., Lundekvam, H. ; Borresen, T., (2005). Adaptation of RUSLE in the Eastern part of the Mediterranean Region. *Environmental Management*, 34(6), pp.829-41.
2. Alberts, E.E., Holzhey, C.S., West, L.T. ; Nordin, J.O., (1987). *Soil Selection: USDA water erosion prediction project (WEPP)*. St. Joseph, MI: American Society of Agricultural and Biological Engineers USDA.
3. Anghel, T. , Bilaşco, Ş., (2008). The Motru basin-GIS application on sheet erosion. *Geographia Napocensis*, 2(1), pp.90-108.
4. Annan, A.P., (2001). *Ground penetrating radar workshop notes*. Ontario: Sensors and Software Inc.
5. Arghiriade, C., (1968). Cercetări privind capacitatea de retenţie a apei în culturile tinere de protecţie de pe terenurile degradate.: Centrul de Documentare Tehnică pentru Economia Forestieră. Bucureşti
6. Armaș, I.,(2006). Risc și vulnerabilitate. Metode de evaluare aplicate în geomorfologie. Editura Universității din București. București
7. Badea, L. (sub redacție), (1983). *Geografia României I. Geografie fizică*. Editura Academie RSR. București
8. Badea, L., Niculescu, G. , Sencu, (1976). *Harta Geomorfologică a României scara 1: 1000000*. Academia Română Institutul de Geografie. București
9. Bailey, S.D., Wintle, A.G., Duller, G.A.T. , Bristow, C.S., (2001). Sand deposition during the last millennium at Aberffraw Anglesey, North Wales as determined by OSL dating of quartz. *Quaternary Sciences Reviews*, 20, pp.701-04.
10. Băloiu, V., (1965). *Amenajarea torenţilor pe teritoriul agricol*. Editura Agrosilvică. Bucureşti
11. Băloiu, V. , Ionescu, V., (1986). Apărarea terenurilor agricole împotriva eroziunii, alunecărilor şi inundaţiilor. Editura Ceres. Bucureşti
12. Bălteanu, D., (1983). *Experimentul de teren în geomorfologie*. Editura Academiei RSR. București
13. Bălteanu, D., (1992). Natural hazards in Romania. *Revue Roumaine de Geographie*, 36, pp.47-57.
14. Bălteanu, D., (1997). Geomorphological hazard of Romania. In C. Embleton și C. Embleton-Hamann, eds. *Geomorphological Hazards of Europe*. Elsevier. pp.409-27. Amsterdam
15. Bălteanu, D., Dinu, M. , Cioacă, A., (1989). Hărțile de risc geomorfologic (Exemplificări din Subcarpații și Podișul Getic). *Studii și Cercetări de Geologie, Geofizică și Geografie*, XXXI, pp.9-13.
16. Bălteanu, D. (sub redacție), (2012). Recent landform evolution in Romanian Carpathians and Pericarpathian Regions. In D. Loczy, M. Stankoviansky și A. Kotarba, eds. *Recent Landform Evolution. The Carpatho-Balkan-Dinaric Region*. Londra și New York: Sringer. pp.249-87.
17. Băncilă, I.(sub redacție), (1980). *Geologie Inginerească*. Editura Tehnică. București
18. Barat, C., (1963). La geomorphologie appliquee en Roumanie. Constatations et suggestions. *Revue de Geomorphologie Dynamique*, XIV, pp.10-12.
19. Bates, P.D. , De Roo, A.P.J., (2000). A simple raster-based model for flood inundation simulation. *Journal of Hydrology*, 236, pp.54-77.
20. Bates, P.D., Horritt, M.S., Fewtrell, T.J., (2010). A simple inertial formulation of the shalow water equations for efficient two-dimensional flood inundation. *Journal of Hydrology*, 387, pp.33-45.
21. Beckinsale, R.P. , Chorley, R.J., (1991). Historical and Regional Geomorphology 1890-1950. In *The History of the Study of Landforms or the Development of Geomorphology*. Routledge. p.Volume III. Londra și New York

22. Belozerov, V., (1972). *Clima orașului Cluj și a împrejurimilor. Teza de doctorat*. Universitatea Babeş-Bolyai. Cluj-Napoca
23. Bilaşco, Ş. et al., (2009). Implementation of the USLE model using GIS techniques. Case study the Someşean Plateau. *Carpathian Journal of Earth and Environmental Sciences*, 4(2), pp.123-132.
24. Blaga, G., Filipov F.,Paulette L., Rusu I., Udrescu S., Vasile D.,(2008). *Pedologie*. Editura Mega. Cluj-Napoca
25. Boengiu, S., (2003). *Geologie Generală. Îndrumător de lucrări practice*. Tipografia Universităţii din Craiova. Craiova
26. Bogdan, O. , Frumușelu, D., (2002). *Atlas geografic. România. Mediul și rețeaua electrică de transport*. Editura Academiei Române. București
27. Box, G.E.P. , Jerkins, G.M., (1976). *Time series analysis: Forcasting and Control*. 2nd ed. Holden-Day. San Francisco
28. Brockwell, P.J. ,Davis, R., (1991). *Time series: Theory and Method*. Spriger-Verlag. New York
29. Brunsden, D., (2002). Geomorphological roulette for engineers and planners: some insights into an old game. *Quaterly Journal of Engineering Geology and Hydrology 35*, pp.101-42.
30. Bryce, R.M. , Sprague, K.B.,(2012). Revisiting detrended fluctuation analysis. *Nature*, (martie).
31. Bunte, K. , Abt, S.R., (2001). Sampling surface and subsurface particle-size distribution in wadable gravel- and cobble-bed streams for analyses in sediment transport, hydraulics and streambed monitoring. Rocky Mountain Research Station. Fort Collins
32. Buynevich, I.V., FitzGerald, D.M. , van Heteren, S., (2004). Sedimentary records of intense storms in Holocene barrier sequences, Maine, USA. *Marine Geology*, 210, pp.135-48.
33. Buz, V. , Rus, I., (2002). *Geografie Tehnică-Topografie*. Editura Eurodidact. Cluj-Napoca
34. Carter, J.R., (1988). Digital representation of topographic surfaces. *Photogrammetric Engineering and Remote Sensing*, 54(11), pp.1577-80.
35. Cassidy, N.J.,(2009). Electrical and magnetic properties of rocks, soils and fluids. In J. H.M., ed. *Ground penetrating radar.Theory and applications*. Elsevier Science. pp.41-73. Oxford
36. Cassidy, N.J., (2009). Ground penetrating radar data processing, modelling and analysis. In H.M. Jol, ed. *Ground penetrating radar. Theory and applications*. Elsevier. pp.141-176. Amsterdam
37. Chen, Z., Ivanov, P.C., Hu, K. , Stanley, H.E., (2002). Effect of nonstationarities on detrended fluctuation analysis. *Physical Review E*, 65(4).
38. Cheval, S. ; Baciu, M.; Dumitrescu, A.; Breza, T.; Legates, D. R.; Chendeș, V,(2011). Climatologic adjustments to monthly precipitation in Romania. *International Journal of Climatology*, 31, pp.704-714.
39. Christie, M., Tsoflias, G.P., Stockli, D.F. , Black, R., (2009). Assessing fault displacement and off-fault deformation in an extensional tectonic setting using 3-D ground-penetrating radar imaging. *Journal of Applied Geophysics*, 68, pp.9-16.
40. Chrzanowski, A., Chen, Y.Q. , Secord, J.M., (1986). Geometrical analysis of deformation surveys. In Y., B., ed. *Modern Methodology in Precise Engineering and Deformation Surveys-II*., 1986. Massachusetts Institute of Technology. Massachusetts
41. Clichici, O., (1975). *Geologie Structurală şi Cartografie Geologică*. EdituraUniversității "Babeş-Bolyai". Cluj-Napoca
42. Coates, D.R., (1971). *Environmental Geomorphology*. State University of New York. Binghamton
43. Codarcea, A. , Răileanu, G., (1967). *Harta geologică L-34-XII scara 1:200 000. Foaia 10 Cluj*. Institutul Geologic al României. Bucureşti
44. Coteț, P., (1973). *Geomorfologia României*. Ed. Tehnică. Bucureşti
45. Coteț, P., (1978). O nouă categorie de hărți, hărțile de risc și importanța lor geografică. *Terra*, X(3).
46. Coulthard, T.J., (1999). *Modelling upland catchment response to Holocene environmental change*. School of Geography, University of Leeds: Teză de doctorat nepublicată.
47. Coulthard, T.J., (2001). Landscape evolution models: a software review. *Hydrological Processes*, 15, pp.165-73.
48. Coulthard, T.J., Hicks, D.M. , Van De Wiel, M.J., (2007). Cellular modelling of river catchments and reaches: Advantages, limitations and prospects. *Geomorphology*, 90, pp.192-207.
49. Coulthard, T.J., Kirkby, M.J. , Macklin, M.G., (2000). Modelling geomorphic responseto environmental changein a upland catchment. *Hydrological Processes*, 14, pp.2031-45.
50. Coulthard, T.J., Lewin, J. , Macklin, M.G., (2005). Modelling differential catchment response to environmental change. *Geomorphology*, 69, pp.222-41.
51. Cristescu, N., (1978). *Topografie Inginerească*. Editura Didactică şi Pedagogică. Bucureşti
52. Croitoru, A.E., (2007). *Excesul de precipitaţii din Depresiunea Transilvaniei*. Casa Cărţii de Ştiinţă. Cluj-Napoca
53. Cruden, D.M., (1991). A simple definition of a landslide. *Bulletin of the International Association of Engineering Geology*, 43, pp.27-29.
54. Davis, J.L. , Annan, A.P., (1989). Ground penetrating radar for high-resolution mapping of soil and rock stratigraphy. *Geophysical Prospecting*, 37, pp.531-51.
55. De Blasio, F.V., (2011). *Introduction to the physics of landslides*. Springer. Dordrecht Heidelberg Londra New York
56. Diodato, N., (2005). Predicting RUSLE (Revised Universal Soil Loss Equation) mounthly erosivity index from readily available rainfall data in Mediterranean area. *The Environmentalist*, 25, pp.63-70.
57. Doan, A.M., (2007). *Bechtel Corporation*. [Online] Available at: www.bechtel.com [Accessed 2010].
58. Dobre, R., (2005). Impactul amenajărilor sectorului de autostradă Comarnic-Predeal asupra reliefului. *Comunicări de Geografie*, IX.

59. Dobre, R., (2007). Pretabilitatea terenurilorpentru o legătură feroviară în sectorul Câmpina -Predeal. *Comunicări de Geografie*, XI.
60. Dobre, R., Mihai, B. , Savulescu, I., (2011). The geomorphotechnical map: A highly detailed geomorphic map for railroad infrastructure improvement. A case study for the Prahova River Defile (Curvature Carpathians, Romania). *Journal of Maps*, pp.126-137.
61. Evans, K.G. , Willgoose, G.R., (2000). Post-mining landform evolution modelling. Effects of vegetation and surface ripping. *Earth Surface Processes and Landforms*, 25, pp.803-824.
62. Fărcaş, I., (1983). Probleme speciale privind climatologia României, partea I, Factorii climatogenetici. Universitatea Babeş-Bolyai. Cluj-Napoca
63. Farr, T.G. et al., (2007). The Shuttle Radar Topography Mission. *Reviews of Geophysics*, 45, p.33.
64. Flageollet, J.C., (1989). *Les mouvements de terrain et leur prevention*. Editura Masson. Paris
65. Flanagan, D.C. , Livingstone, S.J., (1995). *Water Erosion Prediction Project (WEPP) Version 95-7 User Summary*. NSERL Raport Nr.11.
66. Fleming, C., Marsh, S.H. , Giles, J.R.A., (2010). Introducing elevation models for geoscience. In *Elevation Models for Geoscience*. The Geological Society. pp.1-5. London
67. Floca, L. , Reteşan-Floca, D., (2003). Analiza percepţiei şi acceptabilităţii riscurilor environmentale- premisă a dezvoltării durabile. *Riscuri şi Catastrofe, VolI,Casa Carţii de Ştiinţă, Cluj-Napoca*.
68. Florea, N., (1988). *Harta solurilor XVIII-XII Scara 1:200000. Foile Turda și Cluj.* București: Institutul de Cercetări Pedologice și Agrochimice.
69. Florea, N. , Munteanu, I., (2003). *Sistemul Român de Taxonomie a Solurilor*. Editura Estfalia. Bucureşti
70. Gavrilă, I.G., Anghel, T. , Buimaga-Iarinca, Ş., (2012). The Influence of Fluvial Dynamics on Geoarchaeosites from the Danube Bank (The Măcin Branch). Case Study: Troesmis Fortress (Romania). *Air and water components of the environment*, 4, pp.329-36.
71. Goodchild, M.F. , Mark, D.M.,(1987). The fractal nature of geographic phenomena. *Annals of Association of American Geographers*, 77(2), p.265–278.
72. Goţiu, D. , Surdeanu, V., (2002). Procese geomorfologice contemporane în Ţara Haţegului. *Revista de Geomorfologie*, 4, pp.103-07.
73. Goţiu, D. , Surdeanu, V., (2004). Impactul indus de exploatarea în carieră a calcarului de la Crăciuneşti. *Geography within the context of contemporary development*, pp.106-12.
74. Goţiu, D. , Surdeanu, V., (2007). *Noţiuni fundamentale în studiul hazardelor naturale*. Presa Universitară Clujeană. Cluj-Napoca
75. Goţiu, D. , Surdeanu, V., (2008). *Hazardele naturale și riscurile asociate din Țara Hațegului*. Presa Universitară Clujeană. Cluj-Napoca
76. Goudie, A.S., (2001). Applied geomorphologie: An introduction. *Zeitschrift fur Geomorphologie Supplementband 124*, pp.101-10.
77. Grecu, F., (1997). Etapele întocmirii hărții expunerii la risc a terenurilor din bazine hidrografice de deal. *Memoriile Secțiunii Științifice ale Academiei Române*, Seria IV(XVII), pp.307-23.
78. Grecu, F., (1997). *Fenomene naturale de risc geologice și geomorfologice*. Editura Universității din București. București
79. Grecu, F., (2002). Risk prone lands in hilly regions: Mapping stages. In R.J. Allison, ed. *Applied Geomorphology*. John WileyșiSons. pp.49-64. Chichester
80. Grecu, F., (2003). Aspecte ale reprezentării cartografice a fenomenelor de risc geomorfic. *Riscuri și Catastrofe*, II, pp.323-31.
81. Grecu, F., (2009). *Hazarde şi riscuri naturale*. IV ed. Editura Universitară Bucureşti. Bucureşti
82. Grecu, F., Comănescu, L. , Cruceru, N., (2003). The perception of the geomorphic risk in different territorial geosystems. Dynamics and applied significations. *Geomorphological sensiitivity and systems response*, pp.87- 98.
83. Grecu, F., Marculeț, I. , Dobre, R., (2006). Pretabilitatea reliefului pentru căile de comunicațieîn Podișul Hârtibaciului. *Comunicări de Geografie*, X.
84. Grecu, F. , Sandu, M., (2000). The Hârtibaciu Tableland. Geomorfological hazard. *Studia Geomorphologica Carpatho-Balcanica*, 34, pp.95-105.
85. Grigore, M., (1972). *Cartografia geomorfologică*. Centrul de multiplicare al Universităţii din Bucureşti. Bucureşti
86. Gurth, P.L., (2010). Geomorphometric comparison of ASTER GDEM and SRTM. In *Volume XXXVIII*. 2010. ISPRS. Orlando
87. Hancock, G.R. et al., (2010). A catchment scale evaluation of the SIBERIA and CAESAR landscape evolution models. *Earth Surface Processes and Landforms*, 35, pp.863-75.
88. Holobâcă, I.H., (2010). *Studiul secetelor din Transilvania*. Presa Universitară Clujeană. Cluj-Napoca
89. Horvath, C., Bilaşco, Ş. , Antal, Y.M., 2008. Quantitative estimation of soil erosion in the Drăgan river watershed with the USLE type ROMSEM model. *Geographia Napocensis*, 2 (1), pp.82-89.
90. Hui, L.,Xiaoling, C.; Lim, K. J.; Xiaobin, C.; Sagong, M.,(2010). Assessment of soil erosion and sediment yield in Liao wtershed, Jiangxi Province, China, using USLE, GIS and RS. *Journal of Earth Science*, 21(6), pp.941-953.
91. Hutchinson, M.F., (1988). Calculation of hydrologically sound digital elevation models. In *Proceedings of the Third International Symposium on Spatial Data Handling*. Sydney, 1988. International Geographic Union.
92. Hutchinson, M.F., (1989). A new procedure for gridding elevation and stream line data with automatic removal of spurious pits. *Journal of Hydrology*, 106, pp.211-232.
93. Hutchinson, M.F. , Dowling, T.I., (1991). A continental hydrological assessment of a new grid-based digital elevation model of Australia. *Hydrological Processes*, 5, pp.45-58.
94. Ianoș, I., (1994). Riscul în sistemele geografice. *Studii și cercetări de geografie*, XLI.

95. Ianovici, V., (1969). *Geografia văii Dunării româneşti*. Editura Academiei RSR. Bucureşti
96. Ichim, I., Bătucă, D., Rădoane, M. , Duma, D., (1989). *Morfologia şi dinamica albiilor de râu*. Editura Tehnică. Bucureşti
97. Ichim, I. , Rădoane, M., (1986). *Efectele barajelor în dinamica reliefului. Abordare geomorfologică*. Editura Academiei RSR. Bucureşti
98. Ichim, I., Rădoane, M. , Rădoane, N., (1996). *Analiza cantitativa in geografia fizică.Metode şi aplicaţii*. Editura Universităţii Alexandru Ioan Cuza. Iaşi
99. Ioniță, I., (2000). Formarea și evoluția ravenelor din Podișul Bârladului. Editura Corson. Iași
100. Ioniță, I., (2000). Geomorfologie aplicată. Procese de degradare a regiunilor deluroase. Editura Universității Al. I. Cuza. Iași
101. Ioniţă, I., (2007). Gully development in the Moldavian Plateau of Romania. In K. Helming, J.L. Rubio și J. Boardman, eds. *Soil erosion research in Europe*. Catena Special Issue vol 68. pp.133-40.
102. Ioniţă, I., (2011). The human impact on soil erosion and gulling in the Moldavian Plateau, Romania. *Landform Analysis*, 17, pp.71-73.
103. Ioniță, I. , Ouatu, C., (1985). Contribuții la studiul eroziunii solurilor din Colinele Tutovei. *Cercetări Agronomice în Moldova*, 3.
104. Ioniţă, I., Rădoane, M. , Mircea, S., (2006). Romania. In J. Boardman și J. Poesen, eds. *Soil Erosion in Europe*. John Wiley. pp.155-66. Chichester
105. Irimuş, I.A., (2003). Riscuri geomorfice în regiunea de contact interjudeţeană din nord-vestul României. *Riscuri şi Catastrofe, Vol I, Casa cărţii de Ştiinţă, Cluj-Napoca*.
106. Irimuş, I.A., (2006). Hazarde și riscuri asociate proceselor geomorfologice în aria cutelor diapire din Depresiunea Transilvaniei. Casa Cărţii de Ştiinţă. Cluj-Napoca
107. Jol, H.M., (2009). *Ground Penetrating Radar. Theory and Aplications*. I ed. Elsevier Science. Oxford
108. Jol, H.M. , Bristow, C.S., (2003). GPR in sediments: advice on data colection, basic procesing and interpretation, a good practice guide. In C.S. Bristow și H.M. Jol, eds. *Ground Penetrating Radar in sediments*. Geological Society Special Publications 211. pp.9-27. Londra
109. Jol, H.M. et al., (2003). Stratigraphic imaging of the Navajo Sandstone using ground penetrating radar. *The Leading Edge*, 22, pp.882-87.
110. Jol, H.M., Smith, D.G. , Meyers, R.A., (1996). Digital ground penetrating radar(GPR): An improved and very effective geophysical tool for studying modern coastal barriers (exemples for the Atlantic, Gulf and Pacific coasts, USA). *Journal of Coasal Research*, 12, pp.960-68.
111. Jones, D.K.C., (1980). Brithish applied geomorphology: An aparaisal.. *Zeitschrift fur Geomorphologie Supplementband 36*, pp.48-73.
112. Jones, D.K.C., (1980). British applied geomorphology: An aparaisal. *Zeitschrift fur Geomorphologie Supplementband 36*, pp.48-73.
113. Keary, P. , Brooks, M., (1991). *An itroduction to geophysical exploration*. II ed. Blackwell Scientific Publications. Boston
114. Kendall, M.G., (1970). *Rank correlation methods*. Griffin. Londra
115. Kirkby, M.J., (1980). Modelling water erosion processes. In M.J. Kirkby și R.P.C. Morgan, eds. *Soil Erosion*. Wiley. pp.183-216. Chichester
116. Konecsny, K., (1997). Bilanțul hidrologic în Podișul Transilvaniei și în regiunile montane aferente. Teză. Cluj-Napoca
117. Kouli, M., Soupios, P. , Vallianatos, F., (2009). Soil erosion prediction using Revised Universal Soil Loss Equation (RUSLE) in a GIS framework, Chania, Northwestern Crete, Greece. *Environmental Geology*, 57, pp.483-97.
118. Laflen, J.M. et al., (1991). WEPP soil erodibility experiments for rangeland and cropland soils. *Journal of Soil and Water Conservation*, 46, pp.29-34.
119. Lane, S.N., (1998). Hydraulic modelling in hydrology and geomorphology: a review of high resolution approaches. *Hydrological processes*, 12, pp.1131-50.
120. Leclerc, R.F. , Hickin, E.J., (1997). The internal structure of scrolled floodplain deposits based on ground-penetrating radar, North Thompson River, British Columbia. *Geomorphology*, 21, pp.17-38.
121. Lukas, S. , Sass, O.,(2011). Internal structures and radar reflection patterns of modern moraines at the Gorner Glacier, Switzerland. In I.P..F.H.M.și.P.A.A. Martini, ed. *Ice-Marginal and Periglacial Processes and Sediments*. Geological Society Special Publications 354. pp.77-92. Londra
122. Mac, I., (1985). Progrese în geomorfologia aplicată din România în ultimii 20 de ani. *Terra*, XVII(2).
123. Mac, I. , Drăguţ, L., (1997). Rolul reliefului în dezvoltarea, amenajarea teritorială şi esteticaurbană a oraşului Deva. *Analele Universităţii de Vest din Timişoara*, Seria Geografie(7).
124. Mac, I., Irimuș, I.A. , Zemianschi, S., (1995). Pretabilitatea reliefului pentru amenajările urbane în zona Turda. *studia Universitatis Babeş-Bolyai*, Seria Geographia XL(1).
125. Mac, I. , Petrea, D., (2003). Sisteme geografice la risc. *Riscuri și Catastrofe*, II, pp.13-26.
126. Mac, I. , Râpeanu, M., (1995). Premisele geomorfologice pentru localizarea şi dezvoltarea oraşului Predeal. *Studia Universitatis Babeş-Bolyai*, Seria Geographia XL(1).
127. Mac, I., Rus, I. , Şerban, G., (2003). Cartografierea, o alternativă în evaluarea riscurilor naturale. *Riscuri şi Catastrofe*, II, pp.313- 322.
128. Macklin, M.G. et al., (2006). A geomorphological approach to the management of rivers contaminated by metal mining. *Geomorphology*, 79(3-4), pp.423-47.
129. Manea, S., Batali, L. , Popa, H., (2003). *Mecanica Pamânturilor*. Conpress Bucureşti. Bucureşti

130. Martiniuc, C. , Băcăuanu, V., (1963). Cercetări de geomorfologie aplicată în sprijinul sistematizării urbane şi rurale din Moldova (Metodica cercetărilor). *Analele Ştiinţifice ale Universităţii din Iaşi*, T. IX, p.sec.2.
131. Martiniuc, C. , Hârjoabă, I., (1975). Probleme actuale ale geomorfologiei aplicate. In *Lucrările Colocviului Naţional de Geomorfologie aplicată şi Cartografiere Geomorfologică*. Iasi, 1975.
132. Mateescu, C., (1963). *Hidraulică*. editura Didactică şi Pedagogică. Bucureşti
133. Matei, L., (1983). *Argilele panoniene din Transilvania*. Editura Academiei. Bucureşti
134. Mihăilescu, V., (1939). Porniturile de teren şi clasificarea lor. *Revista Geografică Română*, An II, pp.Fasc.II-III.
135. Mihăilescu, N.S., (1955). *Geologie Tehnică Volumul II*. Editura Tehnică. Bucureşti
136. Milligan, G., Fookes, P. , Lee, M.,(2005). Engineering behaviour of soils and rocks. In P.G. Fookes, E.M. Lee și G. Milligan, eds. *Geomorphology for Engineers*. 2009th ed. Dunbeath: Whittles Publishing. pp.137-69.
137. Moldovan, F., (1999). *Meteorologie-Climatologie*. Editura Dimitrie Cantemir. Târgu Mureş
138. Moldovan, F., Sorocovschi, V. , Holobâcă, I., (2002). Deficitul pluviometric ca fenomen climatic de risc în Depresiunea Transilvaniei. *Revista Riscuri şi Catastrofe*, 1, pp.90-97.
139. Morariu, T., (1968). Simpozionul internaţional de geomorfologie aplicată. *Studia Universitatis"Babeş-Bolyai",seria geologie-geografie,nr.1*.
140. Morariu, T., (1969). Travaux du symposium international de geomorphologie appliquee: Bucharest 1967. 1969. Academia R.S.România. Bucharest
141. Morariu, T. și Gârbacea, V., (1968). Déplacements massifs de terain de type glimee en Roumanie. *Revue Roumaine de Géologie, Géophysique, et de Géographie, Série de géographie*, 1-2, pp.Tom I-II.
142. Morgan, R.P.C. et al., (1998). *The European soil erosion model (EUROSEM): documentation and user guide*. UK: Silsoe College Cranfield University.
143. Mosley, M.P. , Tindale, D.S.,(1985). Sediment variability and bed material sampling in gravel-bed rivers. *Earth Surface Processes and Landforms*, pp.465-82.
144. Moţoc, M., (1963). Eroziunea solului pe terenurile agricole şi combaterea ei. Editura Agrosilvică. Bucureşti
145. Moţoc, M. et al., (1975). *Eroziunea solului şi metode de combatere*. Editura Ceres. Bucureşti
146. Moţoc, M. , Sevastel, M., (2002). Evaloarea factorilor care determină riscul eroziunii hidrice în suprafaţă. Editura Bren. Bucureşti
147. Moţoc, M., Stănescu, P. , Taloiescu, L., (1979). Modele de estimare a eroziunii totale şi efluente pe bazine hidrografice mici. Buletin ICPA. Bucureşti
148. Munteanu, S.A., (1953). *Corectarea torenţilor*. Editura Agrosilvică. Bucureşti
149. Munteanu, S.A., Gaspar, R. ,Băloiu, V., (1970). Corectarea torenţilorşi combaterea eroziunii terenurilor. În *Manualul inginerului hidrotehnician*. Editura tehnică. Bucureşti
150. Murray, A.B. , Paola, C., (1994). A cellular model of brainded rivers. *Nature*, 371, pp.54-57.
151. Murray, A.B. , Paola, C., (1997). Properties of a cellular braided stream model. *Earth Surface Processes and Landforms*, 22, pp.1001-25.
152. Murray, A.B. și Paola, C., (2003). Modelling the effect of vegetation on channel pattern in bedload rivers. *Earth Surface Processes and Landforms*, 28, pp.131-43.
153. Mutihac, V., Stratulat, M.I. , Fechet, R.M., (2007). *Geologia României*. Editura Didactică şi Pedagogică. Bucureşti
154. Nicholas, A.P., (2005). Cellular modelling in fluvial geomorfology. *Earth Surface Processes and Landforms*, 30, pp.179-95.
155. Oncu, M., (2008). *Elemente de pedogeografie*. Casa Cărții de Știință. Cluj-Napoca
156. Oncu, M. , Bilașco, Ș., (2009). Microregiunea Brad: Solurile și modul de utilizare a terenurilor. *Geographia Napocensis*, 1, pp.41-48.
157. Oncu, M. , Bilașco, Ș., (2010). Valea Sebeșului- Considerații biopedogeografice. *Geographia Napocensis*, IV(1), pp.23-31.
158. Oprișan, E. et al., (2011). Sinteza studiilor de fundamentare a schemelor directoare de amenajare și management ale bazinelor hidrografice. Componenta plan de amenajare. București: Administrația Națională ”Apele Române” Institutul Național de Hidrologie și Gospodărire a Apelor.
159. Panizza, M., (1996). *Environmental Geomorphology*. Elsevier. Amsterdam
160. Parajka, J., Merz, R. , Bloschl, G., (2005). A comparison of regionalisation methods for catchment model parameters. *Hydrology and Earth System Sciences Discussions*, 2, pp.509-42.
161. Patriche, C.V., Căpăţână, V. , Stoica, D.L., (2006). Aspects regarding soil erosion spatial modeling using the USLE-RUSLE within GIS. *Geogrphia Technica*, 2, pp.89-97.
162. Penck, A., (1894). *Morphologie der Erdoberflache*. Verlag von J. Engelhorn. Stuttgart
163. Peng, C.K. et al., (1994). Mosaic organisation of DNA nucleotides. *Ohysical Review E*, 49(2).
164. Petrea, R., (1998). Dimensiunea geomorfologică în dezvoltarea şi estetica urbană a oraşelor mici din Dealurile de Vest (Sectorul dintre Barcău şi Crişul Negru). Ed. Universităţii din Oradea. Oradea
165. Petrea, D., (2005). *Obiect, metodă şi cunoaştere geografică*. Editura Universităţii din Oradea. Oradea
166. Petrea, D., Rus, I. , Petrea, R., (2006). Restructurări plan-spațiale în evoluția recentă a albiei Crișului Repede (între Ciucea și Oradea). *Revista de Geomorfologie*, 8, pp.35-44.
167. Pierini, J.O. , Telesca, L., (2010). Fluctuation analysis of monthly rainfall time series. *Fluctuation and Noise Letters*, 9(2), pp.219-28.
168. Plackett, R.L., (1983). Karl Pearson and the Chi-Squared test. *International Statistical Review*, 51(1), pp.59-72.
169. Popa, A. , Fărcaş, V., (2004). *Geotehnică*. Editura U.T.Pres. Cluj-Napoca
170. Pop, O., Buimaga-Iarinca, Ș., Stoffel, M. , Anghel, T., (2012). Reponse des epiceas(Picea Abies(L.) Karst.) a l accumulation des sediments dans le basin de retention Dumitrelul (Massif du Călimani, Roumanie). *Arbres et Dinamiques*, Acceptat.

171. Popescu Argeşel, I., (1977). *Munții Trascăului. Studiu geomorfologic*. Editura Academiei RSR. București
172. Posea, G., (1982). Regionarea geomorfologică – unitățile de relief ale României. In *Enciclopedia geografică a României*. Editura Ştiinţifică şi Enciclopedică. pp.39-40. Bucureşti
173. Posea, G., (2005). *Geomorfologia României. Relief-tipuri, geneză, evoluție, regionare*. II ed. Editura Fundaţiei România de Mâine. Bucureşti
174. Posea, G. , Badea, L., (1984). *România – unităţile de relief, hartă 1 : 750.000*. Editura Ştiinţifică şi Enciclopedică. Bucureşti
175. Posea, G. , Popescu, N., (1967). Importanţa hărţii geomorfologice în amenajarea teritorială. *Studia Universitatis Babeş-Bolyai*, Seria Geologie-Geografie(2).
176. Rădoane, M., (1983). Relieful şi procesele reliefogene din zona lacului de baraj Izvorul Muntelui de pe Valea Bistriței Moldovenești. Teză. Iași
177. Rădoane, N., (2002). *Geomorfologia bazinelor hidrografice mici*. Editura Universităţii Suceava. Suceava
178. Rădoane, M., Cristea, I. , Rădoane, N., (2011). Geomorphological mapping. Evolution and trends. *Revista de geomorfologie*, 13, pp.19-41.
179. Rădoane, M., Ichim, I. , Rădoane, N., 1995. Gully distribution and development in Moldavia. *Catena*, 24.
180. Rădoane, M., Ichim, I., Rădoane, N. , Surdeanu, V., (1988). Asupra profilului longitudinal și factorul formă a ravenelor din Podișul Moldovenesc. *Studii și Cercetări GGG Seria Geografie*, 37.
181. Rădoane, M. , Rădoane, N., (2001). Eroziunea terenurilor și transportul de aluviuni în sistemele hidrografice Jjia și Bârlad. *Revista de Geomorfologie*, 3, pp.73-86.
182. Rădoane, M. , Rădoane, N., (2004). Geomorfologia aplicată în analiza hazardelor naturale. *Riscuri şi Catastrofe*, 1, pp.57-68.
183. Rădoane, M. şi Rădoane, N., (2005). Dams, sediment sources and reservoir silting in Romania. *Geomorphology*, 71, pp.112-25.
184. Rădoane, M. și Rădoane, N., (2007). *Geomorfologie Aplicată*. Editura Universității Ștefan cel Mare. Suceava
185. Rădoane, M., Rădoane, N., Dumitriu, D. , Cristea, I., (2007). Granulometria depozitelor de albie ale râului Prut între Orofteana şi Galaţi. *Revista de Geomorfologie*.
186. Rădoane, M., Rădoane, N., Dumitriu, D. , Miclăuș, C., (2008). Downstream variation in bed sediment size along the east carpathians rivers. Evidence of the role of the sediment sources. *Earth Surface Landforms and Processes*, 33(5), pp.674-94.
187. Rădoane, M., Rădoane, N. ,Ichim, I., (1994). Ecuații de regresie multiplă pentru evaluarea ratei de avansare a ravenelor din Podișul moldovenesc. *Studii și Cercetări GGG, Seria Geografie*, XLI.
188. Rădoane, M., Rădoane, N. și Ichim, I., (1997). Analiza multivariată a ravenelor din Podișul Moldovenesc. *Studia Universitatis Babeş-Bolyai*.
189. Rădoane, M., Rădoane, N., Ichim, I. , Surdeanu, V., (1999). *Ravenele. Forme, procese și evoluție*. Presa Universitară Clujeană. Cluj-Napoca
190. Răileanu, G. , Saulea, E., (1967). *Harta geologică L-34-XVIII scara 1:200 000. Foaia 18 Turda.* Bucureşti: Institutul Geologic al României.
191. Renard, K.G., Laflen, J.M., Foster, G.R. , McCool, D.K., (1994). The revised universal soil loss equation. In R. Lal, ed. *Soil erosion research methods*. II ed. Ankeny IA: Soil and Water Conservation Society.
192. Richardson, E.V., Simons, D.B. , Julien, P.Z., (1990). *Highway in the river environment*. Final Report. Fort Collins: National Highway Institute Engineering Research Center, Colorado State University.
193. Roberts, M.C., Bravard, J.P. , Jol, H.M., (1997). Radar signature and structure of an avulsed channel: Rhone River, Aoste, France. *Journal of Quaternary Science*, 12, pp.35-42.
194. Roşca, D., Breier, A. , Teodor, S.M., (1980). Probleme legate de colmatarea lacurilor din România. *Hidrotehnica*, 25(11).
195. Sandmeier, K.J., (1993). ReflexW, 5.0. The 2D procesing and 2D/3D interpretation software for GPR, Reflection seismics and Refraction seismics. SandmeierK.J. Karlsruhe
196. Sandu, M. , Bălteanu, D.,(2005). Hazarde naturale din Carpații și Subcarpații dintre Trotuș și Teleajen. Editura Ars Docendi. București
197. Săndulache, A. , Sficlea, V., (1966). *Cartografie-Topografie*. Editura Didactică și Pedagogică. București
198. Săndulescu, M., (1984). *Geotectonica României*. Editura Tehnică. București
199. Sandu, I. et al.,)(2008). *Clima României*. Editura Academiei Române. București
200. Sass, O., (2008). The use of GPR in determining talus thickness and talus structure - case studies from the European Alps. In C.și.K.C. Hauck, ed. *Applied Geophysics in Periglacial Environments*. Cambridge University Press. pp.165-71. Cambridge
201. Sass, O., Bell, R. , Glade, T., (2008). Comparison of GPR, 2D-resistivity and traditional techniques for the subsurface exploration of the Öschingen landslide, Swabian Alb (Germany). *Geomorphology*, 93, pp.89-103.
202. Savu, A., (1963). *Podișul Someșan. Studiu geomorfologic*. Teza. Cluj-Napoca
203. Savu, A. , Mac, I., (1972). Relieful judeţului Sălaj ca factor în distribuția şi dezvoltarea asezărilor omeneşti. *Studia Universitatis Babeş-Bolyai*, Seria Geologie-Geografie(1).
204. Schaefer, M.G. , Baker, P.E., (2002). Extended precipiotations time series for continuous hydrological modeling in Western Washington. Department of Transportation Washington State.
205. Schofield, W. , Breach, M., (2007). *Engineering Surveying*. 6th ed. Elsevier Ltd. Oxford
206. Sheriff, R.E. , Geldart, L.P., (1982). *Exploration Seismology Volume I: Hystory, Theory and Data Aquisition*. Cambridge University Press. New york
207. Smith, D.G., Jol, H.M., (1995). Ground penetrating radar: antenna frequencies and maximum probable depths of penetration in Quaternary sediments. *Journal of Applied Geophysics*, 33, pp.93-100.

208. Spearman, C., (1904). The proof and measurement of association between two things. *American Journal of Psychology*, 15, pp.72-101.
209. SRCS, (1979). *Sistemul Român de Clasificare a Solurilor*. Institutul de Cercetări pedologice și Agrochimice. București
210. Stângă, I.C., 2011. Climate agressivness and rainfall erosivity. *Riscuri și Catastrofe* , 9(2), pp.21-32.
211. Surdeanu, V., (1985). Considerații asupra inventarierii alunecărilor de teren în vederea întocmirii hărților de risc. *Lucrările Seminarului geografic „Dimitrie Cantemir”*, 5, pp.25-32.
212. Surdeanu, V., (1986). Landslides and their role in reservoir silting. *Zeitschrift fur Geomorphologie.* , 58, pp.165-72.
213. Surdeanu, V., (1990). Sistemul geomorfologic al alunecărilor de teren. *Studia Universitatis Babeş- Bolyai*, XXXV(2).
214. Surdeanu, V., (1992). Corelații între alunecările de teren și alte procese denudaționale. *Studia Universitatis Babeş-Bolyai*, XXXVII(1-2).
215. Surdeanu, V., (1997). La repartition des glissements de terrain dans les Carpates Orientales. *Geographia Fisica e Dinamica Quaternaria*, 19.
216. Surdeanu, V., (1998). *Geografia terenurilor degradate*. Presa Universitară Clujeană. Cluj-Napoca
217. Surdeanu, V., Gotiu, D., Rus, I. , Crețu, A., (2006). Geomorfologie aplicată în zona urbană a municipiului Cluj-Napoca. *Revista de Geomorfologie*.
218. Surdeanu, V., Rus, I. , Goțiu, D., (2006). Integrated slope processes susceptibility analysis and risk assesment of the Cluj county. Case study Cheia. In *Rural space and local development*.. Presa Universitară Clujeană. Cluj-Napoca
219. Tachikawa, T., Hato, M., Kaku, M. , Iwasaki, A., (2011). The characteristics of ASTER GDEM version 2. Vancouver
220. Tachikawa, T. et al., (2011). *ASTER Global Digital Elevation Model Version 2-Summarz of Validation Results*. NASA Land Processes Distributed Active Archive Center.
221. Tucker, G.E. , Slingerland, R.L., (1994). Erosional dynamics, flexural isostasy and long-lived escarpments: A numerical modeling study. *Journal of Geophysical Research*, 99(B6)
222. Tufescu, V., (1966). Modelarea naturală a reliefului și eroziunea accelerată. Editura Academiei. București
223. Ujvari, I., (1972). *Geografia apelor României*. Editura Științifică. București
224. Van De Wiel, M.J., Coulthard, T.J., Macklin, M.G. , Lewin, J., (2007). Embedding reach-scale fluvial dynamics within the CAESAR cellular automaton landscape evolution model. *Geomorphology*, 90, pp.283-301.
225. van Overmeeren, R.A., (1998). Radar facies of unconsolodated sediments in Netherlands: A radar stratigraphy interpretation method for hydrogeology. *Applied Geophysics*, 40, pp.1-18.
226. Vancea, A., (1960). *Neogenul din Bazinul Transilvaniei*. Editura Academiei RPR. București
227. Varnes, D.J., (1978). Slope movement types and processes. In R.L. Schuster și R.J. Krizek, eds. *Landslides-Analysis and Control*. National Academy of Sceinces. pp.11-33. Washington
228. Vladimirescu, I., (1984). *Bazele hidrologiei tehnice*. Editura Tehnică. București
229. Voiculescu, M., (2002). *Fenomene geografice de risc în Masivul Făgăraș*. Editura Brumar. Timișoara
230. Wahba, G., (1990). Spline models for Observational data. In *CBMS-NSF Regional Conference Series in Applied Mathematics*.. University of Winsconsin. Madison
231. Wang, W., Yang, X. , Yao, T., (2012). Evaluation of ASTER GDEM and SRTM and their suitability in hydraulic modelling of a glacial lake outburst flood in Southeast Tibet. *Hydrological Processes*, 26(2), pp.213-25.
232. Wentworth, C.K., (1922). A scale of grade and class terms for clastic sediments. *The Journal of Geology*, 30, pp.377-92.
233. Wilcoxon, F., (1945). Individual Comparisons by ranking methods. *Biometrics Bulletin*, 1(6), pp.80-83.
234. Willgoose, G., Bras, I. și Rodriques-Itrube, I., (1991). Results from a new model of river basin evolution. *Earth Surface Processes and Landforms*, 16, pp.237-54.
235. Williams, J.R., (1975). Sediment-yield prediction with universal equation using runoff energy factor. In *Present and prospective technology for predicting sediment yields and sources*. USDA-ARS: ARS-S-40.
236. Wischemeier, W.H. și Smith, D.D., (1965). *Predicting rainfall erosion losses from cropland East of the Rocky Mountains*. Agriculture Handbook Nr 282. Us Department of Agriculture Purdue Agricultural Experiment Station. Purdue
237. Wischemeier, W.H. , Smith, D.D., (1978). *Predicting rainfall erosion losses- Aguide to conservation planning*. Handbook Nr. 537. US Department of Agriculture. Washington
238. Woolhiser, D.A., Smith, R.E. , Goodrich, D.C., (1990). *KINEROS: A kinematic runoff and erosion model: documentation and user manual*. ARS-77. Agricultural Research Service.
239. Yang, W., Bardossy, A. , Caspary, H.J., (2010). Downscaling daily precipitations time series using a combined circulation and regression based approach. *Theoretical and Applied Climatology*, 102, pp.439-54.
240. Ylmaz, O., (2001). Seismic data analysis:Processing, inversion and interpretation of seismic data. Vol.I și II. Society of Exploration Geophisicists. Tusla
241. Zugrăvescu, D., Polonic, G., Horomnea, M. , Dragomir, V., (1998). Recent vertical crustal movements on the romanian territory, major tectonic compartments and their relative dynamics. *Revue Roumaine de Geophysique*, 42.
242. ***, (1969). Travaux du Symposium Internaţional de Geomorphologie Appliquee. Bucureşti.
243. ***, (1975). Lucrările Colocviului naţional de geomorfologie aplicată şi cartografiere geomorfologică: Iaşi 26-28 octombrie 1973. Iaşi.
244. 1243-88, S., (1983). *Clasificarea şi identificarea pământurilor*. Institutul Român de Standardizare Institutul Român de Standardizare. București
245. EEA, (2006). *Corine Land Cover*. [Online] Available at: http://www.eea.europa.eu.

246. ESRI, (2010). *ArcGIS 10*. Licenţă Academică Universitatea Graz.
247. ESRI,(2010). *ESRI ArcGIS help files*. ESRI Inc.
248. MALAGeoscience, (2012). *Products: Mala GPR ProEx System*. [Online] Available at: http://www.malags.com.