“BABES - BOLYAI” UNIVERSITY

FACULTY OF GEOGRAPHY

NIRAJ BASIN
STUDY OF APPLIED GEOMORPHOLOGY

~ Abstract of the Ph.D. Thesis~

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PART I CONCEPTUAL AND METHODOLOGICAL APPROACH AND RESEARCH HISTORY

PART II NIRAJ BASIN AREA – GEOGRAPHICAL IDENTITY

PART III SPATIAL AND TEMPORAL ANALYSIS OF THE MORPHODYNAMICS FROM THE NIRAJ RIVER BASIN AS A BASIS FOR TERRITORIAL PLANNING

CUVINTE CHEIE: *Applied Geomorpholofy, Landslides, Meandering, Soil Erosion, Fluvial erosion, Land Pretability, Multi-Hazard, Multi-Risc, Niraj basin.*

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INTRODUCTION

The analytical approach in the present study, based on the availability of necessary data and information, was set in order to better understand the potential in geomorphology and the geographical risk phenomena in the Niraj Basin, by the studying of the generating factors, of the qualitative and quantitative characteristics, as well as of their effects in the geographical environment.

The solutions and results of the applicative geomorphological analysis ca be put into practice, hence they have as main characteristics their applicability. Developing the applicability nature of the geomorphological research becomes essential, as an optimal relief valorisation and the offering of veridical solution for solving the identified problems are desired.

The motivation behind choosing the present theme stems from the passion for Geomorphology and the study of geographic risk phenomena, as well as from the desire to study the Niraj Basin with the purpose of applying specific principles and of identifying the applicability of the geomorphology methods, used for the obtaining of practical solutions to the identified dysfunctions. Hence the present paper is structured into three main parts:

PART I CONCEPTUAL, METODOLOGICAL ASPECTS AND THE STATE OF THE ART

Applied geomorphology as a branch of geomorphology has as main objective the application of geomorphological knowledge for solving the restriction situations determined by the existing relief, as well as the geomorphological potential evaluation so that favourability and its role as a resource be increased and the damaging natural hazard effects be diminished as much as possible. For urban planning, an important role is given to the hazard/risk map drawing in order to prevent natural disasters, namely to identify the flooding and landslides natural risks. Hence there exists the necessity of their identification in every territorial-administrative unit.

GENERAL OBJECTIVES

Taking into account the general Applied Geomorphology characteristic objectives, the author wishes that the present study, focused on the Niraj Basin, tackle with a series of general and characteristic objectives:

- Process and phenomena identification as risk generating sources within the territorial equation;

- Interdependence identification among the several most important geomorphological processes operating in the Niraj Basin and the way in which they affect the precincts of a settlement and the communication networks.
- Spatial-temporal evaluation of susceptibility and hazard to the geomorphological processes inducing risk;
- Building an applicative model for a basin management plan of the Niraj Basin in response to the risk factors.

RESEARCH METODHODOLOGY

The present paper is the result of personal studies undertaken, on the research of written texts and cartographic materials, the collecting of data and information, synthesis, analysis and the processing of schematic and cartographic material with the help of specialised software (fig.1).

From a didactic point of view, the present paper has a double nature: a fundamental one (gathering knowledge related to the genesis and the evolution of the relief in the Nirajului Basin) and an applicative one (the results of this scientific study can subsequently serve for highlighting the favourable relief elements and for choosing the best methods of limiting the inherent restrictions at the local level).

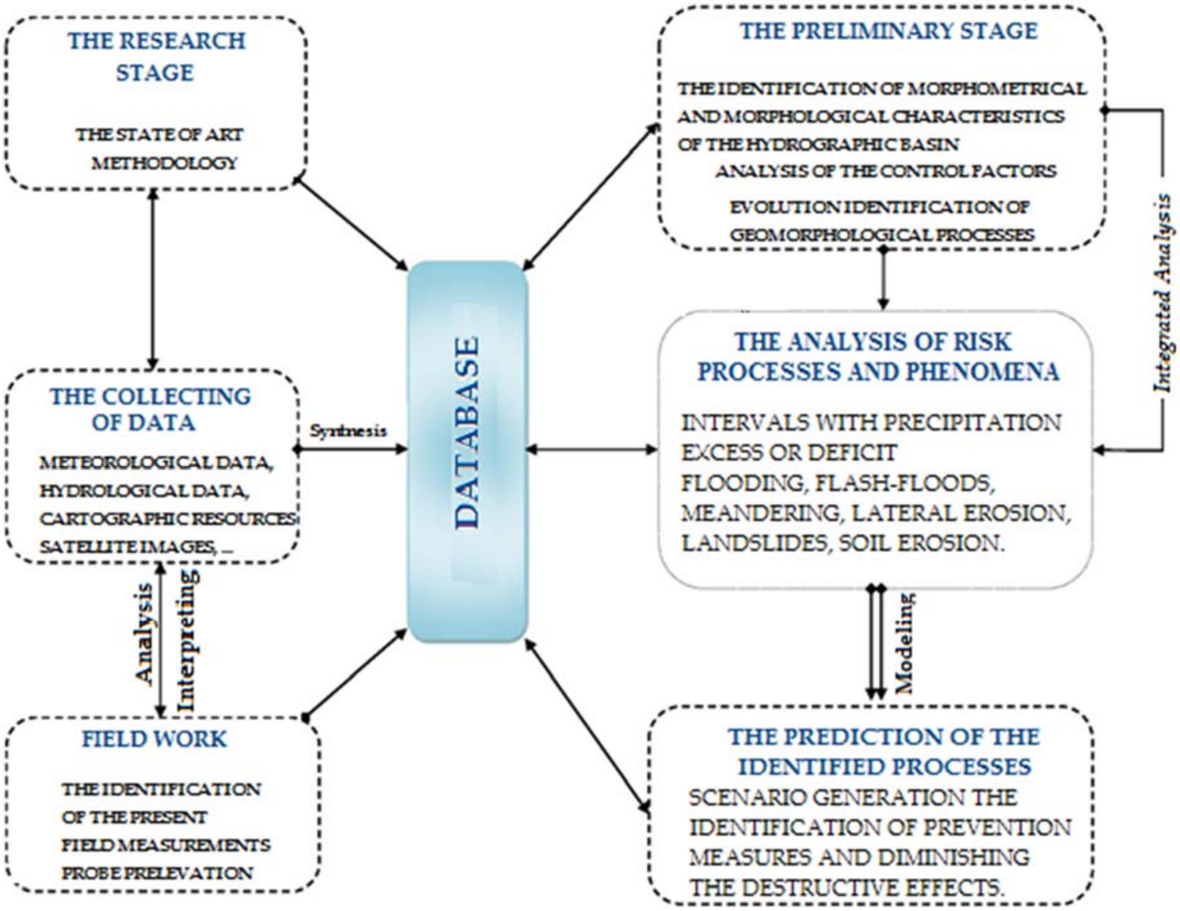


Fig. 1: Methodology

In the first stage, the theoretical grounds of the present study were laid and the most relevant research methodologies chosen, once the scientific literature had been reviewed.

Indirect observation was the method employed on the numerous cartographic materials of a high scientific and practical value. Related to it, the Austrian Maps were analysed, resulted from the second measurement campaign ("Franziszeische Aufnahme") between 1806-1869, resulting in the coverage of the total Romanian territory with a 40 sheet-map. The third topographical measurements campaign (Neue Aufnahme), taking place as of 1869, for 1:100000 scale maps, the 1:25.000 Topographic Maps (edited between 1961-1964), 2.5 m SPOT (2008) satellite images, 2005, 2010 ortophotos, as well as 1:5000 (2005) topographical plans and 2012 and 2013 GOOGLE satellite images are among the other materials used. All of the above-mentioned have been updated to the nowadays situation through several expeditionary observations taken on the site.

The very much valued geographer's *field work,* is the stage that offered several precious information for the identifying of those present areas affected by geomorphological process, of their development pace and of the improvement measures applied by the local authorities. The GPS technology was used in order to do so, hence the active landslides corresponding to May and July 2012, 2013 were identified, as well as the June and July 2012 and 2013 river bed erosion processes, when the topographic measurements were actually taken.

The size distribution of the river bed sediments was established by taking samples, via the *volumetric sampling* on 1 m^2 surfaces, situated at distances of about 10 km from each other, as it is stipulated in Wolman's (1954) and Leopold's method (1970).

The Cavis software was used for the *statistical analysis* of hydrological data (mean and maximum discharges, the quantitative characteristics of the flash-flood hydrograph). The exceedance and non-exceedance probabilities of precipitation and of maximum discharge values, as well as their return periods were obtained with the help of the HYFRAN software. The analysis of the climate data lied at the basis of the genetic factors analysis, whereas the analysis of the monthly precipitations, with the *ASPP method,* lied at the basis of determining the excess precipitation periods.

The cartographic representation of the analysed hydrographic basin was obtained by employing the *Geographic Infromation Systems method,* once the database had been created (and the Digital Elevation Model of the Basin, the slope and aspect etc. were built). The implementation of the method was possible by the use of the ESRI product, namely ArcMap, as well as with other software such as Global Mapper, Quantum GIS, SAGA Gis.

By the comparison of cartographic materials from different time intervals, the author could identify the spatial evolution of the Niraj River for a 100 year period (1860-2013). Hence a series of morphometric parameters of the meanders were analysed (amplitude, wavelength, the radius curvature, sinuosity index) as well as the morphographic evolution of each meander loop (according to the Brice classification, 1974).

It is evident that for reaching the main afore-mentioned objectives, from a methodological and conceptual point of view, a series of detailed stages were undergone while going forward with the study, from one chapter to another.

PART II THE NIRAJ BASIN – GEOGRAPHIC LOCATION

The studied territory, represented by the hydrographic basin of the Niraj River is situated in the Central-Eastern part of the Transylvanian Depression, between the Mureș Basin in the North and the Târnava Mica Basin in the South (fig. 2).

Characteristic elements and geographical relationships:

The unitary character of the studied region derives from its specific traits such as:

- General NE-SW slope, directing the energy fluxes in that direction;
- Altitudinal succession of the relief forms: mountainous relief in the upper basin (>1000 m), high hills relief (400,1-550 m) in the middle part of the basin and low hills (284-400 m) towards the outlet, from which the accentuated slope of the hydrographic basin derives, determining a higher degree of torrentiality of flash-floods hence influencing the time lag, as well as directing the energies generating the relief modelling processes.
- The Niraj River, receiving a significant water quantity through its affluents originating from the mountainous area is characterised by a mixed flow regime (rain and snow).
- The hydrographic basin is superposed to the atmospheric fronts reactivation area; the Western air masses determining the fall of significant precipitation quantities on the Western slope of the Apuseni Mountains and once they have surpassed the Transilvanian Depression and hit the Transylvanian Subcarpatian area they reactivate and determine the fall of precipitation whose values increase with altitude, hence leading to an advanced morphodynamics (landslides are activated, soil erosion is intensified and the river banks erode);

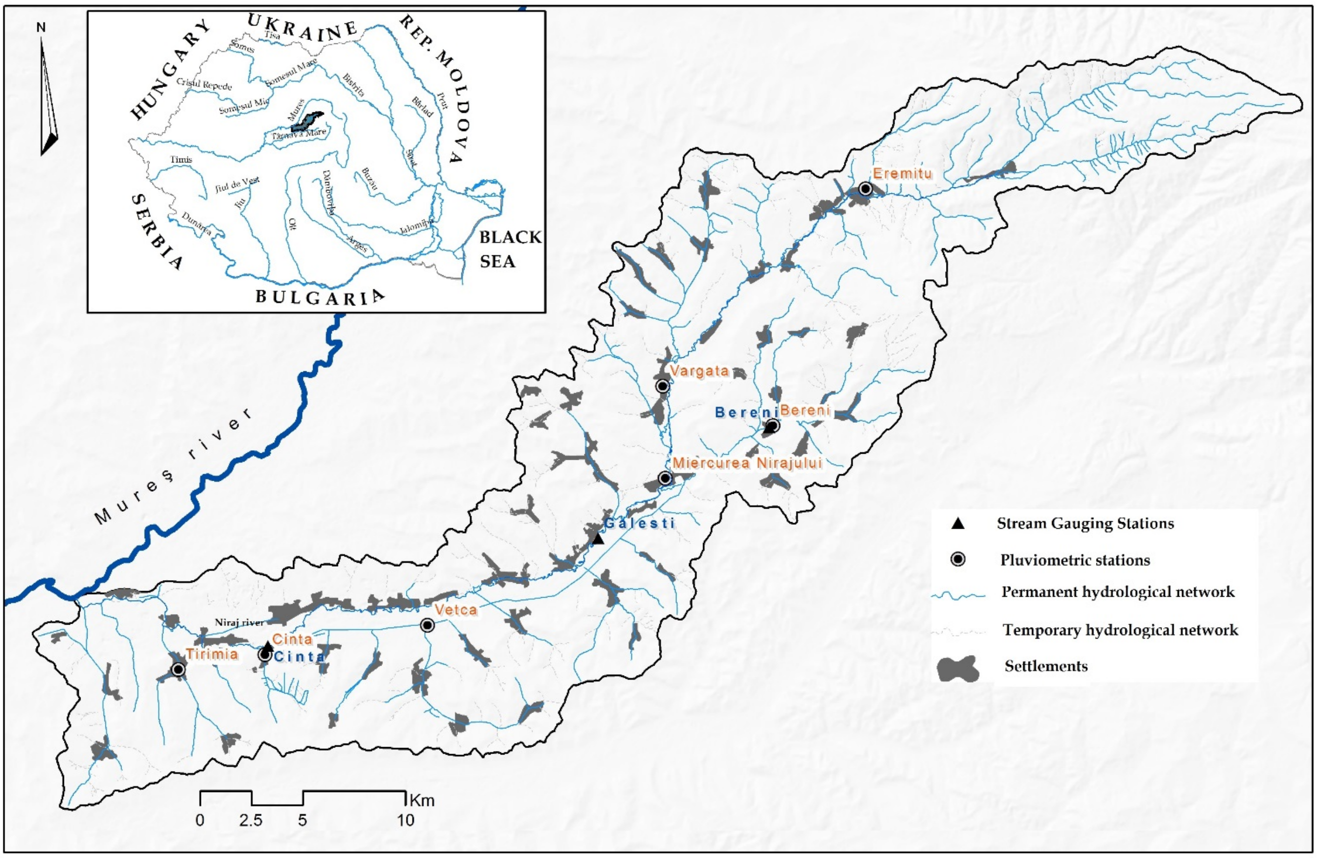


Fig. 2: The geographic location of the Niraj hydrographic basin

The geographical components previously mentioned give unity to the analysed territory, but some differences allow the individualisation of two sectors: the mountainous area and the piedmontainous one, namely the Subcarpatian sector represented by the alternating of hilly areas and depresionary ones, differentiated through the geological composition (Fig. 3), relief morphology, climatic and hydrological characteristics described in the chapters 2 and 3.

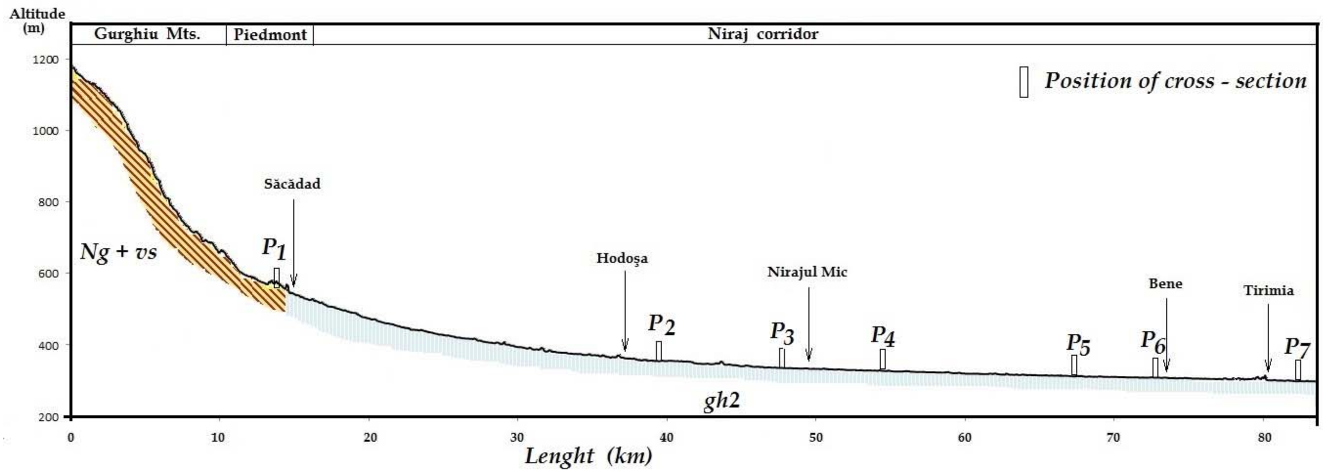


Fig. 3: Longitudinal profile on the Niraj River

3. MORPHOLOGILC AND MORPHOMETRIC CHARACTERISTICS OF THE ANALYSED TERRITORY

Morfometry (Geomorfometry) offers useful information for the present study, by the identification of numeric characteristics that later allow a precise evaluation of the relief (Zăvoianu, 1978), the explaining of the evolution and of the future tendencies. Hence the maps obtained present the favourability and restriction aspects in the study area for the development of settlements, of communicating networks or for the different existent land uses, in accordance with the conditions determined by altitude, slope, drainage depth, fragmentation density, aspect etc.

3.1 MORFOMETRIC AND MORFOGRAFIC CHARACTERISTICS OF THE HIDROGRAFIC BASIN

The basin area counts 658 km^2 (as computed once the water divide of the hydrographic basin was identified on the topographical 1:25000 scale map), hence classifying the basin in the category of middle basins with a regulating flow role, in which the high precipitation quantities fallen in the upper basin areas and the sudden snowmelt in the mountainous are only later felt.

Table 1: morphometric characteristics of the Niraj hydrographic basin

Basin surface (km^2)	Perimetre (km)	Maximum Altitude (m)	Minimum Altitude (m)	Mean Altitude (m)	Mean Width (km)
658	201	1578	284	523	9,29

Relief energy (m)	Drainage density (km/km^2)	Elongation	General slope (°)	Circularity coefficient
1294	1,14	0,43	7,80	2,21

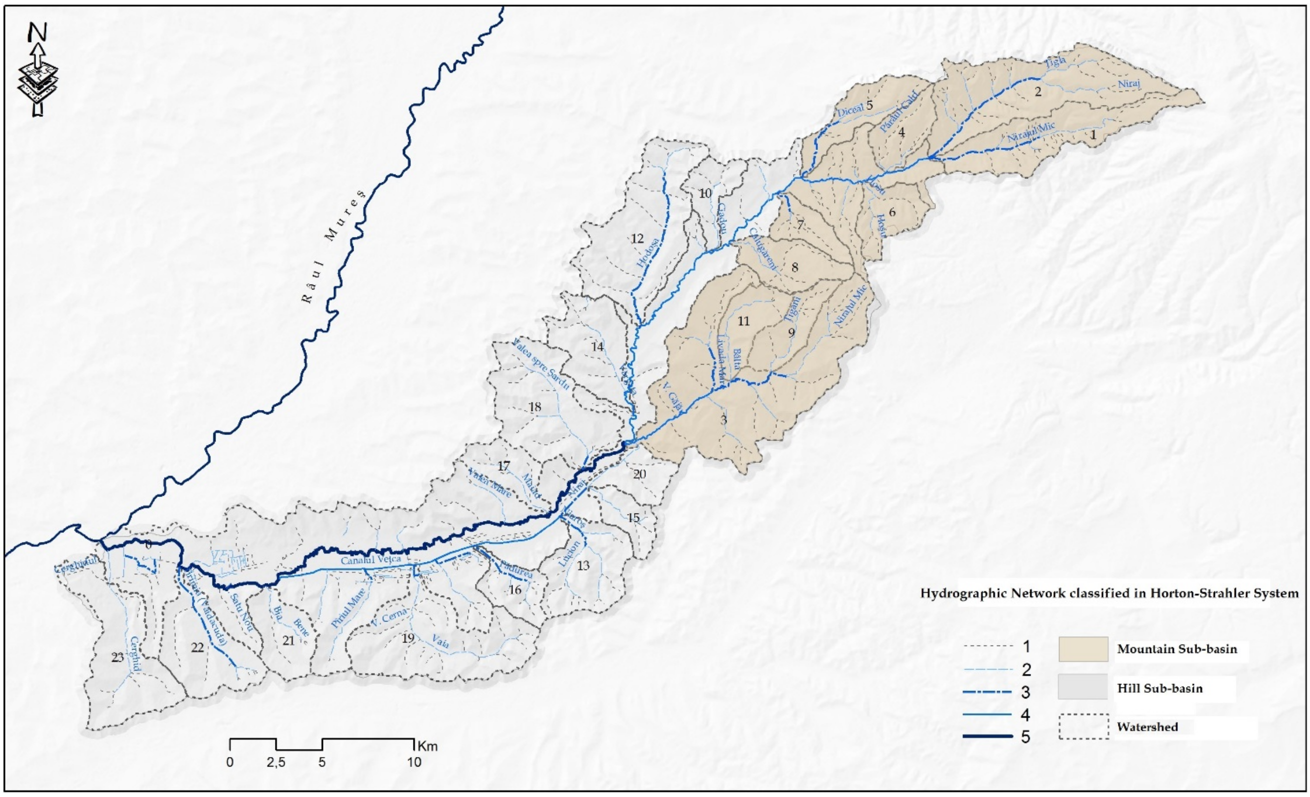


Fig. 4: The Horton-Strahler streamflow organization with a highlighting of the basins in the hilly and

mountainous areas

By comparing the basin shape with the square as a reference form, the value for the Niraj Basin is of 0,26, inferior to the reference value of 1. This prolonged form of the hydrographic basin determines a time difference in the registering of high discharge values and a decrease in the flash-floods amplitude. It can be noticed that the hydrographic basin consists of three subbasins. Important observations are obtained by analysing the hydrologic network according to the order of the streams, by evidencing the incision areas of the neighbouring basins. In order to compute hydrological morphometrical indexes, the subbasins had been previously identified.

For determining the morphohydrographic hierarchy, the methods proposed by Horton, R.E., (1945) and Strahler, A.N., (1957) were employed. In the Nirajului Basin there is a total of 363 segments of 1st order, 213 segments of the 2nd order, 23 corresponding to the 3rd order, 9 segments of the 4th , and 1 of the 5th. It is noticeable the high number of elementary thalwegs, little in length, favouring overland flow.

The presence of these thalwegs is connected to the different resistance opposed to erosion. Their frequency illustrates the influence that lithology has, the résistance opposed to erosion and the vegetal cover. Hence the hydrographic basins in the hilly area, on a layer of marley-clay and a small forestation coefficient, register higher elementary thalweg frequency values (Oaia, Nirajul Mic, Nirajul Mare, Pădurea).

Table 2: River segment length, drainage density and torrentiality degree of the hydrographic basins

	Subbasin	ORDER					RL =Lx/Lx+1	Total Length	Dd =ΣL/F	T = Dd/f
		N1	N2	N3	N4	N5				
1.	Pârâul Litigios	13,98	3,81	-	-	-	8,89	17,79	1,36	2.52
2.	Zambo	20,64	4,92	2,59	-	-	3,04	28,15	1,48	2.35
3.	Pârâul Cald	9,26	2,76	0,97	-	-	3,10	12,99	1,29	1.61
4.	Văraticul	9,91	8,75	2,38	-	-	2,40	21,04	1,05	1.40
5.	Ciadon	5,69	4,68		-	-	5,18	10,37	1,15	1.72
6.	Diceal	5,8	2,69	3,69	-	-	1,44	12,18	0,93	1.01
7.	Ceghid	21,95	8,54	-	-	-	2,57	30,49	1,05	3.75
8.	Pădurea	5,8	2,69	3,69	-	-	1,44	12,18	1,35	0.87
9.	Valea spre Sardu	22,27	8,2	0,78	-	-	6,61	31,25	1,00	1.92
10.	Bogdan	4,79	7,54	-	-	-	0,63	12,33	1,37	4.15
11.	Oaia	36,75	15,41	0,93	-	-	9,47	53,09	1,29	0.94
12.	Tirimia	8,66	1,67	15,18	-	-	2,64	16,92	0,76	1.38

13.	Bene	4,81	8,02	-	-	-	0,59	12,83	1,06	2.52
14.	Nirajul Mic II	46,93	26,35	7,77	8,7	-	2,02	89,75	1,03	1.91
15.	Nirajul Mic	18,04	6,33	8,59	-	-	1,78	32,96	1,31	1.17
16.	Nirajul Mare	20,06	13,98	7,88	-	-	1,6	41,92	1,07	1.26
17.	Stejarul	3,64	4,25	-	-	-	0,85	7,89	1,12	1.58
18.	Aluniş	7,71	0,66	1,49	-	-	6,06	9,86	1,23	1.09
19.	Maiad	6,28	4,35	-	-	-	1,44	10,63	1,06	1.77
20.	Săcădad	7,79	3,4	-	-	-	2,29	11	1,1	1.83
21.	Pârâul Mare	4,11	5,74	0,89	-	-	3,57	11	1,1	0.92
22.	Hodoşa	34,22	12.51		-	-	2,73	47	1,23	3.32
	Bazinul Nirajul	715,22	180,48	59,89	54,56	42,29	2,33	1052,44	1,59	1.73

$N_{1,2,3,4,5}$ – river order number, R_L – length ratio, Dd – Drainage density (km/km^2), T – Torrentiality degree

By seeing the hydrographic basin as an open system, with its organization and hierarchy, in order to understand its functioning the control variables need to be analysed. Since the solid and liquid discharge is conditioned by the fallen precipitation quantity, the streamflow organization with its specific morphography and morphometry is conditioned by the lithological, structural, cover, land use and anthropic characteristics. The liquid and solid streamflow can be seen as a longitudinal axis of maximum concentration of the mass and energy fluxes (Bojoi et all., 1998). The necessary database for this analysis is composed by the value the confluence angle and the adaptation angle gives, expressed in degrees, the length of the floodplain upstream and downstream of the curvature point, where the adaptation angle was measured (expressed in meters) and the Horton-Strahler number. By analysing the hydrological parameters of the floodplain sectors in the Nirajului Basin, several yet unstudied aspects have been determined, which are worth to be explained (the analysis was done on the basis of the method proposed by Bojoi et all.1998).

3.2. MORPHOMETRIC AND MORPHOLOGICAL CHARACTERISTICS OF SLOPES

Chapter 3.2 comprises morphometric and morphological characteristics of slopes such as altitude, declivity, drainage density and depth, slope curvature, profile and plan curvature, total curvature and aspect. These parameters are included as input data in the models that determines the probability of landslides occurrence.

3.3. MORPHOMETRIC CHARACTERISTICS OF RIVER BEDS

Cross-sections and information on meanders obtained from measuring meanders on maps of different ages are included in a database, and the analysis of the river bed focuses on:

- including the river bed of Niraj river in a typology
- identifying variability in the morphometry of the river bed and the flood plain

- the dynamics of cross-sections along the river

Extracting cross-section from GIS software has the advantage of reduced time required compared to measuring them on site, however some cross-section were measured on site for validation.

The cross-sections in the mountain area indicate a deep river bed, steep slope and sectors of narrow flood plain that alternate with sectors where the flood plain widens (fig. 5).

In the hilly subcarpathian area the cross-sections widen when considered from upstream towards downstream and on the terraces settlements developed in time (fig. 6 and fig. 7). However, because of changes in the geological components, the slopes have a high geomorphological risk, being susceptible to landslides, mass movements and torrents.

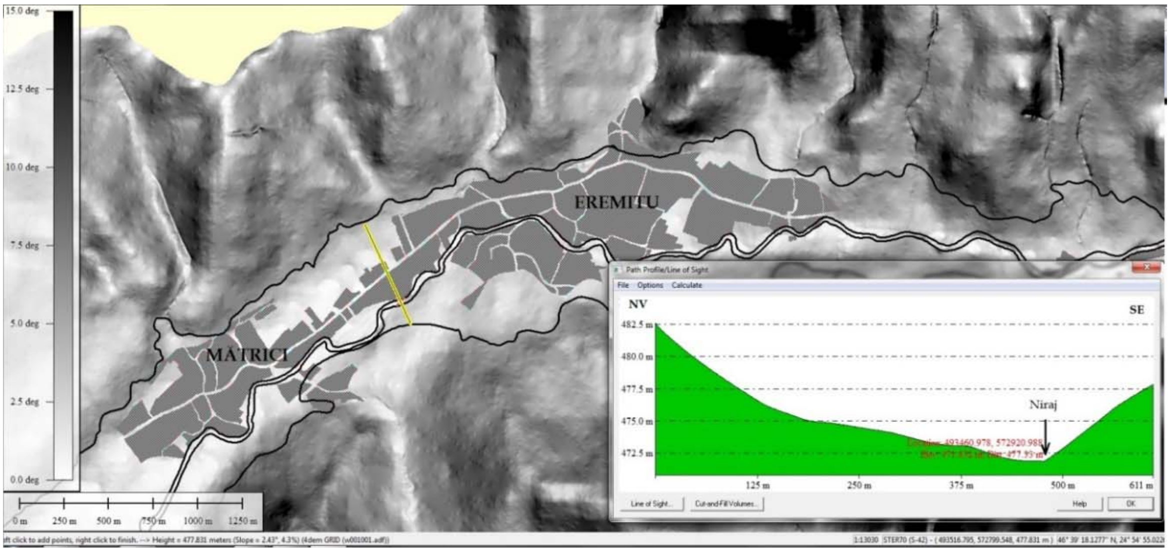


Fig. 5: Cross-section in the flood plain of Niraj River downstream of Eremitu

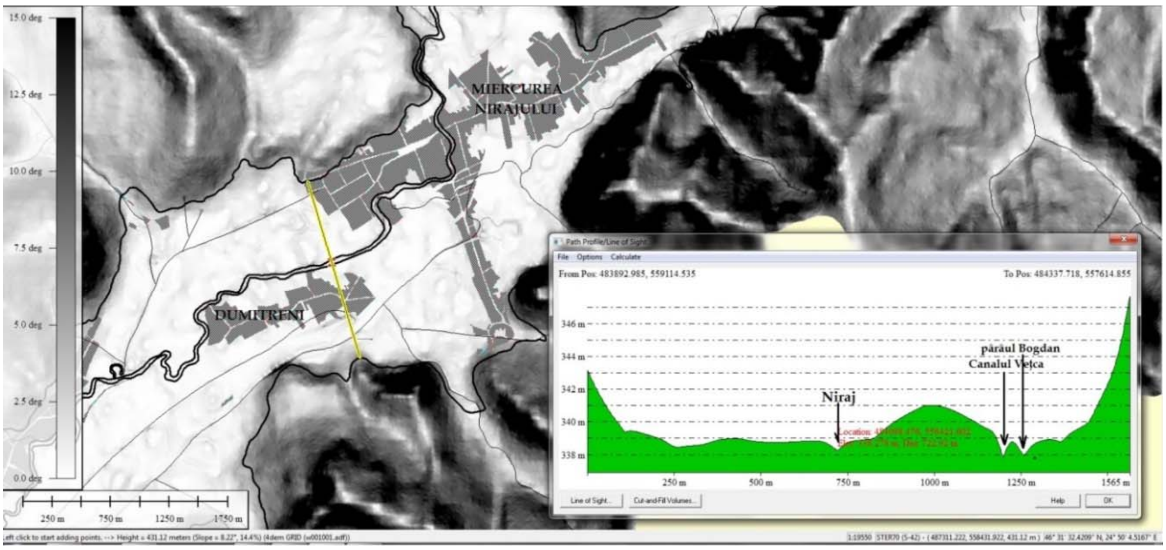


Fig. 6: Cross-section in the flood plain of Niraj River downstream of Miercurea Nirajului

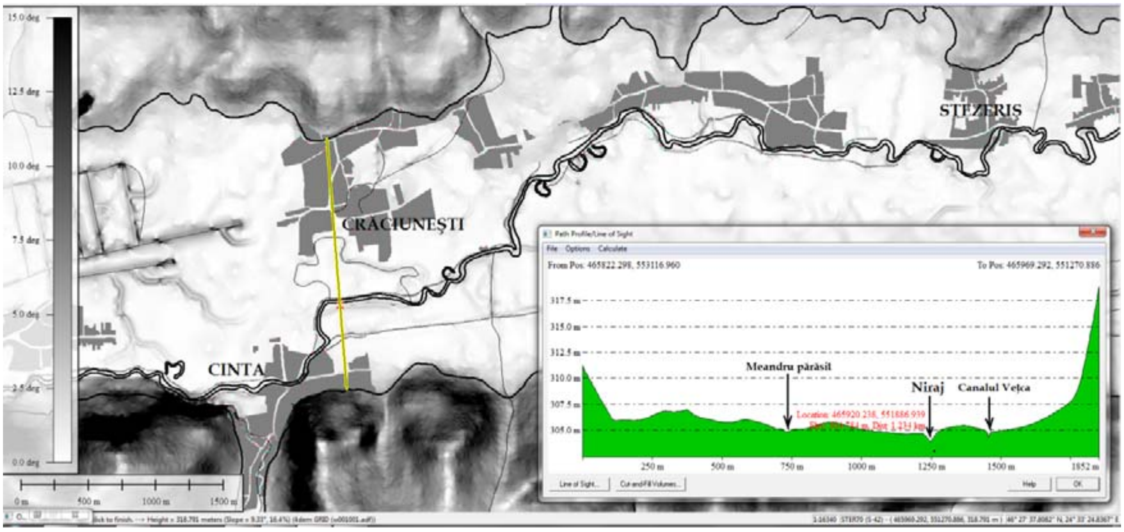


Fig. 7: Cross-section in the flood plain of Niraj River downstream of Crăciuneşti

In the lower basin, as a result of reduced slope and change in the geological conditions, the river energy determines lateral erosion and transport of sediments that accumulate in lateral areas, in the riverbed (holms) and in the confluences (alluvial cone).

The analysis of the dynamics of the river bed relies on the meanders of Niraj river, for which elements like curvature, the meander belt, width of the riverbed, length of watercourse between the ends of the meander bow and the meander length were measured. These elements were used to identify the meandering area, to calculate the erosive power of the river according to the discharge values at maximum flow and to determine the flood area.

By analysing the variation in the coefficient of meandering there is a clear decreasing trend, it ranging from 1.7, that indicates a meandering course, to 1.17, that corresponds to winding rivers. Based in the average value of 1.17 of 2012, Niraj river can be considered to be a winding river.

Table 3: Variation of the coefficient of meandering 1806-2012

Sinuousity 1806	**Sinuousity 1869**	**Sinuousity 1970**	**Sinuousity 2012**
1,7	1,67	1,59	1,17
Meandering River	*Meandering River*	*Meandering River*	*Sinuousity River*

There parameters where calculated on all available maps that cover 100 years, and thus the spatial and temporal evolution of the river bed was determined. GIS makes possible the statistical analysis of the indexes, a graphical representation of them and a correlation between the indexes, the altitude, the basin’s area or the length of the river.

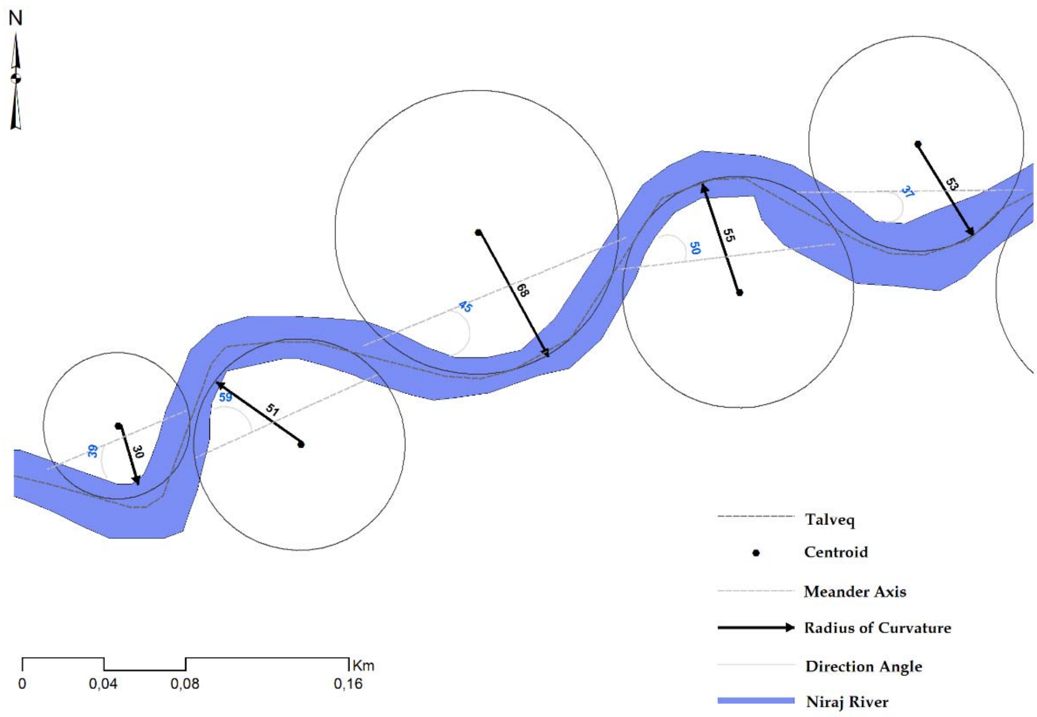


Fig. 8.: Morphometrical indexes of meanders determined in GIS

4. PHYSICAL-GEOGRAPHICAL FACTORS THAT DETERMINE THE ACTUAL RELIEF

Factors that lead to change in the topography and that are presented in chapter 4 include: climate, hydrological factors, soil, tectonics and human influence.

The analysis of these factors implied:

- identifying a trend in the mean annual precipitation values for the period 1970-2012 (decadal and seasonal trends);
- identifying precipitation excess or deficits by using the Weighted Anomaly Standardized Precipitation index;
- the trend analysis and analysis of the variation in average and maximum runoff, and identifying their return periods;
- analysis of the vegetation and soil. In this phase, the settlements and sub-basins were classified according to their naturalness and according to the human impact on forests and agricultural land.

The analysis of the morphometric characteristics enabled the division of the active river channel into 7 sectors, their typology being mainly differentiated according to the slope and the sinuosity index (table 4).

Table 4: Morphometric and geologic characteristics of the river sectors

Caract.	Sect.	Sect.	Sect.	Sect.	Sect.	Sect.	Sect.	Niraj

	1	2	3	4	5	6	7	
Geology	Ng+vs	pn	qh2	qh2	qh2	qh2	qh2	-
Lenght (km)	14	24	9	7	13	6	9	82
Slope (m/m)	6,77	9,66	7,25	5,16	2,01	1,14	1,12	3,64
Sinuousity max	1,62	2,27	1,95	1,58	1,75	1,27	1,12	2,27
Sinuousity medium	1,26	1,43	1,43	1,22	1,25	1,20	1,06	1,27

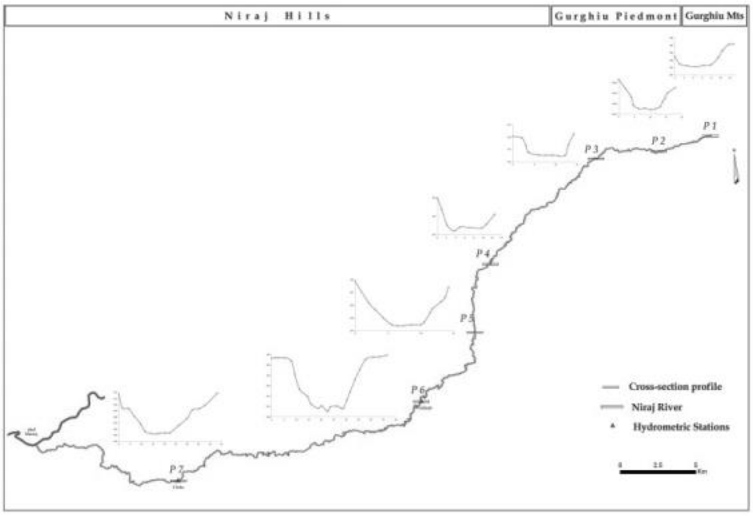


Fig. 9: Position of cross-sections

In this study the bankfull discharge is represented by the discharge responsible for the present riverbed formation. In order to determine the bankfull discharge, a series of cross-sections were created in the field to identify the elements of the active channel cross-section for seven river sectors with different riverbed typology.

Using the data collected in the field, a series of specific parameters were identified (Fig. 10):

Active channel cross-section area (ω) as a sum of the subsections (I…XVI) limited by the vertical measurement lines (h1…hn), using known formulas to calculate triangular and trapezoid areas;

$$\omega = [(h_1 b_1)/2] + [(h_1 + b_2) b_2]/2 + \ldots + [(h_{n-1} + h_n) b_{n-1}]/2 + [(h_n b_n)/2] \text{ (m)}$$

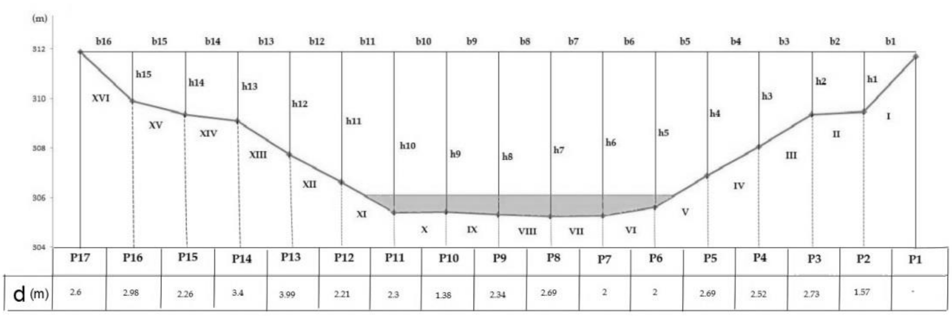


Fig. 10: Profile of cross-section 7 downstream from the Cinta hydrometric station (represents the water level)

- *Wetted perimeter (P) using the formula* (Zăvoianu, 2007) :

$$P = \sqrt{b_1^2 + h_1^2} + \sqrt{b_2^2 + (h_2 - h_1)^2} + \cdots + \sqrt{b_n^2 + h_n^2}, \text{ (m)},$$

where, b1, bn represent the distances between the vertical measurements

h1, hn represent the depth of the vertical measurements

The maximum depth (hmax), the average depth (hmed) and the hydraulic radius (R) have also been determined. The hydraulic radius was calculated as a ratio between the cross-section area (ω) and the wetted perimeter (P)

The bankfull discharge, named by Ichim et al. (1989), the discharge of a full riverbed, represents the fundamental estimative and dimensional parameter of the riverbed hydraulic geometry. A first stage in its calculation is represented by the identification of the bankfull water stage, both in the field and at the riverbed cross-sections.

Further on, the bankfull discharge was calculated using the Manning – Strickler formula Leopold, (1954): $Q_b = A \cdot k \cdot (R^{2/3} \cdot S^{1/2}) / n$,

where: Qb – bankfull discharge [m3/s], A –active channel cross-section area [m2], k –conversion constant [k=1], R – hydraulic radius [m], S – hydraulic slope (slope of the free water surface in uniform movement, equal to the slope of the thalweg slope)[‰], n – roughness coefficient, calculated using the Strickler formula, n = d50 1/6 / 21.1 [m].

Determination of riverbed roughness. The riverbed roughness represents one of the main factors which influence the action of water on riverbeds and river banks, therefore, its determination is an important and indispensable stage in such a study as the present one.

In order to determine the riverbed roughness, the grain size of the channel deposits was analysed for each river sector. In the minor bed, this analysis was performed globally (without differentiating between pavement and subpavement), the results being classified into 14 granulometric classes according to the Wenthworth scale, at a 1 phi interval: blocks (> -8 phi), boulders (between -6 and -8 phi), gravel (between -1 and -6 phi), sand (between 4 and -1 phi) and silt (< 4 phi).

In the present study, the riverbed roughness was determined using the Stickler formula:

$$n = D_{50}^{1/6} / 21{,}1$$, unde:

n = roughness, A = area of cross-section, R = hydraulic radius, S = slope of the channel, Q = discharge, D50 = median diameter.

Stream power determination The stream power is an indicator which is considered in the literature as the main factor in the assessment of minor bed erosion and dynamics (Hickin & Nanson, 1984), in the analysis of sediment transport (Bagnold, 1966) and sediment unloading (Simons, 1966), which is also dependent on the concept of bank resistance. The stream power expresses the capacity of a river to load and transport sediments during its flow, at a punctual level. Thus, the estimation of this parameter is essential in the identification of the riverbed dynamic trends.

In 1966, Bagnold defines the power of a water stream as a product between the specific water density, the discharge and the slope of the water surface: $\Omega = \gamma \cdot Q \cdot S$, where, Ω = stream power, γ = water density [kg/m3], Q = discharge [m3/s], S = slope of the channel [m/m]

By dividing the stream power per unit area, Bull (1979) uses the following expression in order to determine the available power for erosion and transport at each cross-section: (formula 3):

$\omega = \Omega / W$, where: ω = Specific stream power [W/m], Ω = stream power [W/m], W = width of the active channel [m].

Other studies determining the stream power have highlighted specific longitudinal trends (Magilligan, 1992; Lawler, 1995; Leece, 1997; Knighton, 1999). The new GIS technologies and LIDAR elevation models enabled the calculation of the stream power at continental scale (Finlayson et al., 2002; Finlayson & Montgemetry, 2003) as well as at the level of large and medium catchment areas (McCandless et al., 2002; 2003; Jain et al., 2006; Worthy, 2005; Stacey, 2007), the authors stating the necessity of using a DEM with a minimum resolution of 1 m2 in order to produce any useful results. However, the majority of studies related to bankfull discharge and its corresponding stream power (both for applications and innovative studies)

According to the previously described methodology, a series of indispensable work stages can be anticipated in the identification of the relationship between river flow and meander pattern, their results being described in the following section.

A first stage is represented by the identification of the granulometric spectrum of bed material in relationship to the variables which define the catchment area (surface, geology, elevation and slope) as well as the granulometric distribution on the longitudinal profile, determined through the granulometric statistical analysis (Fig.11).

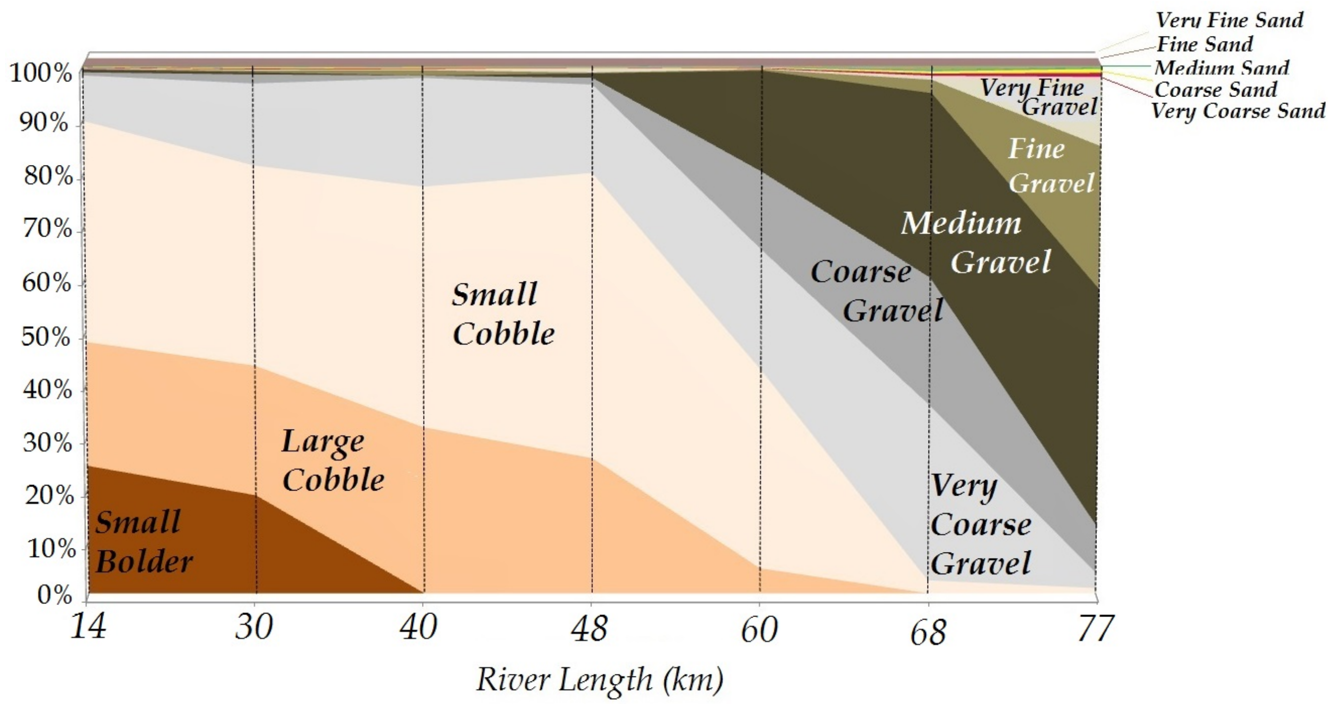


Fig. 11: Granulometric spectrum of channel deposits

The ideal distribution of the riverbed deposits along the river follows the principle of the decreasing percentage of granulometric classes in the flow direction (Rădoane et al., 2002). In this case study, however, certain variations can be noticed which are explained through the material input brought by the main tributaries, as well as by the effect of dyke building and channel adjustment works. In 1875, by analysing the variation of riverbed sediment dimension along rivers, Sternberg identified a decrease of the grain size according to an exponential relationship.The same situation can also be identified for the Niraj River: blocks are dominant in the upper catchment area followed by the boulder and gravel classes, their percentage increasing in the medium and lower catchment area. This sorting process of riverbed material, progressing over a long period of time, took place according to the riverbed resistance to the effects of liquid and solid flow characterised by a specific stream power.

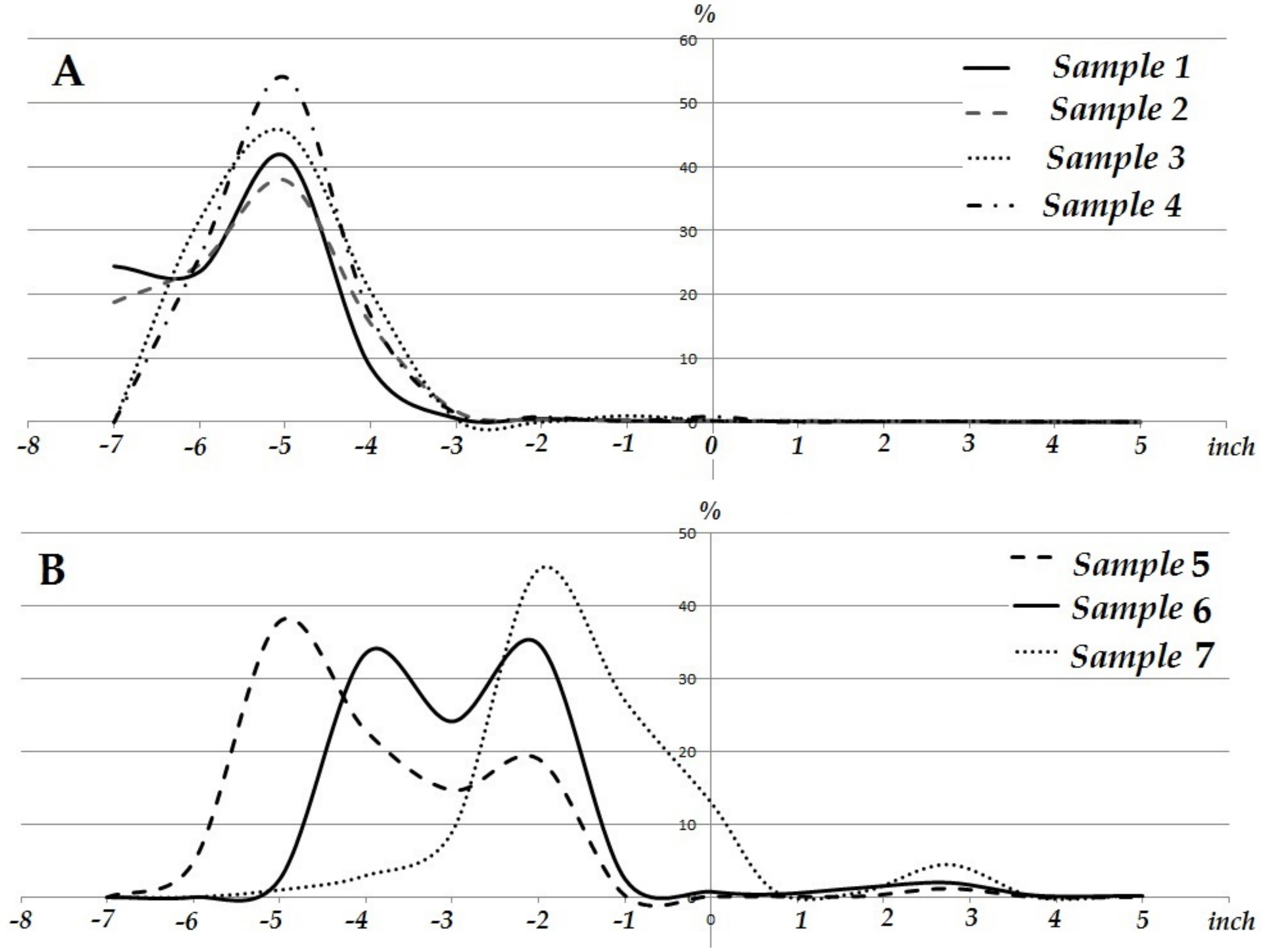


Fig. 12: Distribution histograms of channel deposits

The histograms of the upper and medium sectors are characterised by unimodality (Fig. 12.A) while the histogram of the lower sector is characterised by the bimodality of riverbed sediments (Fig. 12.B). The same characteristics can be identified for the rivers in north-eastern Romania, due to the competition between the processes of sorting and attrition (Rădoane et al., 2002). In order to determine the cause of the decrease of sediment dimension along the river, worldwide studies concentrated on the ratio between hydraulic sorting (Knighton, 1982) and mechanical attrition (Ibbeken, 1983), at the segregation level of riverbed deposits.

In the laboratory stage, the sampled data were statistically analysed and, as a result, the value of the median diameter was identified (D50), a necessary parameter in the quantification of minor riverbed roughness (fig. 12).

A decreasing trend of the D50 value can be noticed along the river, from a value of 0.915, characterising the sample number 1 at the kilometre 16 of the river, to the value 0.356, for the sample number 7, on the lower part of the stream, at the kilometre 74 of the river.

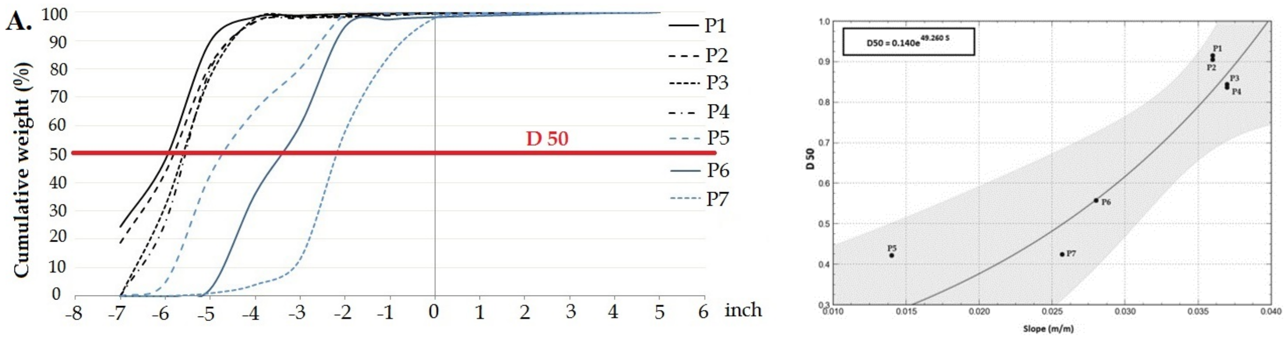


Fig. 13: Value of median diameter D50 and the correlation D50 – river slope (m/m)

The average correlation (R2=0.566) between the median diameter (D50) and the river slope also reflects a decrease in the dimensions of the riverbed material on the longitudinal profile.

By using the data of the cross-section profiles and applying the previously presented methodology and the Manning – Strickler formula in reference points, the values of the bankfull discharge were determined. In the case of two cross-sections the validation of the results is possible due to the proximity of hydrometric stations: Gălești (profile 6) and Cinta (profile 7).

One can notice an increase of the bankfull discharge values along the river due to the changes of the morphometric parameters characterising the minor bed (the wetted perimeter and the area of active channel cross-section), the highest calculated value is reached at profile 7 (in the close vicinity of the hydrometric station Cinta).

Table 5: Calculated values of bankfull discharge

No.	P (m)	A (m)	R (m)	S (‰)	n	Vm (m/s)	Qb (m^3/s)
1	20.3	10.9	0.538	1.745	0.046	1.9	*20.8*
2	33.6	19.6	0.584	1.745	0.046	2.0	*39.3*
3	29.8	17.7	0.595	2.756	0.047	2.5	*44.7*
4	23.0	22.6	0.982	2.756	0.047	3.5	*79.6*
5	29.5	29.4	0.995	0.465	0.040	1.7	*50.1*
6	96.2	111.5	1.159	0.465	0.043	1.7	***195.3***
7	89.8	174.7	1.945	1.957	0.041	5.3	***928.2***

where P – wetted perimeter, A – area of active channel cross-section, R – hydraulic radius, S – slope of the channel, n – roughness, Vm – average velocity, Qb – bankfull discharge, Qm – average discharge (1950-2013).

Identification of Return Periods for Maximum Discharge Using the data available at the hydrometric stations Bereni and Cinta (located in the close vicinity of the cross-sections 6 and 7) the occurrence probability of the maximum discharge necessary in the estimation of future trends was determined. In the present study, the maximum discharge, with a return period of 1.5 years, has the value of 41.6 m3 at the Cinta hydrometric station and 28.9 m3 at Bereni hydrometric station.

Table 6: Exceedance probability and return periods of the maximum and dominant discharges calculated at the Cinta and Bereni hydrometric stations

Return period (T)	Exceedance probability (%)	Qmax	
		Cinta	Bereni
1000	0.1	493	237
200	0.5	383	186
100	1	335	164
50	2	287	142
20	5	223	113
10	10	175	90.6
5	20	127	68.6
3	33	92.3	52.4
2	50	62.2	39.5
1.5	**66**	**41.6**	**28.9**
1	90	28.3	20.9

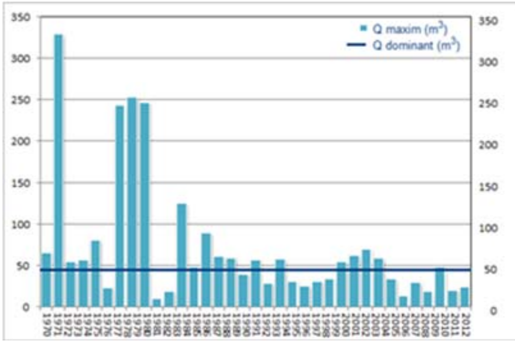


Fig. 14: Absolute frequency of years in which the maximum discharge was higher than Qmax with 1,5 year probability

Analysing the graphical variation of the annual maximum discharge (Fig. 14) one can notice the high number of years from the 1970-1979 decade in which the discharge being considered as dominant was over passed, a condition with a return period of 1.5 years in 7 cases. For the next decades, the determined number of such situations was: 6 (1980-1989), 3 (1990-1999), 4 (2000-2009) and a singular event in the interval 2010-2012.

Stream Power Calculation. Another important stage of the present study was represented by the assessment of the energetic conditions which are specific to the maximum flow (by analysing the discharge and the stream power during peak flow using the bankfull discharge) and the normal flow (by analysing the stream power at a multiannual average discharge).

Related to the adjustment of riverbed geometry from the perspective of the concept of optimum energy dissipation (stream power, Shield et al., 2003), the stream power at the level of the active channel cross-section was calculated for a normal flow regime ωm (table 7).

Table 7: The maximum and average specific stream power and stream power values

Nr. Sect.	Qb (m^3/s)	Ω_{max} (W/m)	Ω_m (W/m)	ω_{max} (W/m^2)	ω_m (W/m^2)
1	20.8	127477	-	289	-
2	39.3	53542	-	141	-
3	44.7	13763	-	14.51	-
4	79.6	28113	-	37.28	-
5	50.1	15788	-	14.95	-
6	195.3	14255	85.15	8.77	0,22
7	928	7559	534	3.51	1.21

These energetic values offer information on the relationship between the transport capacity and the resistance to erosion of the river banks. Generally, the riverbed of Niraj River evolves in the context of medium and low energy. Thus, the sectors with low values of stream power, around the value of 10 W/m2 (profiles 6 and 7 which are specific to the lower sector of the Niraj), correspond to the C class of low energy riverbeds (according to the energetic classification of riverbeds made by Nanson & Croke, 1992). These are characterised by a high resistance of the river banks to water erosion which limits the lateral migration of the channel. The sectors with values of 30-300 W/m2 correspond to the class B riverbed, with medium energy. These are considered as riverbeds in a dynamic equilibrium, rarely affected by extreme events as the river dissipates its energy along the major riverbed and its erodability being decreased by the protective role of the vegetation.

The river sectors with a stream power of 30.2 and 105.3 W/m2 developed on gravel bed and characterise the upper and middle parts of the Niraj, which are included in the B2 class where major beds are highly stable to bank overflowing. The B3 class of major beds with lateral migration through meandering processes is characterised by a stream power of 10.4 and 62 W/m2 in the active channel cross-section which determines the dominance of lateral over vertical erosion.

In what concerns the relationship between the bankfull discharge and the morphometric characteristics of the riverbeds, by using the same types of mathematical expressions describing correlations, one notices a high correspondence between these two set of variables, both in national and international researches (table 8). For the Niraj catchment area an increase of the active channel cross-section area can be noticed at the same time with the increase of the upstream catchment area (fig. 15.A as well as a direct relationship between the stream power and the bankfull discharge (fig. 15.B).

Table 8: The relationship between the bankfull discharge, the morphometric characteristics of the riverbed (riverbed width, average depth) and the catchment total area (where : A= aQbkfb, l = cQbkfd, d = eQbkff)

<table>
<tr><th colspan="2">Catchment Area (A)</th><th colspan="2">River Width (l)</th><th colspan="2">Average Depth (d)</th><th colspan="2" rowspan="2">Source / River</th></tr>
<tr><th>a</th><th>b</th><th>c</th><th>d</th><th>e</th><th>f</th></tr>
<tr><td>-</td><td>0.90^{+}</td><td>-</td><td>0.50</td><td>-</td><td>0.40</td><td colspan="2">Leopold, Maddock, 1953</td></tr>
<tr><td>-</td><td>0.87^{+}</td><td>-</td><td>0.42</td><td>-</td><td>0.45</td><td colspan="2">Wolman, 1955</td></tr>
<tr><td>0.90</td><td>0.83</td><td>1.65</td><td>0.50</td><td>0.55</td><td>0.33</td><td colspan="2">Nixon, 1959</td></tr>
<tr><td>-</td><td>0.91^{+}</td><td>2.17-3.98</td><td>0.52</td><td>0.16-0.20</td><td>0.39</td><td colspan="2">Hey, Thorne, 1986</td></tr>
<tr><td>0.28</td><td>0.94</td><td>1.46</td><td>0.52</td><td>0.19</td><td>0.42</td><td colspan="2">McCandless, 2002</td></tr>
<tr><td>0.79</td><td>0.8</td><td>2.65</td><td>0.47</td><td>0.3</td><td>0.33</td><td colspan="2">McCandless, 2003</td></tr>
<tr><td>0.764</td><td>0.70</td><td>-</td><td>-</td><td>-</td><td>-</td><td colspan="2">Ahilan şi colab., 2013</td></tr>
<tr><td colspan="8">ROMANIA</td></tr>
<tr><td>-</td><td>-</td><td>12.67</td><td>0.24</td><td>-</td><td>-</td><td>Ialomiţa</td><td rowspan="3">Minea, G., et all., 2011</td></tr>
<tr><td>-</td><td>-</td><td>6.03</td><td>0.43</td><td>-</td><td>-</td><td>Buzău</td></tr>
<tr><td>-</td><td>-</td><td>3.75</td><td>0.42</td><td>-</td><td>-</td><td>Bâsca</td></tr>
<tr><td>0.69</td><td>1.34</td><td>1.03</td><td>0.69</td><td>-</td><td>-</td><td>Prahova</td><td>Toroimac, 2009, 2013</td></tr>
<tr><td>6.45</td><td>0.78</td><td>6.13</td><td>0.26</td><td>0.73</td><td>0.43</td><td colspan="2">NIRAJ</td></tr>
</table>

These correlations make possible the identification of the specific stream power corresponding to the discharge forming the riverbed on all river sectors.

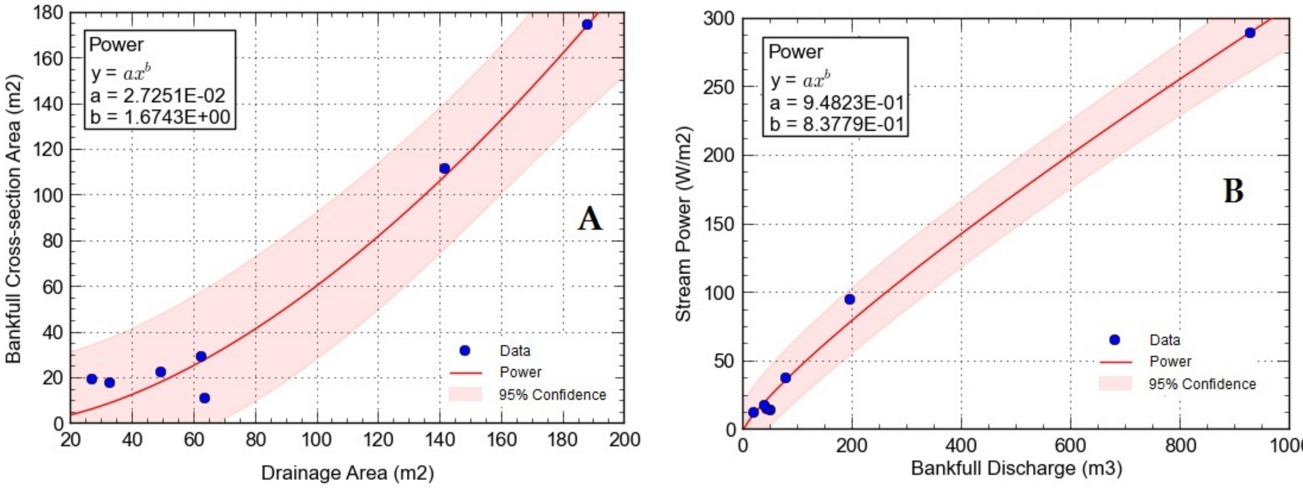
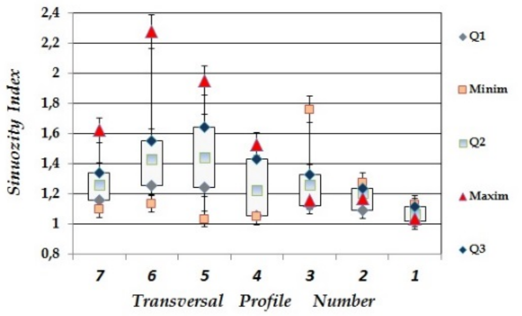


Fig. 15: Correlation between the active channel cross-section and the upstream area (A), correlation between the bankfull discharge and the stream power (B)



As a result of different researches concerning rivers from various geographical areas, a general tendency of rivers changing their morphometric characteristics according to hydraulic elements was identified (Schmitt, 2004; Schmitt et al., 2007; 2011; Pandi et al., 2013).

Fig. 16: The variation of the sinuosity index on all river sectors

The cartographic analysis of the Niraj riverbed dynamics using Austrian Maps, The Second Campaign (1860), The Third Campaign (1910), Topographic maps 1:25000 (1970) and SPOT satellite images (2012) enabled the identification of highly dynamic sectors.

By analysing the evolution of the Niraj sinuosity (Fig. 17) for the seven river sectors, a high dynamics of the sectors 4 and 5 can be noticed, which also have the highest value of stream power at bankfull discharge. The most stable sectors are those from the mountain and piedmontal areas which have a high resistance to erosion, despite the high stream power (Roşca et al., 2013).

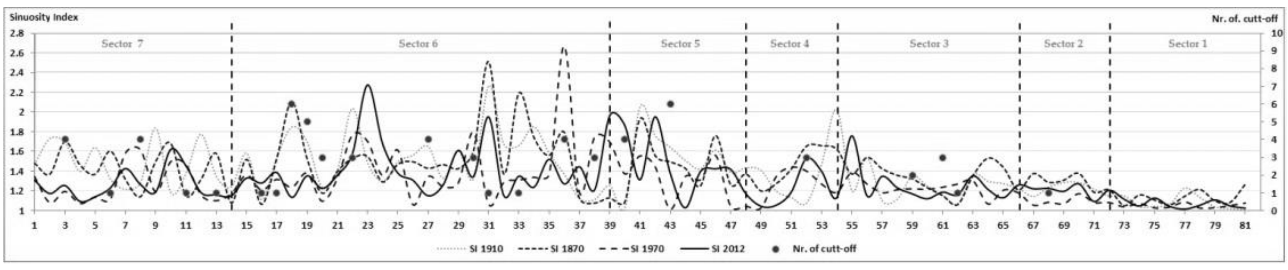


Fig. 17: Variation of the Niraj sinuosity index in the interval 1910-2008

Extreme discharge values lead to meander undercutting (fig. 18) determining a decrease of the river length and, thus, a decrease of the flow concentration time, having obvious effects on the minor bed morphology. The slope of the channel determines higher stream power in cross-sections, especially during extreme events.

Fig. 18 : Undercut banks through meandering processes near Păsăreni settlement (foto 4 June 2012)

To illustrate this situation, two representative sectors were selected. The first sector is located between Vărgata-Mitreşti settlements (fig. 20), it is 3.67 km long and has a sinuosity index of 1.27 (sinuous sector). In the absence of natural and anthropic constraints (terraces, dykes), the river evolved in this sector by passing through lateral migration from a sinuous to a meandering sinuous sector (Fig. 19). This sector is evolving in the context of an average stream power of 37.28 W/m2 at maximum flow, which corresponds to a bankfull discharge with a shorter return period, namely 2.6 years. As a consequence, the river will disseminate its energy creating erosional processes depending on the erosional resistance determined by geology and vegetal protection. In the presented case study one can notice a complete change of meandering processes (according to Hooke classification, 1977) in the vicinity of Mitreşti settlement. The main cause of this change highlighted by the analysis of the existing data was lithology. The meander is located in the area where the lithology changes from marly clays to gravel and sand.

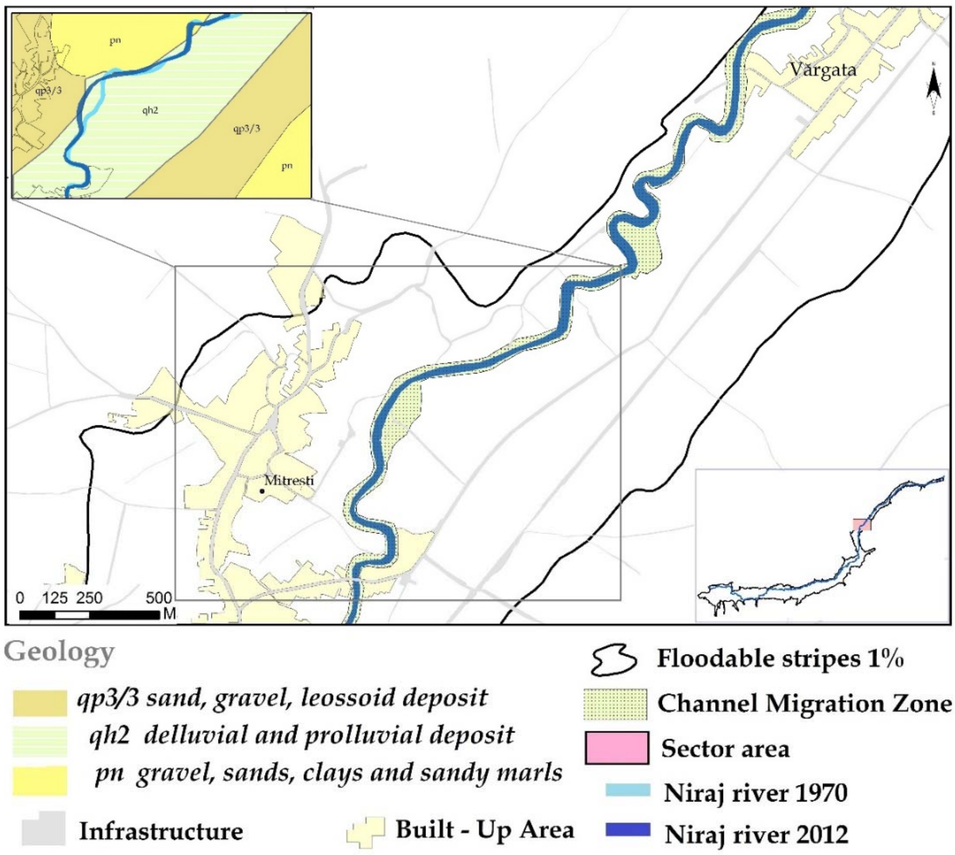
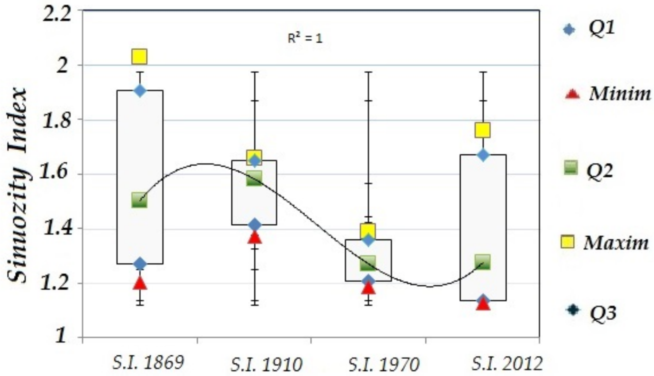


Fig. 20: Channel migration zone on Vărgata-Mitreşti sector

On the other hand (fig. 14) in the second sector, located in the proximity of Acăţari settlement (with a total length of 3528 m and a sinuosity index of 1.65, which includes it in the category of meandering river sectors), a high river dynamics can be noticed in the interval 1869-2012, the variation from the average becoming more obvious especially in the last years (fig. 21). In this sector, the river evolves in a low energy context of 0.22W/m for the average flow and 8.77 W/m for the maximum flow, the return period of the bankfull discharge being 14.9 years.



This river sector offers an image on the effects created by dykes aimed to protect built-up areas against floods, but limiting the space required by river evolution. The same constraint determines the decrease of the Niraj minimum freedom of movement (fig. 22).

Fig. 21: Sinuosity index variation in the interval 1869-2012, in the proximity of Acăţari settlement

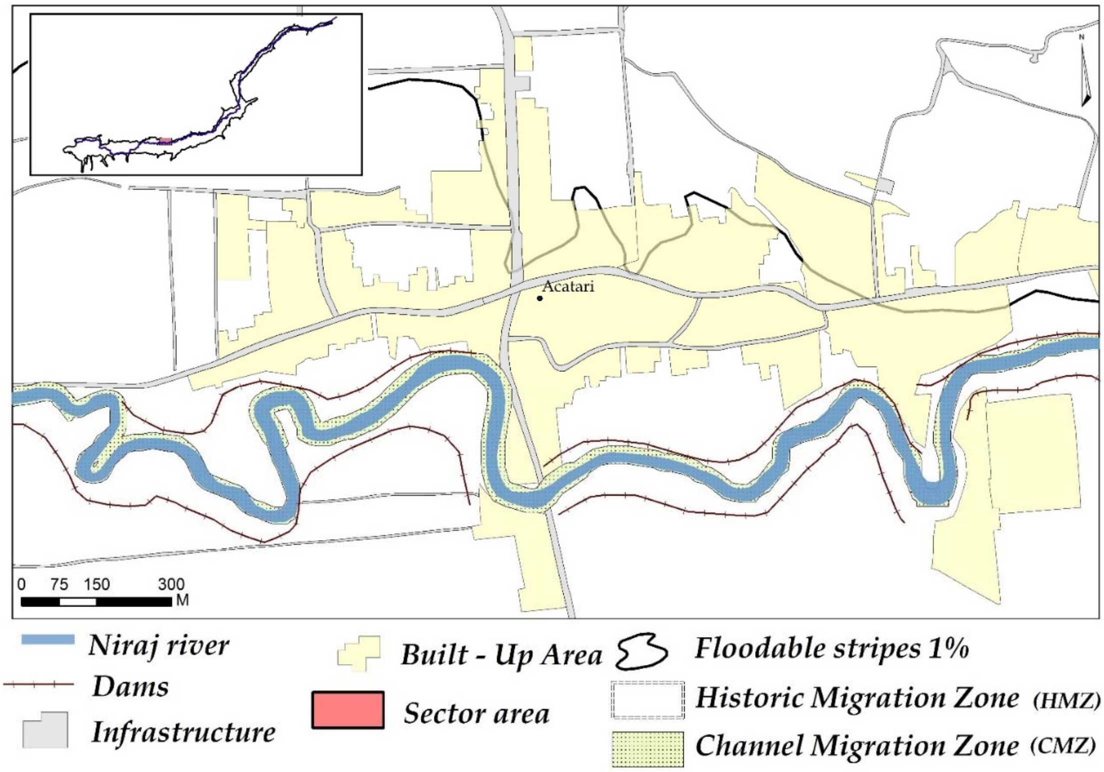


Fig. 22: Channel migration zone in Acăţari sector

The values determined through the presented methodology punctually illustrate the stream power and the bankfull discharge, but the present study further aims at improving qualitative estimations through the quantification of hydraulic parameters and providing a more realistic image of the morphogenetic environments. These are characterised by high, medium and low energy, correlated to the zones of the catchment area (according to Schumm, 1977).

River sectors evolving over the stream power of 35 W/m2 were identified, having a short response time to the upstream changes (<10 years). An important result is represented by the identification of the energy which drives the river evolution, the assessment of bankfull discharge, as the parameter having the highest influence on riverbed stability, and the assessment of its return period. Nevertheless, the studies aiming at identifying the stability of the riverbed and its temporal dynamics will include additional information related to the resistance to erosion, the factor of protective vegetation and the anthropic intervention degree. However, the input determining the irremediable changes inside the system is represented by the maximum flow (during high waters and flash-floods) due to its maximum energetic capacity to produce quantitative and qualitative microscale changes.

PART III SPATIAL-TEMPORAL ANALISYS OF NIRAJ BASIN'S MORPHODYNAMICS AS BACKGROUND OF TERRITORIAL DEVELOPMENT

Because of the need to identify the processes that may lead to changes in the hydrographic system and the extreme phenomena that cause material damage, the preliminary phase required a correct identification of all processes and phenomena that occurred previously.

The methodology used in identifying extreme geomorphological processes is based on a large spatial and temporal database that allows the identification of processes and their spatial and temporal spread, and on the usage of geoinformatic methods that lead to graphical spatial-temporal representation of topography's dynamics and of relationships between the causing factors of the processes analysed. Considering the relief as a support of all social and economic activities, Cocean, P., (2002) includes relief in the components that support the territorial development, components that include climate, hydrological elements, vegetation and soil.

Geomorphological processes that cover the largest areas when active and that can lead to imbalance and damage are: landslides, soil erosion and fluvial erosion.

5. MORPHODYNAMICS OF NIRAJ BASIN

The current change of the topography is an on-going process and functions like an open system that determines the dynamics and variety of the geomorphological landscape. The different intensity degrees of altering factors combined with the resistance of initial topography lead to suitable conditions for the occurrence of some geomorphological processes (areolar erosion, gullies, torrents, mud flows, landslides and falls). Areas affected by mass movements and fluvial erosion are of considerable extent, and these processes affect infrastructure and built elements. This applied geomorphology study focuses on identifying external damage (resulted from extreme variables) and internal damage (resulted from the variation of internal parameters).

In analysing the riverbed systems the following phases were considered:

- the analysis of the recent evolution of Niraj river
- the identification of spatial and temporal variation of meandering
- clear identification of the meandering area of the river

Analysis of recent satellite images lead to the conclusion that the Niraj river consist of a series of straight sectors, winding sectors and meandering sectors, them appearing as a result of the geological and structural conditions and of the river's erosive capacity as wells as because of human intervention.

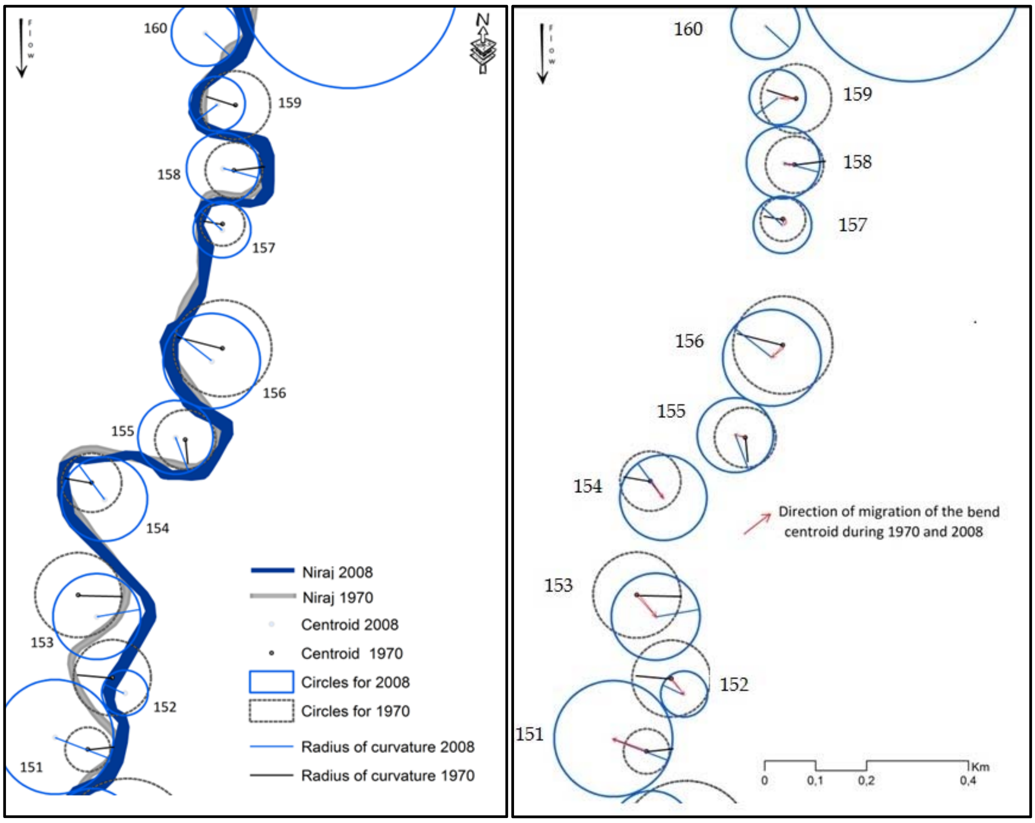


Fig. 23: Meander migration measuring between 1970-2008

The radius of curvature and centroid position of the circle will be used to measure the channel migration for the period between: 1970-2008, represented with red arrow (fig. 23.B).

The rate of change of the radius of curvature for the bank is definite by:

$$\Delta RCA = (RC2 - RC1)/YA \text{ where}$$

ΔRCA = Rate of change in radius of curvature during period A (m/year)
RC1 = Radius of curvature of bank in year 1
RC2 = Radius of curvature of bank in year 2
Y = Number of years in period A

A positive value of the rate of change indicates an expansion (increasing radius) of the value of radius curvature for 1970-2008 period and those with a negative value shows a decrease of radius curvature. Throughout the entire river, 61% of the meander loops have expanded and only 39% have decreased, but the situation differs locally due to changing of the hydrographic basin characteristic parameters as well as varying degrees of anthropic intervention. Another morphometric indicator of the river, the sinuosity index, proves the data veridical. Sinuosity of the Niraj river was calculated from the ratio of channel length to straight-line valley length. Results indicate that sinuosity of the main stream declined from 1,59 (specific to meander river) to 1,17 (specific to sinuosity river) between 1970 and 2008.

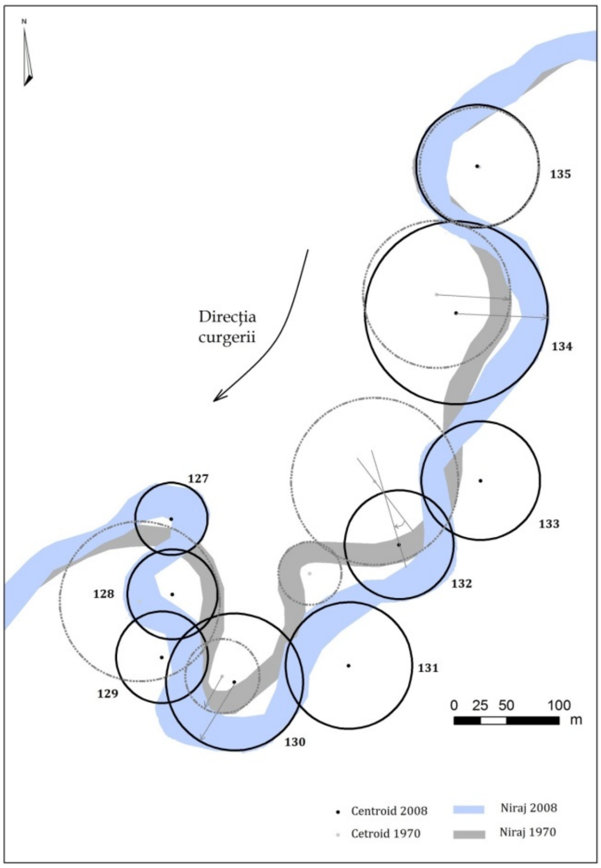


Fig. 24: Style of change of meander bends between 1970-2008 of the Niraj River

In the upper Niraj basin (after the confluence of the Niraj Mic with the Niraj Mare), which corresponds from km 9 to the 38th, the river has an increased energy due to the high slope and that of high water intake, which causes reorganization to the riverbed; this section of the river corresponds to the piedmont part of the Gurghiu mountain and that of the Sub-Carpathian relief, which has a geology that passes from volcanogenic sedimentary deposits to deluvio-proluvium ones consisted of sand, gravel and leosoil deposits. In this sector it can be found both expansions of the meanders and also areas of decreasing. As it can be observed in the middle sector, channel migration has a small variation; exception are cases when man intervened by embanking the river in order to protect people houses situated nearby.

The inferior sector, which is closer to the confluence, being developed on a low slope and geology dominated by gravel, marl and clay receives a higher degree of meandering. Thus, it can be observed cases when the radius of curvature has positive values, which corresponds to the meander expansion from this sector between 1970 to 2008. A positive value of the rate of change indicates an expansion (increasing radius) of the value of radius curvature for 1970-2008 period and those with a negative value shows a decrease of radius curvature.

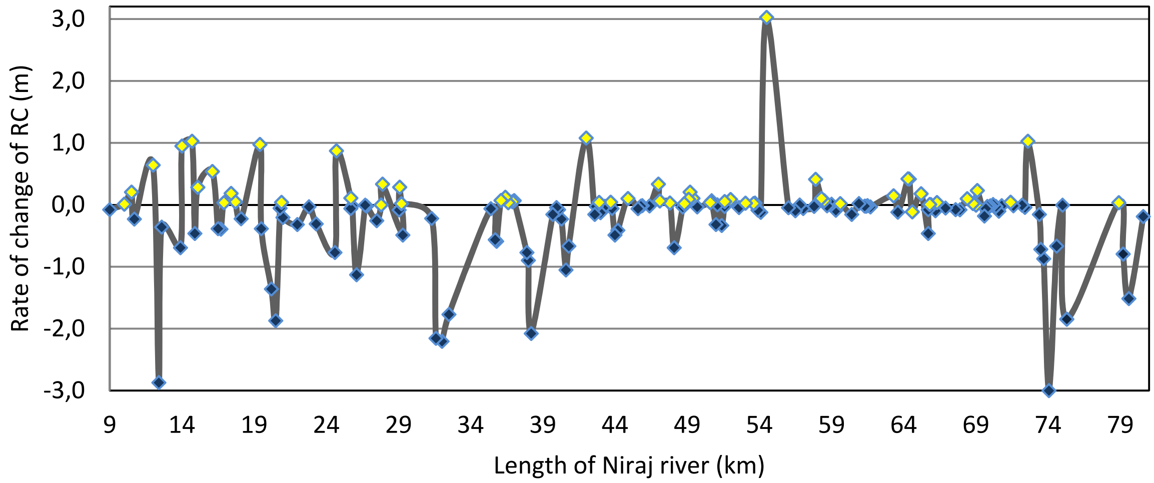


Fig. 25: Variation of the rate of change of RC during the period of record (1970-2008)

Identifying the meandering area of the river. The meandering area of the river was identified according to the methodology developed by the specialists in the Washington Department of Ecology and Transport in 2003. The results will lead to the identification of areas susceptible to fluvial erosion and further on to the identification of risk associated to lateral erosion (FEMA, 1999).

A 100 years interval was considered in analysing the ecological, geomorphological and economical changes.

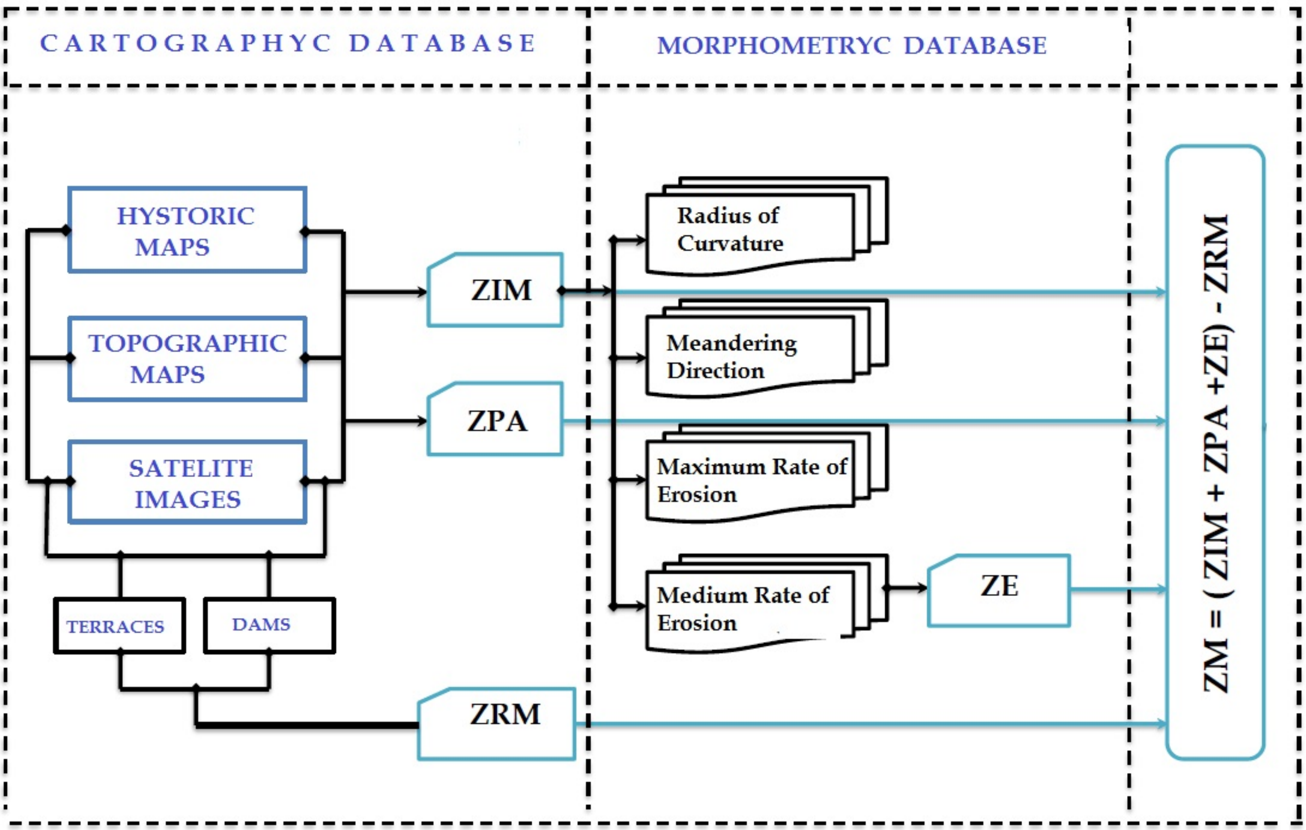


Fig. 26: Methodological schema of the model used to identify the meandering area

In order to identify the meandering area, the maps database included:

- the Historical Migration Zone of 1910
- the erosion era
- Restricted Migration Area that consists of the area inside the meandering area that is not under the direct influence of the river because of the existing terraces or as a result of the anthropic protective measures taken against lateral erosion.

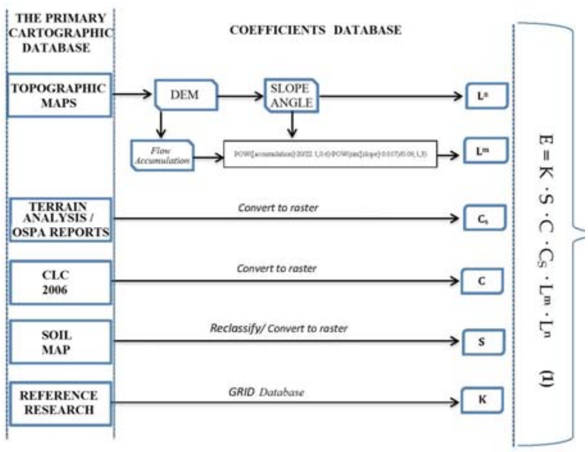
The analysis was meant to identify the zones of potential migration and implied identifying the migration potential area (areas of low, medium and high meandering potential, considering the average and maximum erosion rate, the existence of abandoned channels and proximity of sectors with high geological resistance to erosion).

6. SPATIAL PREDICTION OF THE GEOMORPHOLOGICAL RISK PROCESS.

The spatial probability modelling for soil erosion, landslides, fluvial erosion as well as for floods has a great importance in the identification of the most useful mitigation measures against the negative effects at the level of the natural and human environment.

6.1. Application Of Soil Loss Scenarios Using The ROMSEM Model. The ROMSEM Model (Romanian Soil Erosion Model) has been generated by the use of an empirical model (determined from a series of statistical databases) for the Romanian territory. It has at its foundation the equation developed by Moţoc, M. et al. (1973, revised in 1979, reconfirmed in 2002) which is based on the universal relationship used by the Soil Conservation Service in the USA, taking at the same time into consideration the climatic conditions from Romania.

Taking into consideration that the employed equation has a general form, there exists the need for an objective quantification of values for each of the factors taken into account according to the specificity of the analysed territory.The database consists of vector primary entities (representing the soil, land use, water divide) and raster entities (the Digital Elevation Model (DEM), the erosion coefficient established on the basis of rain erosivity, correction coefficient for anti-erosion works), as well as derived data (correction coefficient for soil erodibility, crop/vegetation and management factor, correction coefficient for the effect of anti-erosion works, slope length (m) and slope angle (%). Obtaining the database composed of these several coefficients was possible via a series of methodological steps which are described in the lines that follow (Fig. 27).



where,
E- mean annual erosion (t/ha/year)
K- Erosivity coefficient established on the basis of climate erosivity
S- Correction coefficient for soil erodibility
C- Correction coefficient for cover-management factor and vegetation characteristics
Cs- correction coefficient for the effect of

Fig. 27: Stages of model application for determining soil erosion

Having had the entire database converted in a raster format, it was via the Raster Calculator function from Spatial Analyst extension that the value of potential soil erosion was computed for every pixel. Hence the value for the annual soil erosion in the Niraj hydrographic basin lies between 0 and 42.07 t/ha/yr (Fig. 29).

Analysing the entire river basin, counting 658 km2, it can be noticed that the largest area of 56.7% (373 km2) registers low values for mean erosion (between 0,5 and 1,5 t/ha/yr). This corresponds to the mountainous areas with a high degree of forestation, resistance to high erosion and a lower degree of anthropic interference.

Erosion values between 0 and 1.5 t/ha/yr corresponding to 30% (197 km2) of the study area, characterise the basin divide covered by forests. 1.5-3 t/ha/yr over a 65 km2 area correspond to hillsides with higher slope values than 10%, where grasslands are predominant.

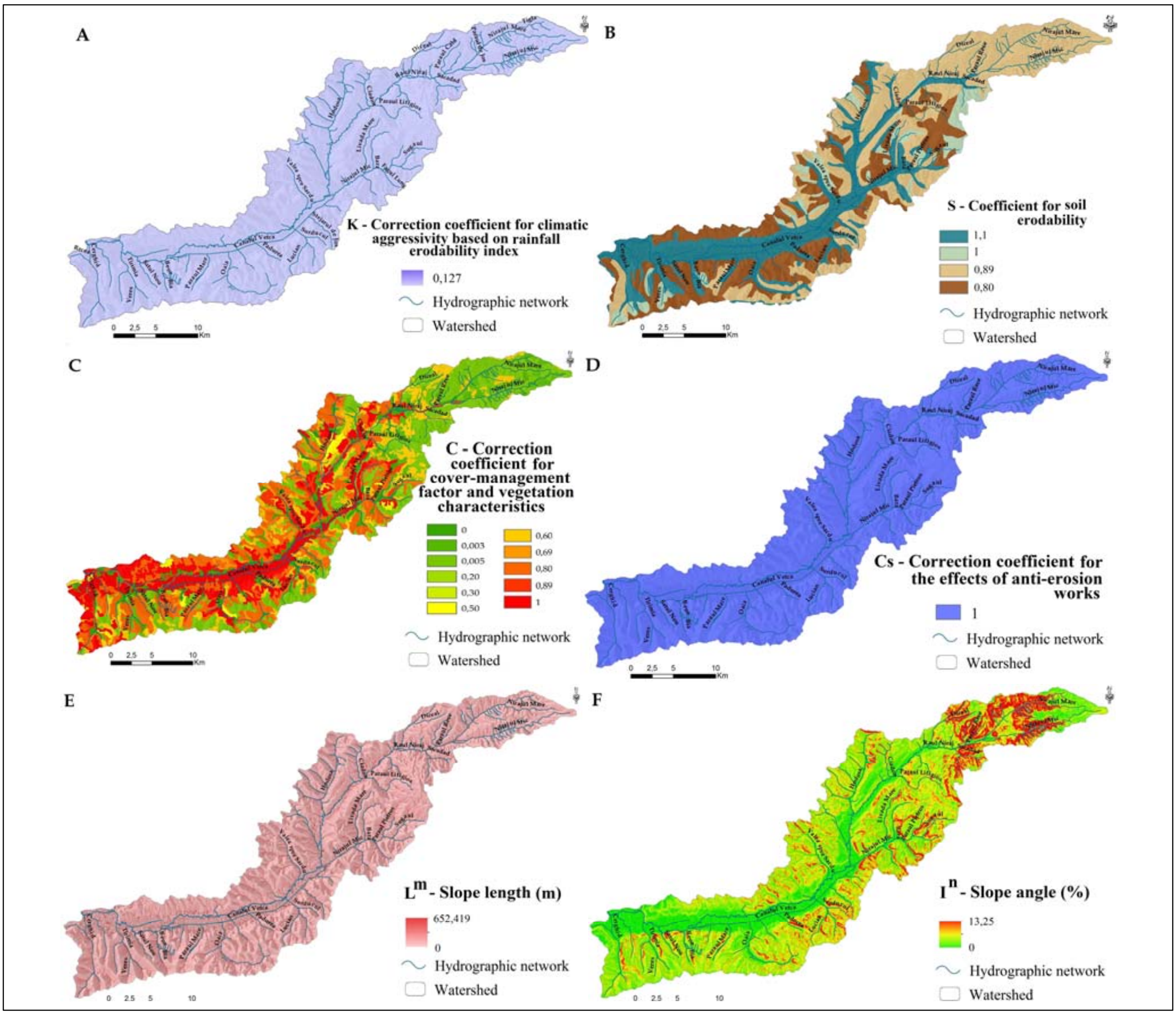


Fig. 28: The cartographic data base used in the modelling process

High erosion values >6 t/ha/yr characterise small areas, namely the higher degree slope areas and the deforested piedmont areas in the settlements' vicinity. The land use categories in these areas generally consist of arable land with no agro-techniques put into practice against soil erosion.

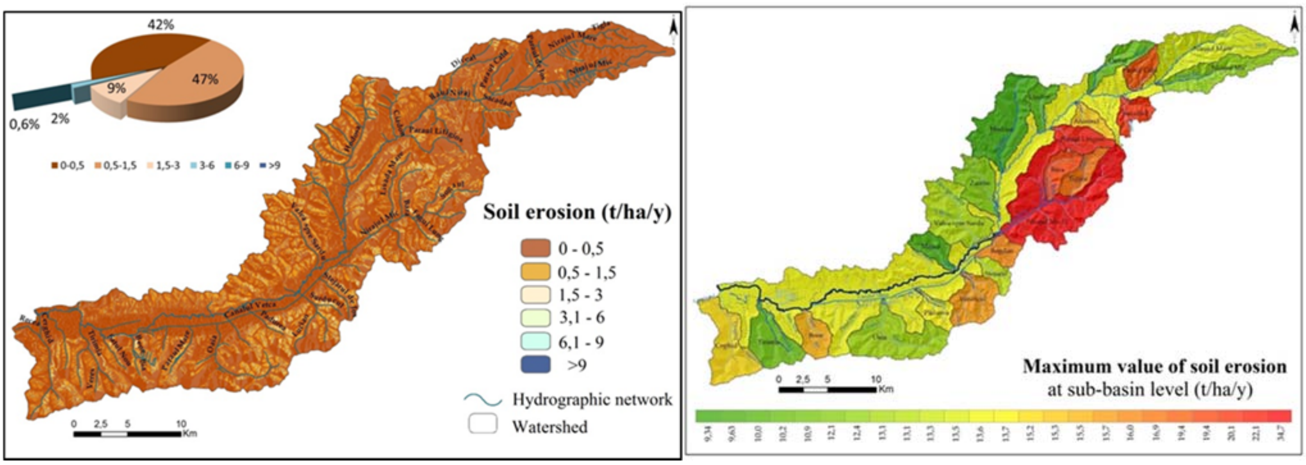


Fig. 29: Mean and maximum soil erosion computed via the RUSLE model

The low values in the areas with a smooth slope are noticeable and specific to the inferior Niraj river basin, a dense populated area with important built-up territory. Our attention will be further focused on the sub-basins' analysis, namely on those sub-basins where soil erosion values are superior to the admissible limits. The admissible limit for the Romanian territory according to Moţoc, M., et al., 1979 lies between 2 and 8 t/ha/yr.

Analysis at the sub-basin level depicts low values for soil erosion (for example on Nirajul Mic and Nirajul Mare sub-basins in the mountainous area) as well as values indicating soil erosion acceleration, for example in the Nirajul Mic II sub-basin, Pârâul Litigios, Săcădad, Pârâul Cald, etc. (Fig. 29B).

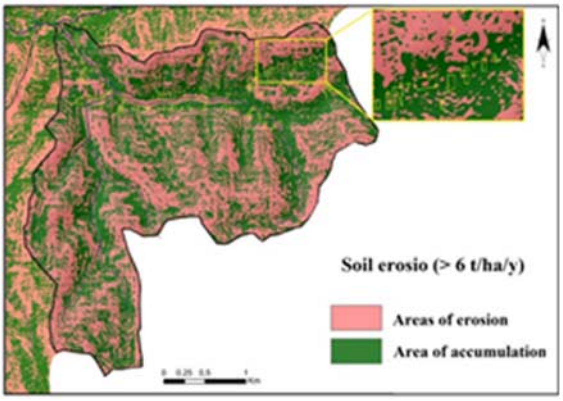


Fig. 30. Erosion and accumulation areas highlighted with the help of profile curvature

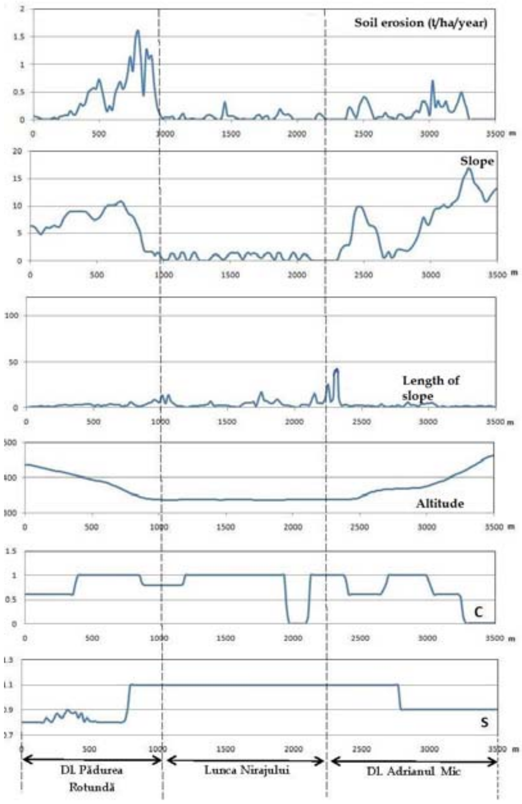


Fig. 31: Complex profile on the Pădurea

At regional level, the influence of hillslope morphographical characteristics is important (convexity, concavity), the microdepressions playing a role in water accumulation and sediment storage, as well as in the complexity displayed within the soil classes. In the example illustrated here (the Săcădad sub-basin), where it had previously been identified an accelerated soil erosion phenomenon, the major role played by the storage areas can be seen. These areas have been identified through the morphometric indicator profile curvature.

Hence the eroded soil from the areas with high erosional potential (mainly located in erosion areas displaying negative values of the profile curvature), once placed the accumulation areas (having positive values of the profile curvature) will remain there depending on the hydrologic and anthropic factor.

In order to test the model a cross profile was selected which makes visible the variation of each factor involved in the process (fig. 31), as well as the way in which the interaction between them determines a certain level of the effective erosion.

6.2.5. LANDSLIDE SUSCEPTIBILITY ASSESSMENT USING THE PRESENT ROMANIAN LEGISLATION (H.G. 447/2003)

The main objective of the present study is to evaluate the landslide susceptibility for an area of 658 km2 according to Romanian Governmental Decision No. 447/2003, by estimating the importance of each class of the eight factors involved: lithology (Ka), geomorphology (Kb), structure (Kc), hydro-climatic factors (Kd), hydrogeology (Ke), seismicity (Kf), forestry/landcower (Kg) and anthropogenic factor (Kh), than using the bivariate statistic methods in a GIS environment we estimate the importance of each class of preparatory factor depending of the characteristic/local conditions.

The cartographic support used in the stage of preparing the digital database for the landslide factors included: the topographic maps 1:25,000, the geology map 1:200,000, the morpho-structural map 1:200,000, the raster grid database representing the spatial distribution of the average precipitation on the studied territory, the hydrogeologic map, the seismic map and CLC Land use from 2006. The digital database represents the input data in the equation for the calculation of landslide susceptibility as established by the Romanian Governmental Decision no. 447/2003. Eight thematic maps were generated and analyzed in order to determine the specific coefficient describing the influence of each preparatory factor on slope instability and calculate the medium hazard coefficient based on formula (Fig. 32).

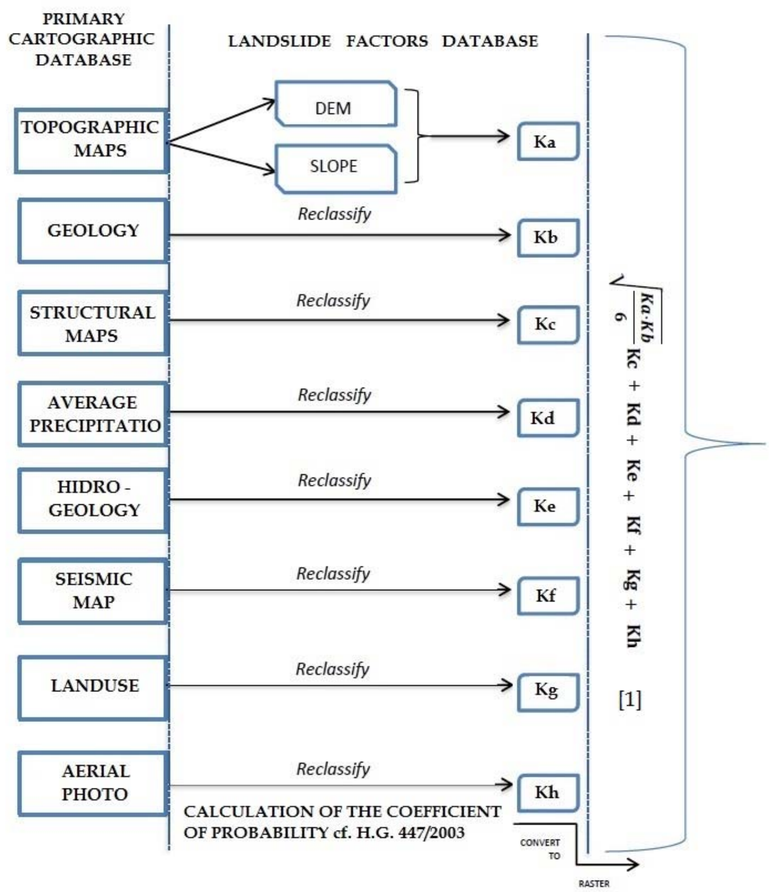


Fig. 32: The methodological chart showing the processes for landslide susceptibility using semi-quantitative methods.

In the case of the H.G. 447/2003, the term hazard is used without considering the temporal element of landslides occurrence or data on the event magnitude, as the literature recommends. The map of average hazard coefficient made according to the H.G. 447/2003 methodology is in fact a map of average susceptibility due to the fact that it reflects the spatial areas susceptible to landslides, and not the temporal element of their occurrence (Fig. 33).

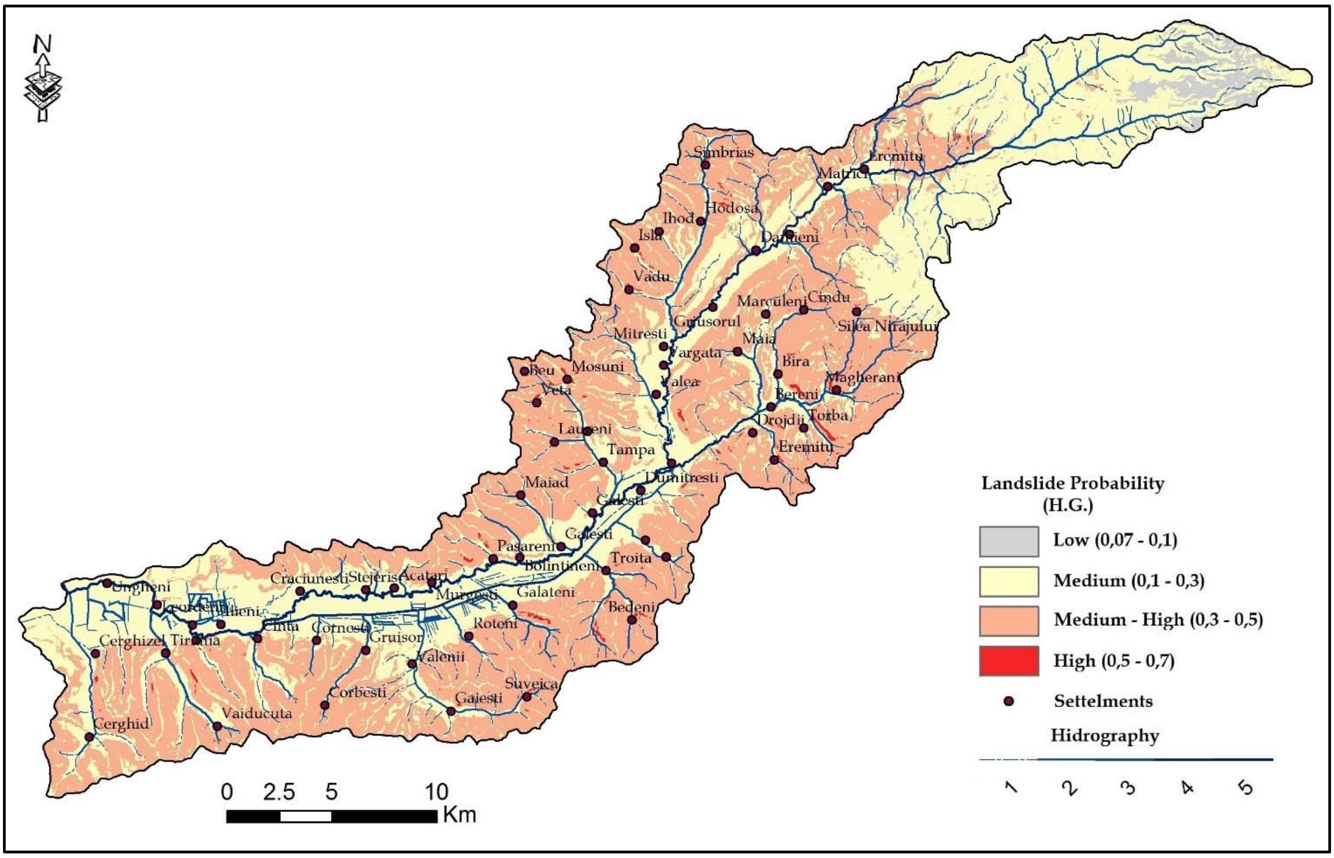


Fig. 33: Landslide susceptibility index map using H.G. model

6.2.5. IDENTIFICATION OF LANDSLIDE OCCURRENCE PROBABILITY THOUGH THE BSA METHOD, USING THE HG COEFFICIENTS OF PROBABILITY

The model based on the BSA was applied to predict the spatial distribution of future landslides by estimating the probability of landslide occurrence starting from the spatial distribution of existing landslides. The variables taken into consideration (Ka,. . .,Kh) were analyzed and then the statistical values of each variable included in the spatial model were calculated based on the bivariate probability equation proposed by Yin and Yan (1988) and Jade and Sarkar (1993).

The model for determining landslide susceptibility relies completely on GIS analysis and raster structures. The database, including among others the slope, the hypsometry and the stream power index

(SPI), was created by derivation from the Digital Elevation Model (DEM), with a resolution of 20 m. The DEM was correctly correlated from a hydrological point of view by removing sink areas and by forcing drainage on water courses (Bilasco 2008). The main objective in preparing the input database in the structure of the model is represented by the need to convert the vector thematic layers (Ka,. . ., Kh) into rasters (Ka0,. . ., Kh 0), at an equal resolution with the DEM, on the basis of the attributes representing the statistical value of the class for a particular probability coefficient.

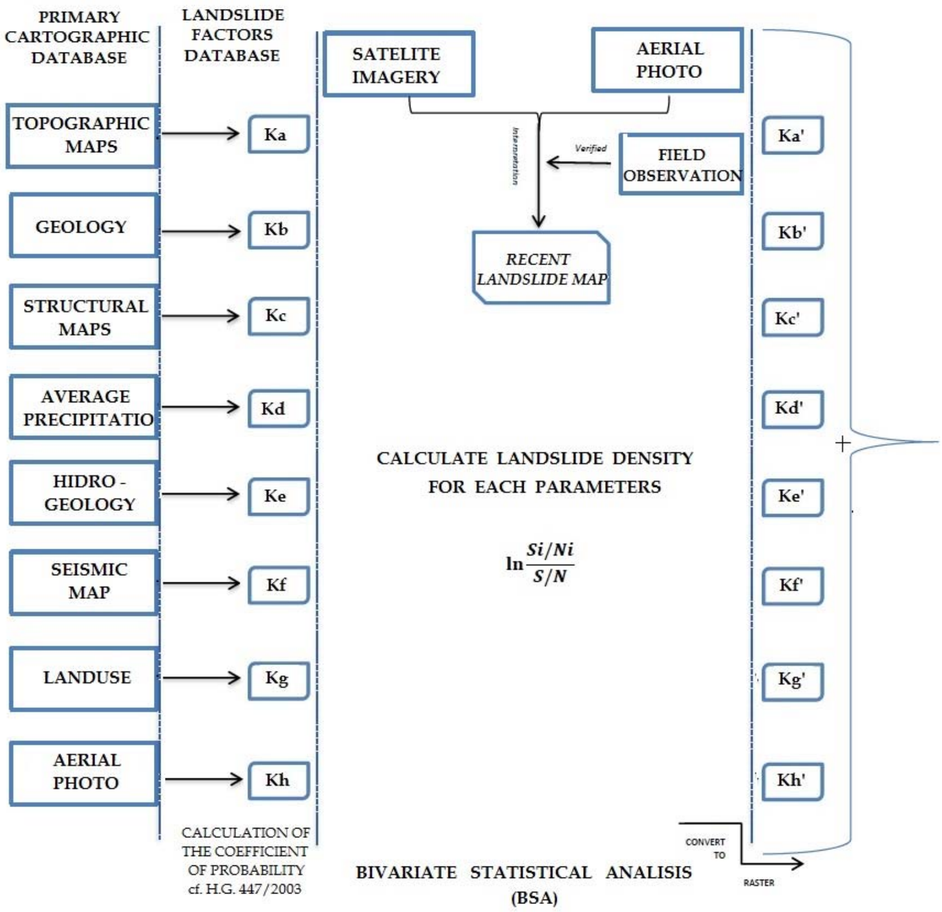


Fig. 34: The methodological chart showing the processes for landslide susceptibility using BSA methods.

Two landslide susceptibility maps (figures 34 A and 34 B) were created by applying the two methodologies described above, using GIS spatial analysis and the functions available in the geoinformatic software Arc Gis. The integration of the derived and modelled databases in the ArcGis software using the corresponding functions for their conversion, analysis and spatial integration enabled the generation of landslide susceptibility maps and their corresponding grid databases. Due to the vast database involved in the spatial analysis which follows the recommendations of the H.G.

According to the specifications included in the Governmental Decision (no. H.G.447/2003) for the Niraj catchment area, we have identified a level of landslide susceptibility varying from low to high, with the lowest value of the medium susceptibility coefficient being 0.078 and the highest value being 0.677, with a mean of 0.280 and a value of standard deviation of 0.10, determined by the heterogeneity of the coefficients involved in the modelling process.

From the total surface of 658 km2, only 2.8% (13.59 km2) display low landslide susceptibility, whereas the largest surface of 319.5 km2 (48.3%) is characterized by medium probability; an average to high probability was determined for a surface of 314.8 km2 (49.1%) and the remaining surface (2.82%) displays a high susceptibility to landslides. The areas with a low probability of landslide occurrence are characterized by factors which ensure the stability of slopes (forest areas, volcanic lithology and low slope angle values).

Tabele 9: Computed statistical values for the GIS model variables.

Crt.	Characteristic interval	Kn	Statistical Value
Ka Lithology	Andesitic	0,20	0
	Volcanogenic-sedimentary conglomerates	0,25	0
	Coluvial and Deluvial deposits of Holocene	0,50	- 0,33
	Sands, Gravels, Clays of Pleistocene	0,60	0
	Gravels, Sands, and `leosoil	0,65	- 0,203
	Marls, Clays, Sands, Gravels, Tuffs of Pliocene	0,70	0
	Gravels, Sands, Clays and sandy Marls	0,85	- 0,159
Kb Geomorphologic	Altitude < 400 m, Slope < 5°	0,1	- 0,558
	Altitude 400-1000m, Slope 5- 10°	0,3	- 0,049
	Altitude 400 - 1000m, Slope 10-20°	0,5	1,120
	Altitude > 1000 m, Slope 20-30°	0,8	- 0,291
	Altitude > 1000 m, Slope > 30°	0,9	0
Kc Structural	Mountains	0,05	0,139
	Area of Diapir Structures	0,35	0,208
	Area of Gas Domes	0,6	- 0,191
Kd hydro-climatic	PP 400-600, SPI -13,8…-4,89	0,05	- 0.021
	PP 600-700, SPI -4,89…1,76	0,5	0,043
	PP 700-800, SPI 1,76…12,32	0,7	- 0,552
Ke Hydro-geological	The level of groundwater in depth >5 m	0,05	0,217
	The level of groundwater up to 5 m	0,4	0,008
Kf Seismic	6° MSK	0,7	-0,080
	7° MSK	0,75	0,492
Kg Land cover	Mixed forest	0,1	- 0,809
	Orchards and vineyards	0,5	0,362
	Agricultural areas	0,85	0,055
	Land occupied by non-irrigated agriculture	0,9	0,190
	Pastures and transitional woodland-shrubs	0,95	0,388
Kh Anthropic	Lack of constructions	0,1	0,151
	The proximity of infrastructure	0,9	-0,503

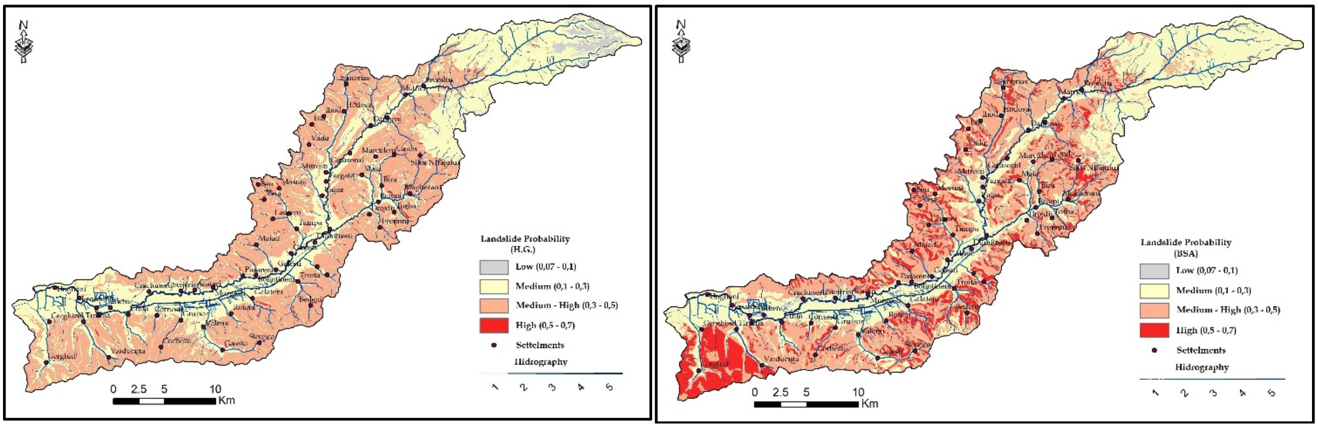


Fig. 35: Landslide susceptibility index map using H.G. model (35 A) and using B.S.A. model (35 B).

From the total surface of 658 km2, only 2.8% (13.59 km2) display low landslide susceptibility, whereas the largest surface of 319.5 km2 (48.3%) is characterized by medium probability; an average to high probability was determined for a surface of 314.8 km2 (49.1%) and the remaining surface (2.82%) displays a high susceptibility to landslides. The areas with a low probability of landslide occurrence are characterized by factors which ensure the stability of slopes (forest areas, volcanic lithology and low slope angle values). The values of low probability characterize the major riverbed of the Niraj River and its main tributaries despite the high slopes from the mountain area and its specific geological structure. Medium and medium to high values characterize the majority of the hilly terrain with geology dominated by clay, marls, colluviums deposits on average slopes and predominantly agricultural land use. High susceptibility values characterize the median and inferior basin, extended to the Tarnava Hills which are characterized by medium geodeclivity, a predominant non-irrigated arable land use, pastures and crops area.

For exemplification, we have drafted a complex profile at the level of the sub-basin Padurea (Fig. 36), with a minimal value of the mean hazard coefficient of 0.11 (average probability), which characterizes the main riverbed of the Padurea River, and a maximal value of 0.57, corresponding to a high susceptibility of landslide occurrence (Kb D 0.8) for the western slope of the Dealul Mare (Fig. 37).

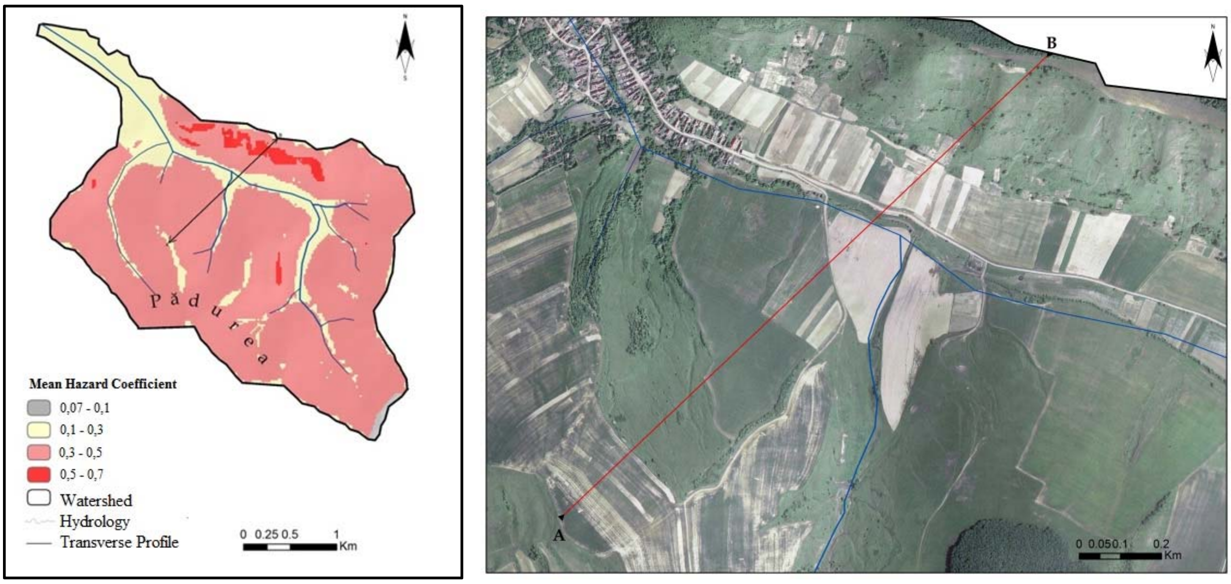


Fig. 36: The mean hazard coefficient at the level of the Padurea sub-basin.

The average multiannual rainfall of 600-700 mm/year and the predominantly agricultural land use (non-irrigated agricultural land, orchards and some narrow surfaces with vineyards; Kn = 0.7), together with poor land management are the cause for the land developing an increased geomorphologic potential (Kf =0.7). The value of the mean hazard coefficient at the level of the entire catchment area, (0.35), includes the sector analyzed in the class of medium-high susceptibility to landslide occurrence.

The comparative analysis at the level of the final results (fig. 37.a) emphasizes the fact that in the majority of cases there is a correlation between the estimative curve of the probability values calculated by means of the two methods. The major differences occur in the cases in which the uncertainty and the degree of generalization rendered by the Governmental Decision model are major. Thus, it is possible to identify territorial surfaces pertaining to Dealul Mare in which the methodology of the Governmental Decision assigns a large proportion of the surfaces from the crosssection into the category of medium-high probability, which is due to geo-morphological and hydro-climatic factors (Kd, Kb), thus minimizing the influence of the forest cover factor (Kg). It also includes the anthropic factor (Kh inexistent) in the same category, making it null and void, together with the Kc (structural factor), the Ka (lithology) with values included in the very high probability class, and the seismic factor (Kf).

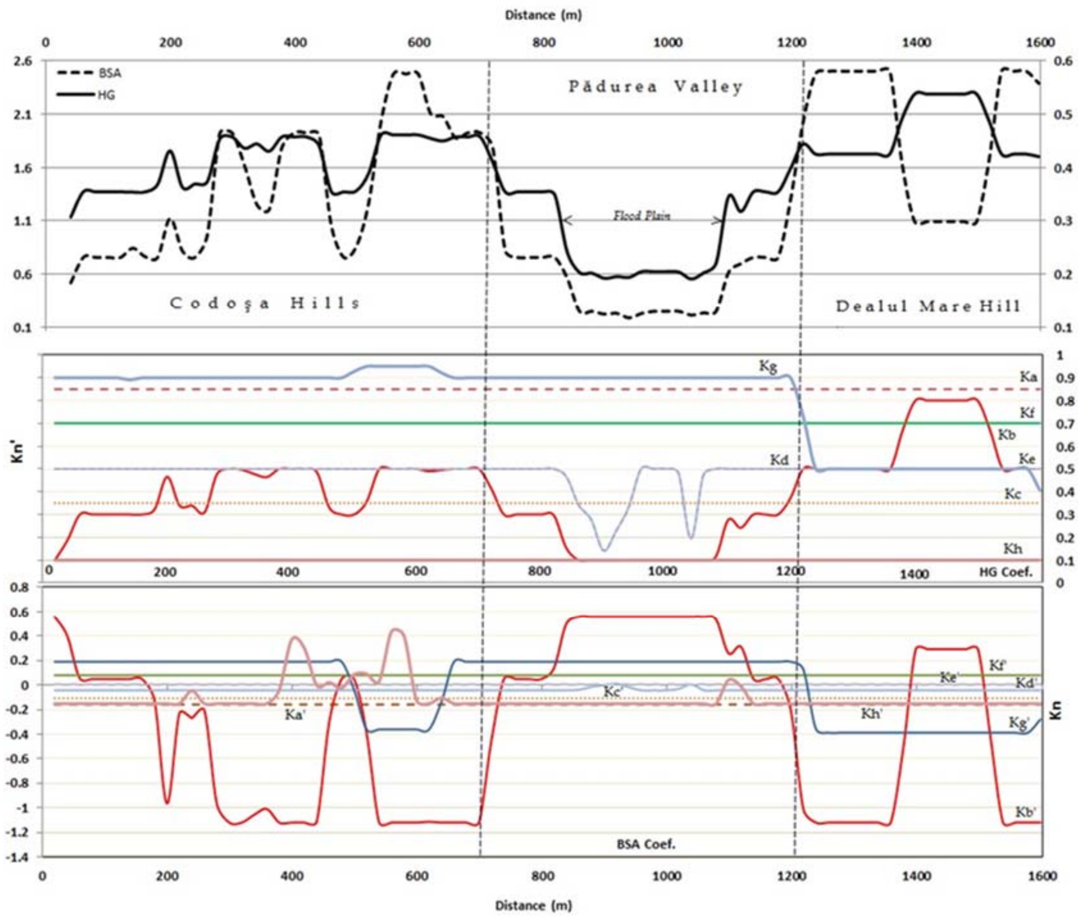


Fig. 37: A complex profile of the Padurea sub-basin.

The same correspondence is visible from the point of view of the probability coefficient value determined by the BSA methodology on the cross-section. However, it fits into the very high probability class, the influence of the susceptibility coefficients being different in the final result owing to the lack of identification of landslides on certain surfaces. Thus, the geomorphologic coefficient (Kb0) that assigns high instability to slopes is not a major influence factor in this case, as no high or very high landslide occurrence was identified at the level of the entire hydrographic basin on the elevation and slope variation, as captured by the profile line. At the opposite end, the highest influence belongs to the Kf0 (seismic coefficient), as a consequence of a high landslide occurrence on the territorial surfaces characterized by a high seismic risk, in the inferior Niraj catchment area.

The comparison of the two models emphasizes discrepancies between the lines of the variation graphs for the values of susceptibility to landslides. In the above-mentioned study case, we have identified four areas of major discrepancy resulting mainly from the geomorphologic factor represented by declivity and elevation.

A nearly perfect correspondence is to be noticed in the valley sector for the analysis of the two models. As for the analysis of the susceptibility coefficients, we may notice a total discrepancy and a random influence of the coefficients in the final results. The analysis of the geomorphologic coefficient

(Kb) obtained by using the model of the Governmental Decision includes its values in the very low class due to low elevation and declivity values characterizing meadow areas, while the analysis of the same coefficient in the BSA model assigns the same territories in the high and very high probability class because of the occurrence of landslides in areas with similar characteristics.

6.2.6. APPLIED STATISTICAL MODEL (BSA) IN IDENTIFYING THE LARGE-SCALE PROBABILITY OF LANDSLIDE OCCURRENCE (THE SMALL NIRAJ SUB-BASIN)

The quantitative assessment of the probability of landslide occurrence which was applied in the previous chapter offered better results than the semi-quantitative assessment. Therefore we selected as a study case the hydrographical sub-basin with the highest landslide density, the Small Niraj, in order to apply the statistical model BSA using the morphometrical factors most often encountered in specialised studies: elevation, slope angle, precipitation amount, slope aspect, drainage density and depth, hydrological soil classes, distance to settlements, roads and streams, land use, lithology, profile and plan curvature, Compound Topographical Index (CTI). Our purpose is to identify the landslide susceptibility (Fig. 38) based on the landslide potential from the Small Niraj river basin transposed in a complete inventory of landslides and based on a more detailed database available for the land use of the studied area, which was created using ortophotoplans with a 0.5 m resolution.

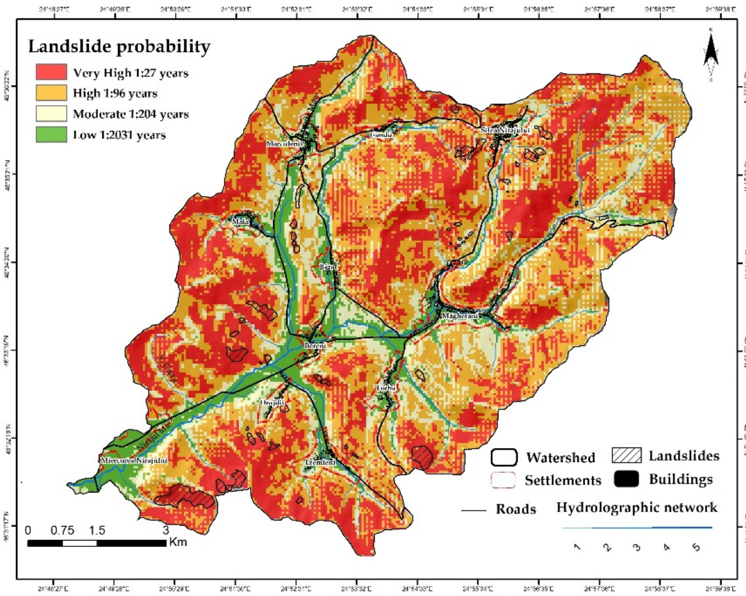
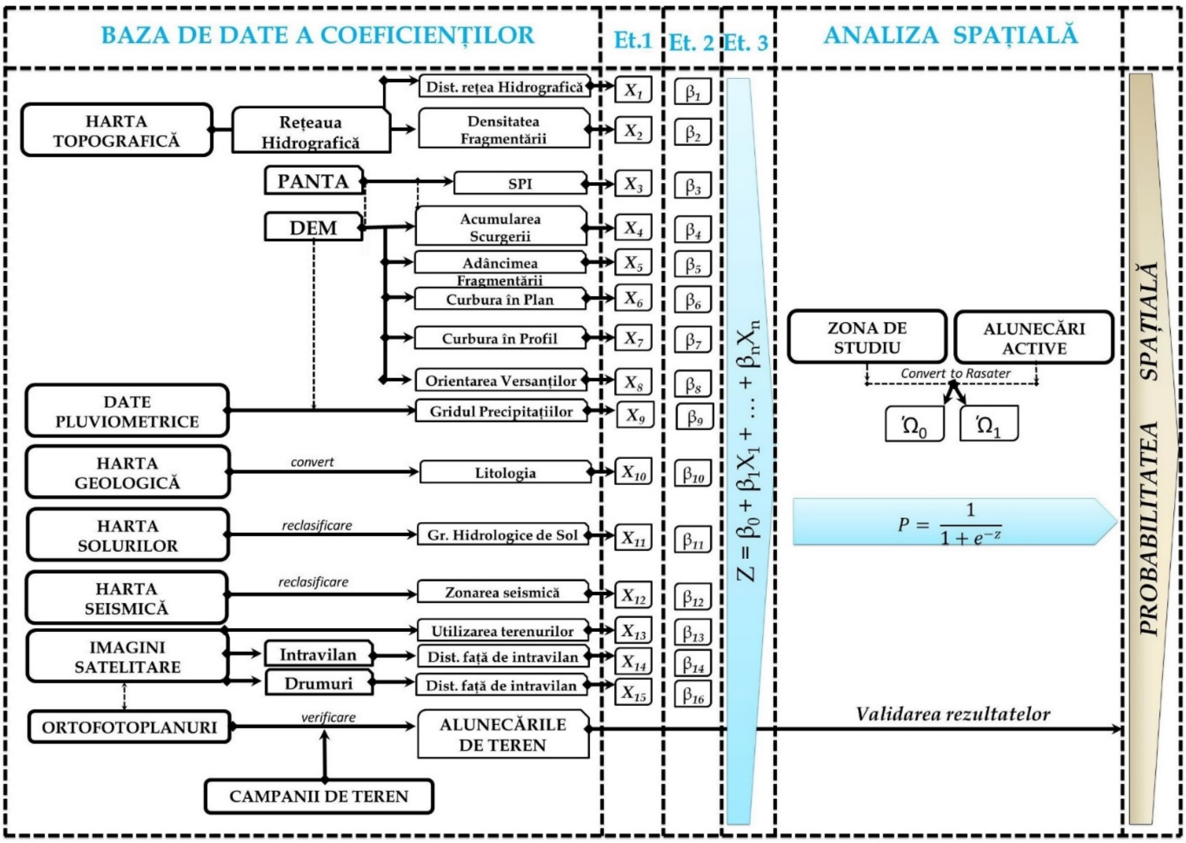


Fig. 38: Landslide susceptibility map (generated with the BSA model)

6.2.7. APPLIED LOGISTIC REGRESSION IN IDENTIFYING THE LARGE-SCALE PROBABILITY OF LANDSLIDE OCCURRENCE (THE SMALL NIRAJ SUB-BASIN)

In the case of the logistic model a series of work stages were followed (Fig. 39) among which we mention the most important. Keeping all the classes of the 16 factors included in the model and the resulting 73 dummy variables leads to an overestimation of the high and very high susceptibility class (for 32.7% and 32.5% of the territory, respectively). However, the spatial expansion of these classes is decreased to 15.2% and 10.9% for the high and very high susceptibility class, respectively, as a consequence of applying the logistic model and, thus, eliminating those classes without a statistical significance.



Et 1 - obținerea variabilelor dummies, Et. 2 - identificarea coeficienților de multiplicare, Et.3 -cuantificarea coef Z

Fig. 39: Methodological flow chart

In order to determine the predictability of the logistic model one has used the AUROC value for the territory used in the validation of the model.

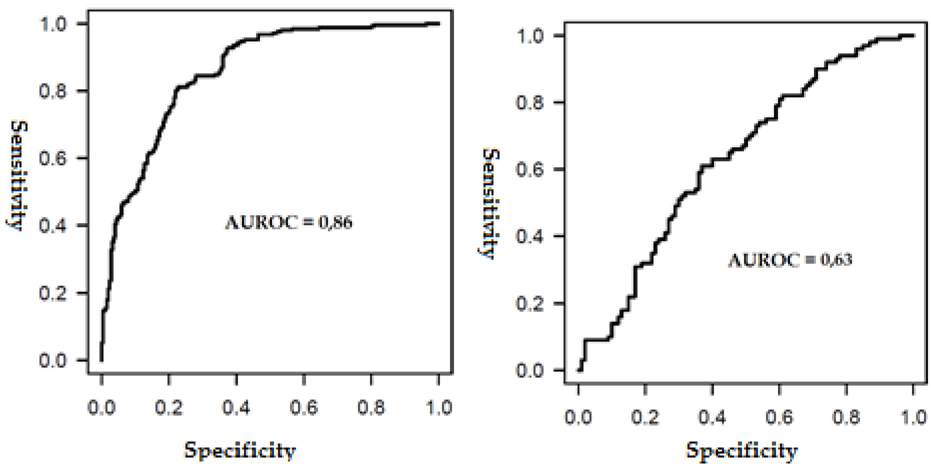


Fig. 40: AUROC of the model data (left) and validation data (right)

The value under the ROC (Relative Operational Curve) is 0.86 for the training set of landslide data and 0.63 for the validation set indicating a good accuracy and predictability of the model.

6.3. PREDICTION OF RIVERBED MIGRATION

The prediction of riverbed migrations was performed from two perspectives: a qualitative approach which determined the resistance to erosion based on geological resistance and vegetation protection (Fig. 41), offering an overview on the potential river erosion, and a quantitative approach incorporating geographical, geomorphological and hydrological aspects.

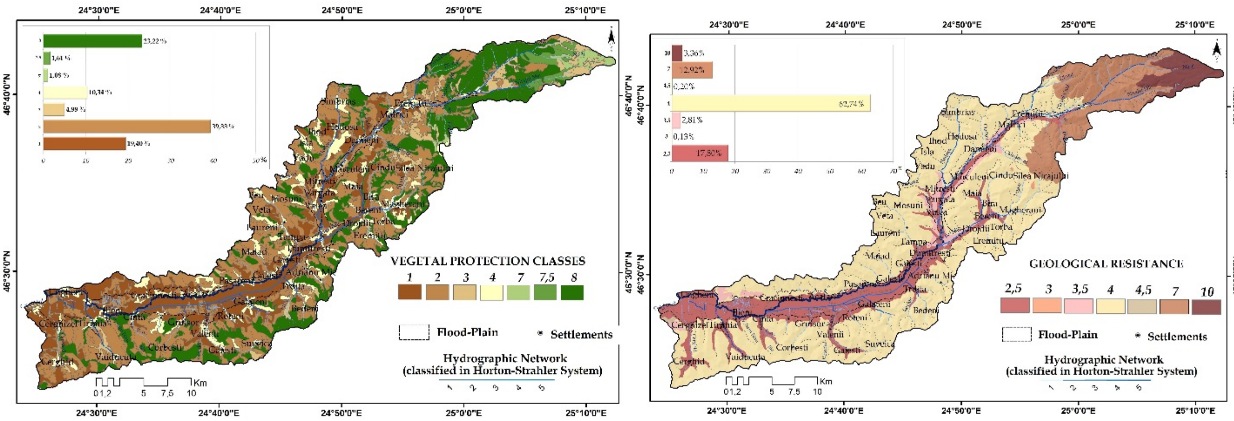


Fig. 41: Map of the coefficients of geological resistance and of the values of vegetation protection in the Niraj river basin

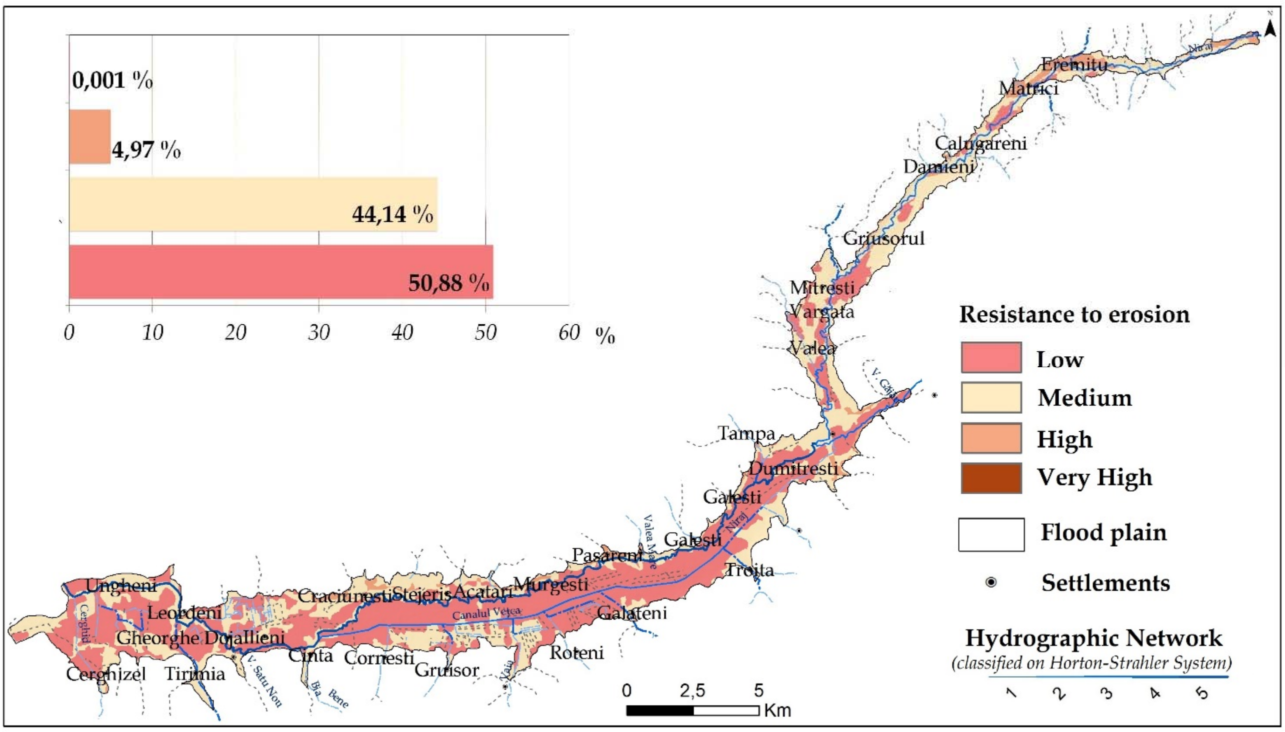
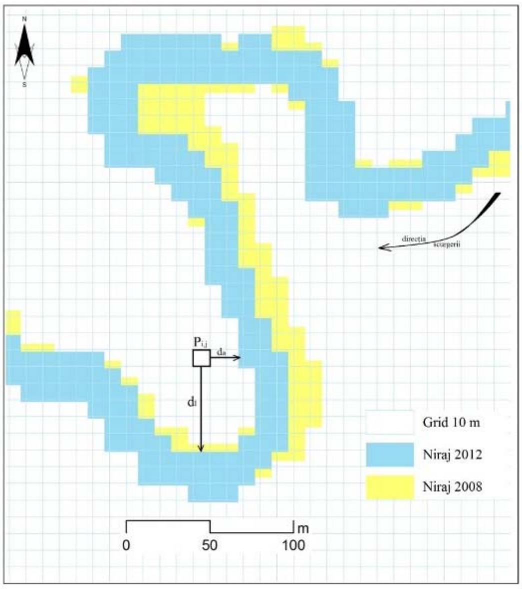


Fig. 42: Map of the resistance to erosion depending on lithology and flood plain vegetation

The quantitative approach includes the identification of the recurrence intervals for bankfull discharge, requiring a long process of data acquisition, therefore the present study includes only a punctual application.



The probability of a cell (characterised by i, j coordinates) being affected by erosion (Fig. 43) for a certain time period is determined as it follows:

$P_{i,j} = f(d_i, d_u)$, (1) where

$P_{i,j}$ = Erosion probability ($0 \leq P_{i,j} \leq 1$)

d_i = lateral distance from the closest cell of the minor riverbed

d_u = distance upstream from the closest cell of the minor riverbed

r = recurrence interval of the bankfull discharge

t = year

n = number of years of the analysed period

Fig. 43: Flow chart of statistical calculation

The main disadvantage of the applied method resides in the dependence of the final result on the quality and the spatial and temporal resolution of the input data (resolution of rasters, frequency and accuracy of cartographic and hydrological data) as well as the long process of data acquisition and processing, this model being not recommended for braided rivers (Graf, W.L., 1984).

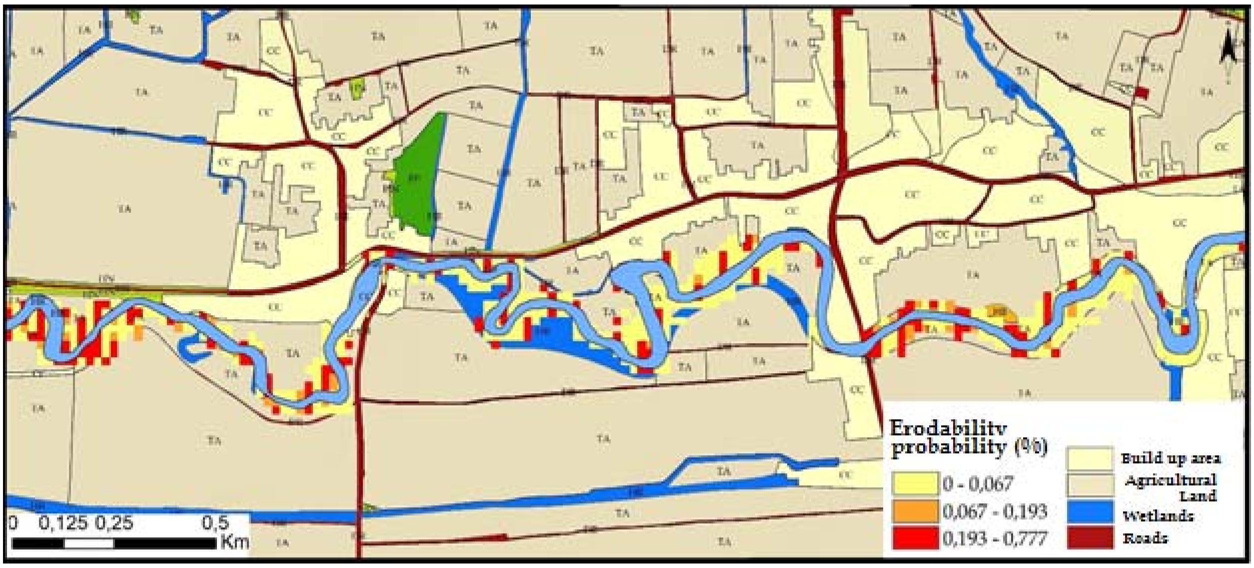


Fig. 44: Erosion probability in the test sector using the 2008-2012 time interval

The results follow several time-consuming methodological stages which require a correlation with local morphometrical data and precise hydrological data in order to increase their local validation rate. In the absence of such data, the model of channel migration was applied in order to identify the areas prone to lateral river meandering, a model which is recommended for the regional studies which determine such "hotspots".

7. THE MULTI-HAZARD APPROACH AND ITS ROLE IN SPATIAL PLANNING

Applied geomorphological studies follow the main objectives of spatial planning: the rational and efficient use of the territory for the sustainable use of resources, of natural and cultural landscapes as well as the protection of settlements against natural disasters. Hence, an important role is played by hazard and risk mapping for the prevention of their negative effects and in order to identify natural risks.

In order to identify the probability of flood occurrence and to assess the elements exposed to risk, having as final product the flood risk map, a series of work stages were needed.

7.1. FLOOD HAZARD AND RISK

The quantification of flood vulnerability and risk is necessary for a better management of priorities in emergency situations. The flood risk zonation is made in applied hydrology through floodable stripes, which are produced using statistical analysis of past data series and their integration in determinist spatial analysis models. The emphasis lies on the spatial and temporal identification of the areas exposed to flooding events, therefore a hazard analysis will be undertaken in the present study according to the existing methodologies for the drawing of Flood Risk Maps and Flood Hazard Maps. These methodologies are included in the legislation, namely the H.G 47/2003 (Governmental Decision 47/2003) and its significant additions on the 5th of September 2013 (Fig. 45).

For the floodplain area identification, spatial analysis via the GIS technology has been employed. The Digital Terrain Model was built via the TopoToRaster interpolation method, on the basis of the existing contour lines, as well as on the maximum altitudes introduced as point type data and the hydrological network identified from topographical maps and recent satellite images. Hence the resulting DEM becomes correct form a hydrological point of view, the flow being directed towards the river bed The identification of the corresponding stages for the maximum flash flood discharges of 1% and 5% probabilities was followed by their transposition on the transversal profiles, measured on the banks of the Niraj River in 42 points chosen according to the existing morphological changes.

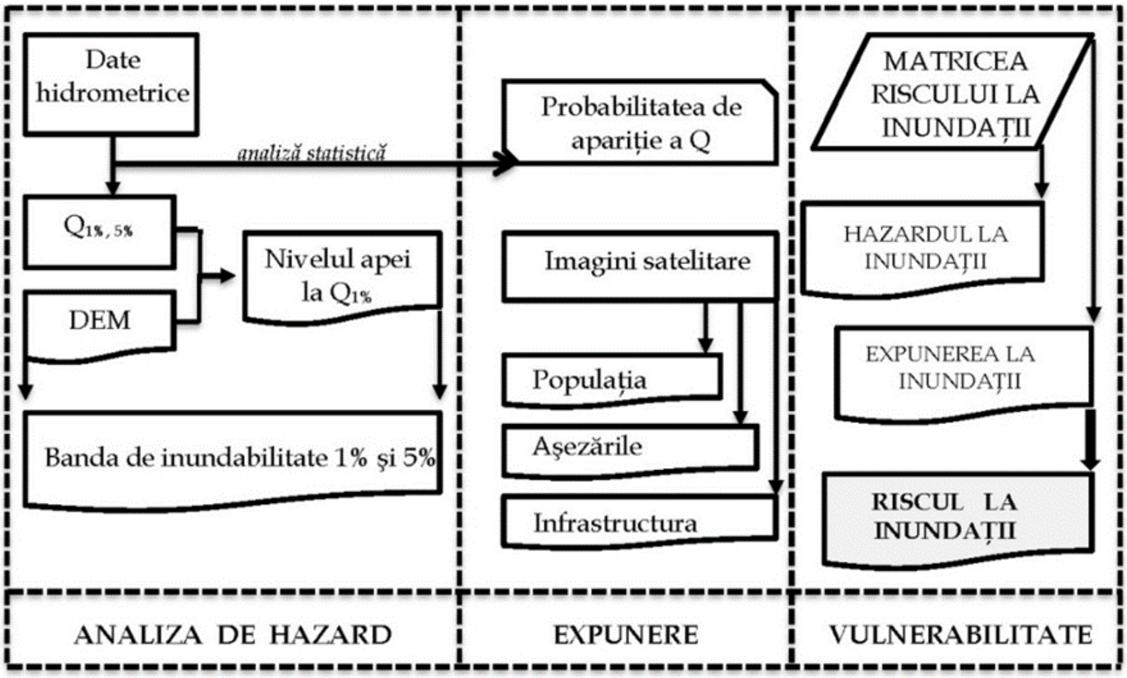


Fig. 45: The methodological chart (Roşca et all., 2014)

On the basis of the historical data registered at the two hydrometric posts (Cinta and Găleşti), the corresponding water stages were identified, taking into account the riverbed morphology (the slopes of the transversal profile and that of the longitudinal profile) (Fig. 46).

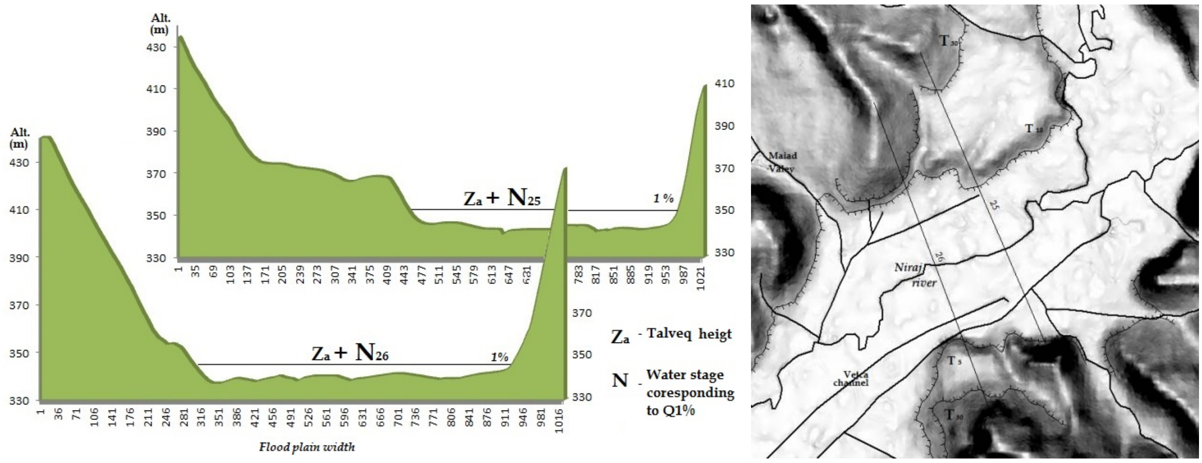


Fig. 46: DEM sections used for obtaining the flood stripes

Tabelul 10: Classes of risk exposure

Exposure class	Description of exposed elements
E_0	- pastures; meadows; forested areas; - marshes; shrub areas (generally deforested ones).
E_1	- vineyards; orchards; complex culture areas; - non-irrigated arable land; agricultural terrain in combination with natural vegetation.
E_2	- discontinuous rural and urban space.
E_3	- roads; airports; homogenous urban space; - industrial and commercial units.

The classification of risk exposure starting from the land use and the different probabilities of extreme phenomena occurrence and their return periods (T) has allowed the generation of a flooding evaluation matrix that was used to identify the different risk levels (Tabelul 10) (Willems şi colab., 2003). Having applied the presented methodology, the corresponding floodplain areas for 1% and 5% have been identified and will be subsequently used in our study (Fig. 47).

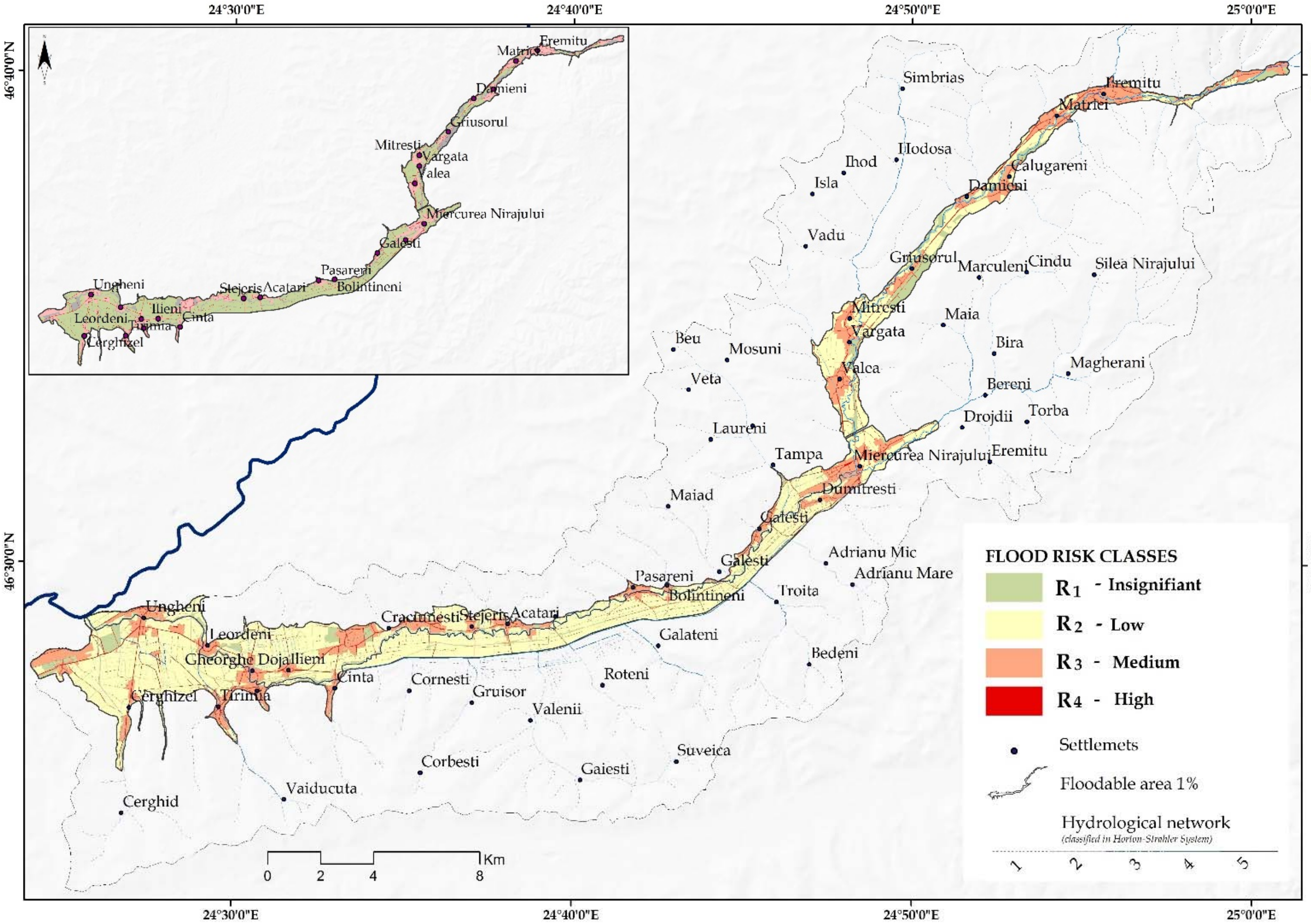


Fig. 47: The Flood Risk Map

Upstream from the Vărgata settlement, the 1% floodplain area is approximately symmetrical, the sectors Vărgata-Miercurea Nirajului, Crăciuneşti-Leordeni having a strong asymmetry on the right side, while the Miercurea Nirajului-Crăciuneşti sector is characterised by a left side asymmetry. These cases of asymmetry are due to the floodplain morphology and to river sectors that have a high lateral mobility, dependent on the resistance to erosion

7.2. LANDSLIDE HAZARD AND RISK

The landslide hazard analysis was performed using GIS techniques relying on raster grids which use pixels as unit areas for integrating spatial data. This analysis highlights the relationship between landslide susceptibility, the prediction curve and the recurrence interval of the precipitation amount considered to act as landslide trigger. Thus, the methodology includes the spatial probability (susceptibility), the temporal probability (hazard) and the magnitude of events (Aleotti and Chowdhury 1999), by following a series of work stages (fig. 78).

Present methods of deep landslide hazard assessment require the identification of the relationships which connect monthly and annual cumulative precipitation and the landslide triggering moment (Zezere et al. 2004b). In this study, the precipitation data were represented by cumulated daily precipitation for 90 days due to the fact that this is a representative interval in the study area, accounting for the seasonal cyclicity of landslide events.

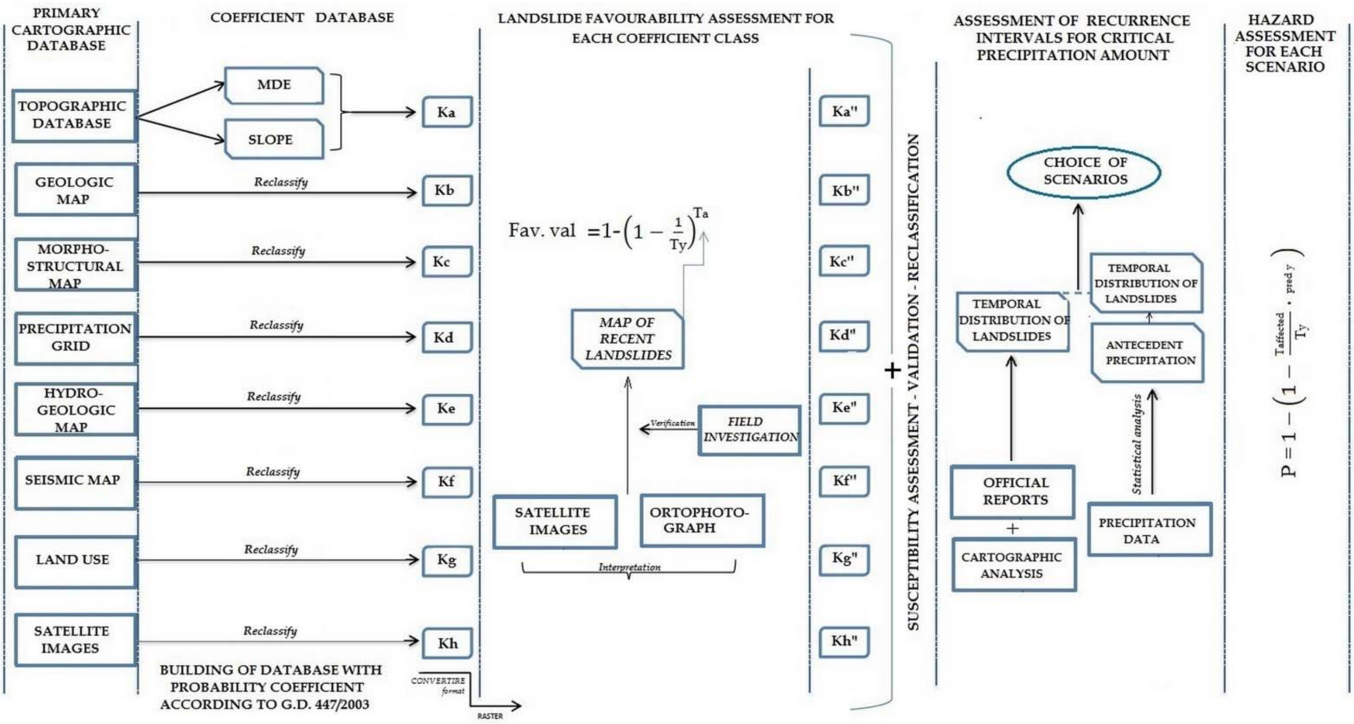


Fig. 78: Flow chart of landslide hazard analysis

By analysing the recorded precipitation amounts in relationship to the number of previous months with cumulative precipitation above the average of the time interval, the landslide events from autumn and winter (including their dry months) were explained. As a result, a high frequency of landslide events was identified on the ascending curve describing the months with precipitation amounts above the annual average while the probability of landslide occurrence has a proportional relationship with the number of consecutive months in which the precipitation amount is higher than the annual average (Fig. 79.A, B, C, D, F).

Table 11: Variation of the pluvial regime in the interval 2005–2012

K lunar	WINTER			SPRING			SUMMER			AUTUMN		
	XII	I	II	III	IV	V	VI	VII	VIII	IX	X	XI
2005						◆	◆		◆			
2006			◆		◆							
2007							◆					
2008						◆	◆					
2009							◆					
2010						◆	◆					
2011								◆				
2012		◆					◆			◆		

Pluvial regime		Very dry		Dry		Normal		Rainy		Very rainy
◆	Active Landslide									

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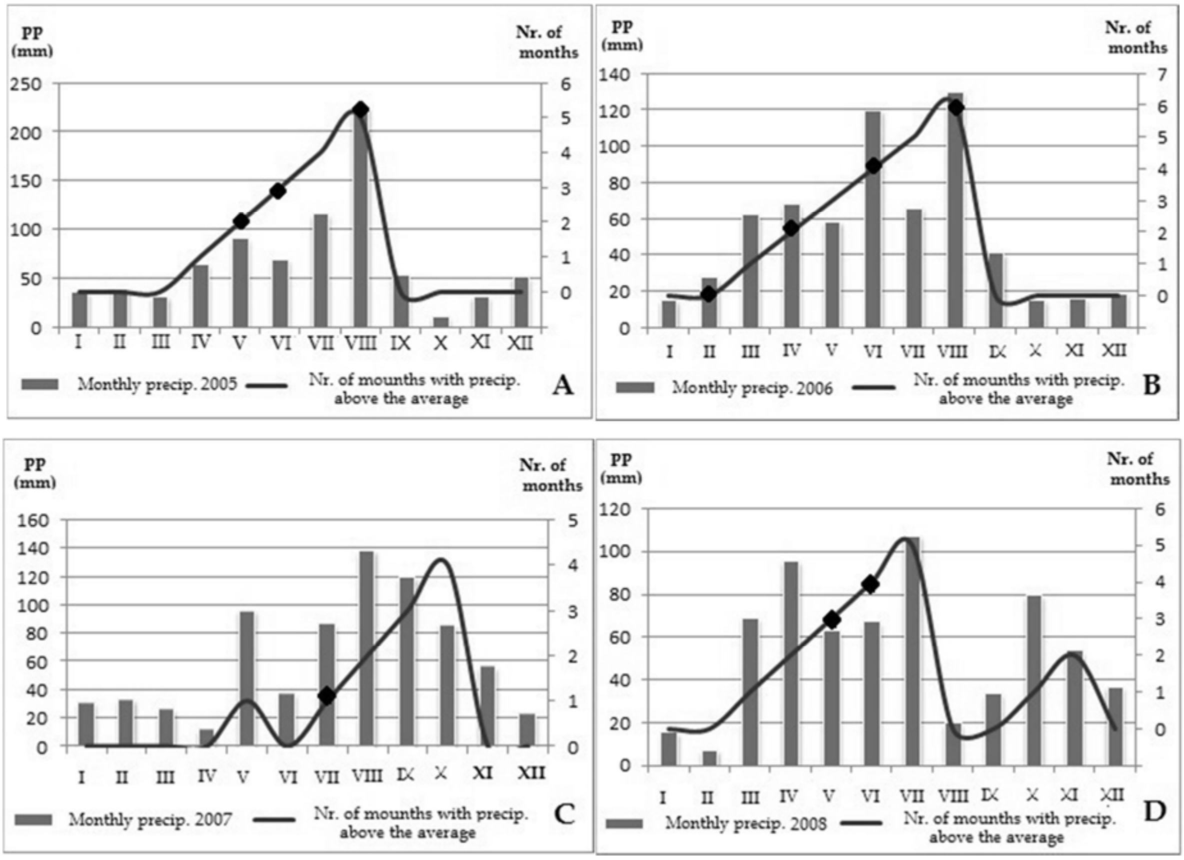


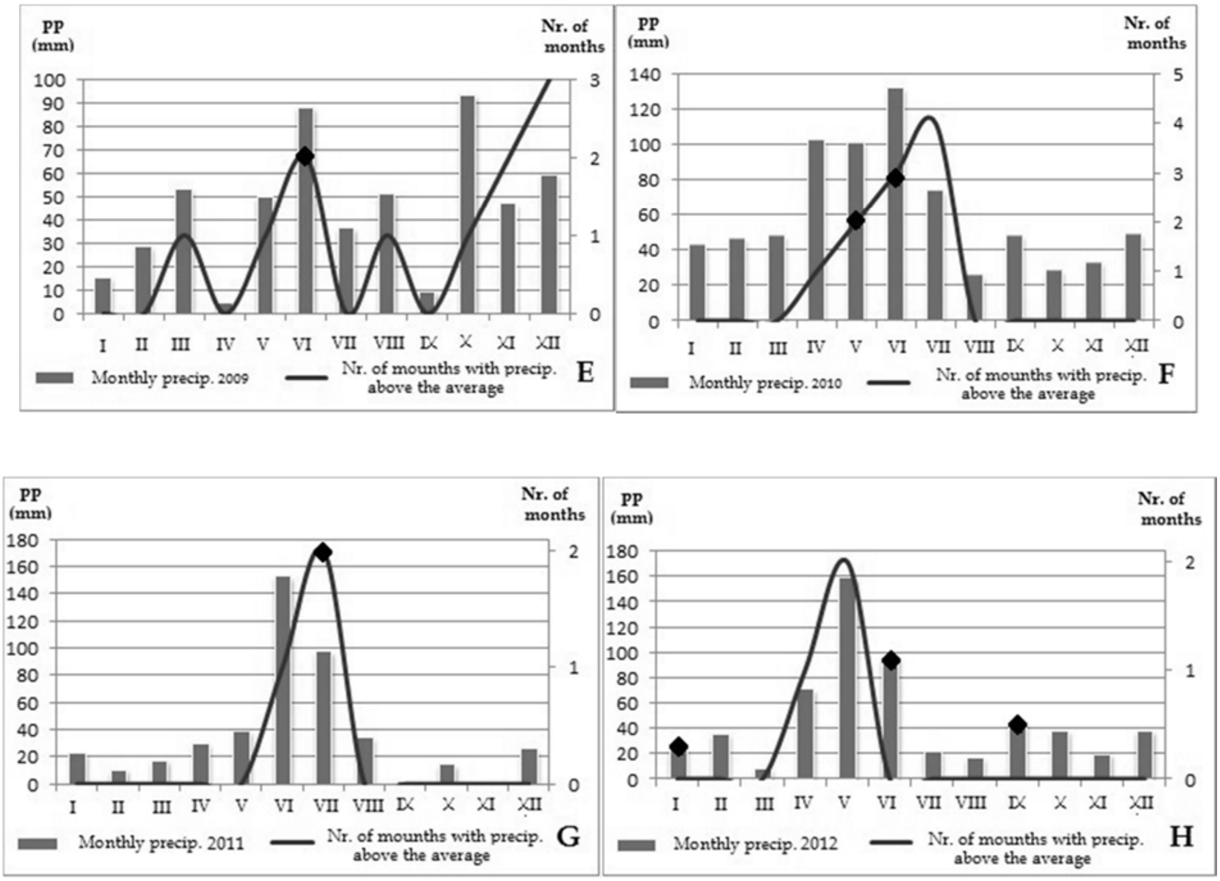


Fig. 79: Variation of monthly precipitation amount and variation of the number of months with precipitation amount above the annual average in 2005 (A), 2006 (B), 2007 (C), 2008 (D), 2009 (E), 2010 (F), 2011 (G) and 2012 (H) (where ◆ represents a landslide event)

Situations in which landslides occurred in months with precipitation values close to or below average were also present, however, when analysing the previous months, the cumulative precipitation amount was above the average, explaining the landslide events.

A database including eight coefficients, which describe both landslide preparatory and triggering factors (table 12), was designed to generate the landslide susceptibility map. For each coefficient class, the favourability value was determined by applying the following formula [1] :

$$Favourability\ value = 1 - \left(1 - \frac{1}{T_y}\right)^{T_a} \quad [1]$$

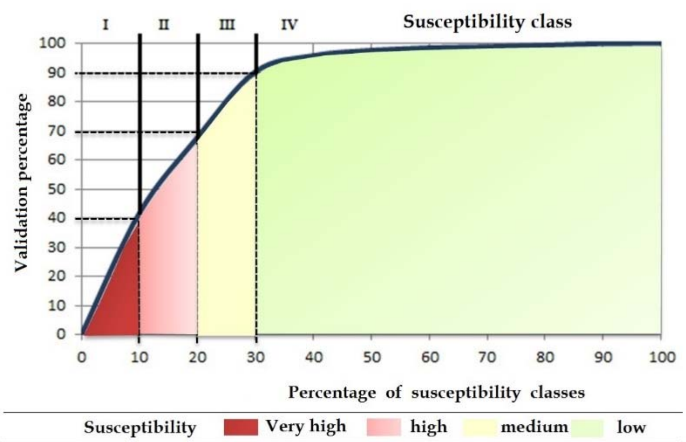
where T_y – number of pixels in each class

T_a – number of landslide pixels in each class (Zêzere et al. 2004a).

Table 12: : Probability coefficient classes and landslide favourability values

Criteria	Coefficient classes	Number of pixels / class	Number of landslide pixels within the class	Favourability value
Ka Lithologic	Andesites with pyroxenes and amphiboles	35762	0	0
	Volcanogenic sedimentary deposits	137528	0	0
	Colluvial and colluvial-proluvial deposits	190939	221	0.001157
	Middle Pleistocene gravel, sand, scree	6849	0	0
	Upper Pleistocene gravel, sand and loess deposits	23208	205	0.008794
	Marly clays, sand with Sarmatian tuff intercalations	2162	0	0
	Gravel, sand, clay and sandy marl	657541	15408	0.02316
Kb Geomorphologic	Elevation < 400 m, Slope angle < 5°	385110	1819	0.004712
	Elevation 400 -1000m, Slope angle 5 - 10°	470586	7211	0.015207
	Elevation 400 - 1000m, Slope angle 10-20°	316744	6463	0.020198
	Elevation > 1000 m, Slope angle 20-30°	38795	341	0.008751
	Elevation > 1000 m, Slope angle > 30°	629	0	0
Kc Structural	Mountain area	213467	1857	0.008662
	Diapir structure area	611202	11732	0.019012
	Gas dome area	231204	2225	0.009577
Kd Hydro-climatic	Precip. 400-600 mm, SPI -13,8…-4,89	23788	311	0.012989
	Precip. 600-700 mm, SPI -4,89…1,76	898940	14988	0.016535
	Precipitation 700-800 mm, SPI 1,76…12,32	129553	532	0.004098
Ke Hydrogeologic	Deep phreatic level	29477	77	0.002609
	Phreatic level down to 5 m	1024592	15737	0.015242
Kf Seismic	6° MSK	975983	12182	0.012404
	7° MSK	78099	3632	0.045441
Kg Sylvic	Forested areas	330979	759	0.002291
	Orchards, vineyards	50685	1880	0.036413
	Agricultural areas with complex cultivation	285305	4869	0.016921
	Non-irrigated arable lands	203560	1969	0.009626
	Grasslands, pastures and deforested areas	183494	6357	0.034051
Kh Anthropic	Lack of built structures	397516	1879	0.004716
	Proximity of infrastructure elements, built-up areas	650429	13883	0.021118

The resulting susceptibility map was reclassified according to the success curve of the model which describes the relationship between the susceptibility classes and the landslides identified in the field for each susceptibility class, after sorting the pixels in descending order (Fig. 80).



The success rate varies according to a logarithmic function (y = 15.745 ln (x) + 29.61), with R2 = 0.95, which indicates a good model fit considering the relationship between the prediction capacity and the landslide inventory used for training the model (Chung and Fabbri 1995).

Fig. 80: Success rate of the susceptibility model (susceptibility classes marked by colour symbols)

Application of temporal landslide hazard scenarios

Starting from the assumption that a cumulative amount of precipitation which has triggered landslides in the past will have the same effect in the future, and using the previously identified probability classes, four scenarios were analysed corresponding to four recurrence intervals of the landslide triggering precipitation events with a known date of occurrence: first scenario (21 May 2005), second scenario (26 April 2006), third scenario (4 July 2010) and fourth scenario (25 February 2013).

The spatial analysis of the landslide hazard was performed using GIS techniques and included a series of work stages for each of the four scenarios. The most important regarded the identification of the number of pixels for each susceptibility class, the number of pixels with landslides, the landslide favourability values and the landslide probability associated to each class (table 3).

The probability of landslide occurrence was calculated for each susceptibility class using formula [2]: (Zêzere et al. 2004b):

$$P = 1 - \left(1 - \frac{T_a}{T_y} * pred\ y\right) \text{ [2], where:}$$

P = probability of landslide occurrence for each scenario;
T_y = number of pixels for each susceptibility class (area of each susceptibility class);
T_a = number of landslide pixels for each susceptibility class (landslide area);
Pred y = landslide favourability value.

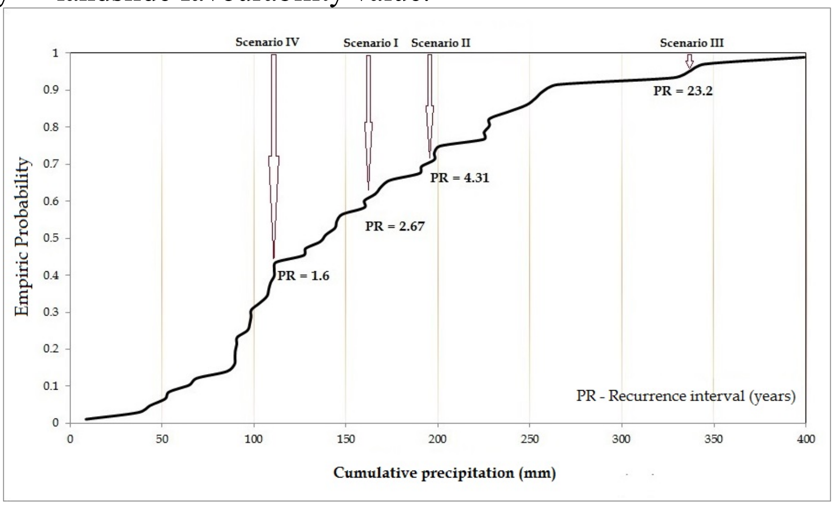


Fig. 81: Empiric probability of three-month cumulative precipitation – arrows point to the cumulative precipitation amount which triggered landslides, having a specific recurrence interval used for the four model scenarios.

When integrating equation [2] in GIS as a spatial analysis equation, the results show that the high landslide susceptibility class (I) is characterised by a probability of 0.021 (1:46 years) according to scenario I (Fig. 82.A), a probability of 0.0226 (1:44 years) according to scenario II (Fig. 82.B), a probability of

0.0298 (1:33 years) according to scenario III (Fig. 82.C) and a probability of 0.0298 (1:33.5 years according to scenario IV (Fig. 82.D).

Table 13: Probability of landslide occurrence for different scenarios

Susceptibility class	Number of pixels/ susceptibility class	Landslide pixels/ susceptibility class	Favourability value	**Probability value**	**Probability (years)**
Scenario I					
I	126136	5538	0.0429	***0.0216***	***46.2***
II	391446	5059	0.0128	*0.00644*	*155*
III	355920	514	0.0014	*0.00072*	*1388*
IV	163487	109	0.00066	*0.00033*	*3030*
Scenario II					
I	126136	5814	0.0450	***0.0226***	***44.2***
II	391446	5133	0.0130	*0.0065*	*153.8*
III	355920	528	0.0014	*0.00074*	*1351*
IV	163487	108	0.00066	*0.00033*	*3030*
Scenario III					
I	126136	7038	0.054	***0.02973***	***33.6***
II	391446	5200	0.0131	*0.0066*	*151*
III	355920	538	0.00151	*0.000754*	*1326*
IV	163487	109	0.0006665	*0.00033*	*3030*
Scenario IV					
I	126136	7688	0.0591	***0.0298***	***33.5***
II	391446	7373	0.0186	*0.0093*	*107.5*
III	355920	558	0.00156	*0.00078*	*1278*
IV	163487	109	0.0006665	*0.00033*	*3030*

In hazard analysis the main focus is placed on spatially and temporally identifying the areas with high probability of being affected in the future by similar events to the ones from the past. Therefore, in order to have a realistic prediction of the landslide prone areas in similar climatic conditions, the variations of landslide probability (in years) were statistically analysed for the 2005-2012 interval.

The prediction scenarios were created by solving the equations of the correlation curves for each susceptibility class, for four representative years for wich the evolution trend of the precipitation amount was determined for each of the four years using the climatic model ALADIN. In order to explain the reason for selecting the ALADIN model, we included: The Aladin model was developed by the National Institute of Meteorology and can be applied only to the Romanian territory, as it was orographically validated to identify the trend of average precipitation.

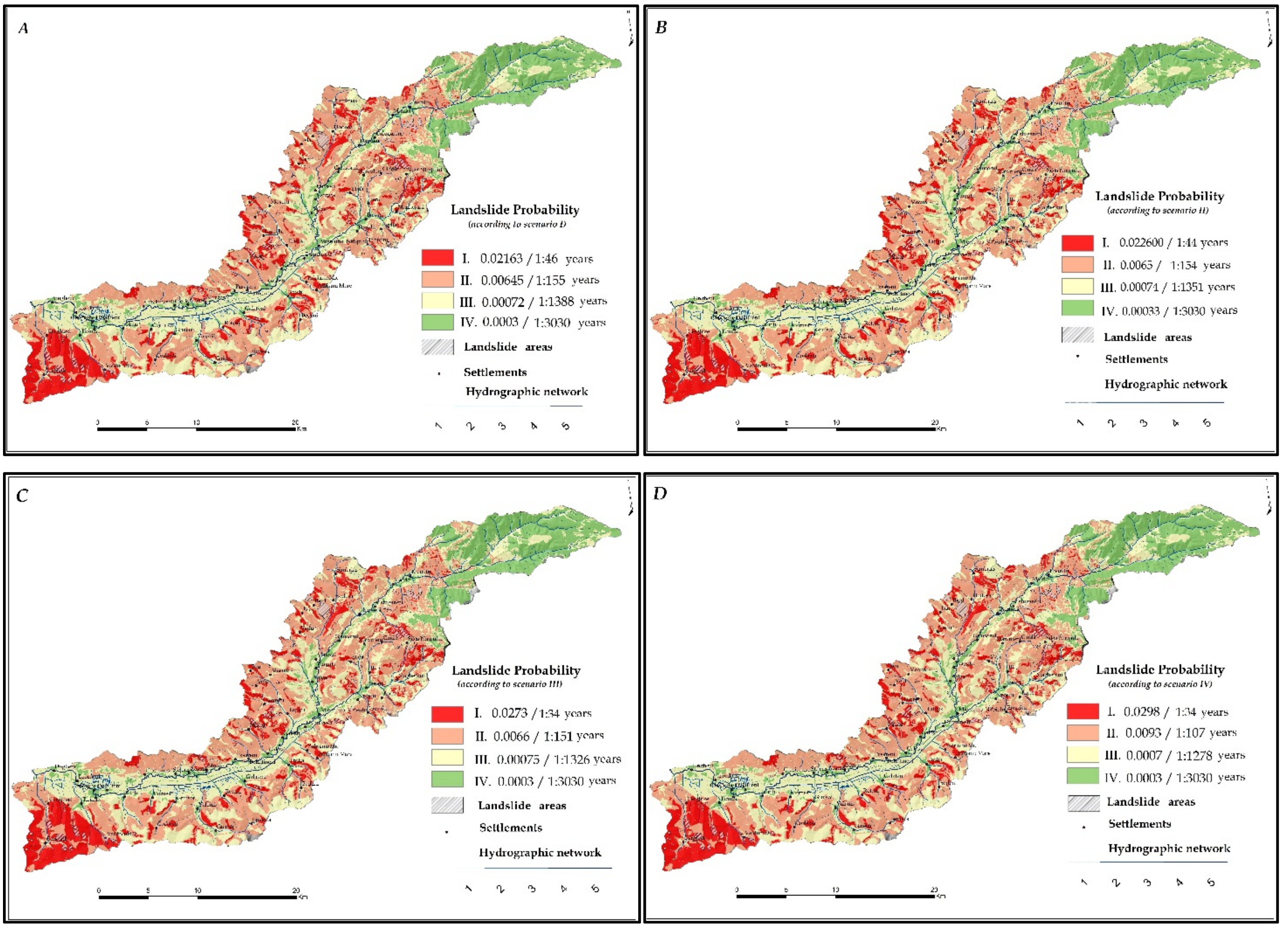


Fig. 82: Probability of landslide occurrence for three-month cumulative precipitation of 190.1 mm (A), 159.8 mm (B), 337 mm (C) and 111.6 mm (D).

Table 14: Probability in years for each susceptibility class

		Scenario				**Prediction scenarios**			
Susceptibility classes		**I. (2005)**	**II. (2006)**	**III. (2010)**	**IV. (2013)**	**P. V. 2021**	**P. VI. 2050**	**P. VII. 2071**	**P. VIII 2100**
	I.	46	44	34	33	24	13	10	8
	II.	155	154	151	107	91	30	6	-
	III.	1388	1351	1326	1278	1195	845	591	241
	IV.	3030	3030	3030	3030	-	-	-	-
		Landslide Probability based of the model results					Prediction scenarios		

Using the prediction methodology, three correlation curves were identified, corresponding to the first three susceptibility classes and defined by the following equations:

- the Saturation Growth-Rate curve was used for the very high susceptibility class, defined by the formula: $Y = \frac{ax}{b + x}$, a = 0.402, b= - 1987.48, x = year of the prediction, y = probability (years)

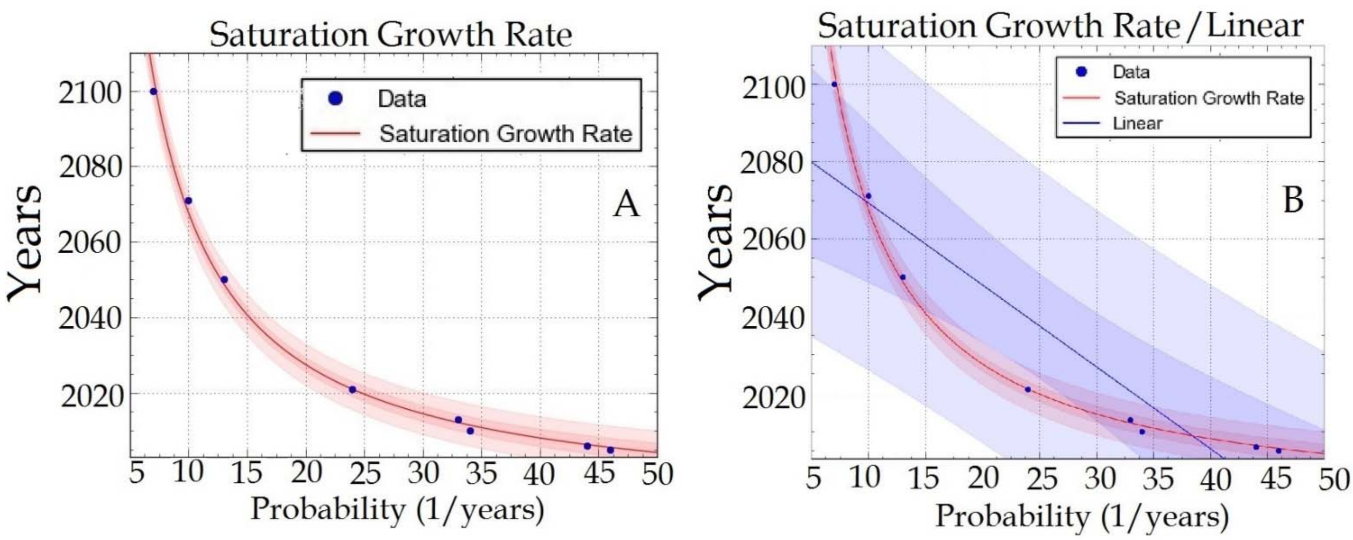


Fig. 83: Graph of the correlation function for the very high susceptibility class (I) (A) and the graphic comparison of the first two correlation curves (B)

- the Rational Function curve was used for the high susceptibility class, defined by the formula:

, a = -9.061339e+009, b = 4357783.3, c = 46112.75, d = - 23.5029, x = year of the prediction, y = probability (years).

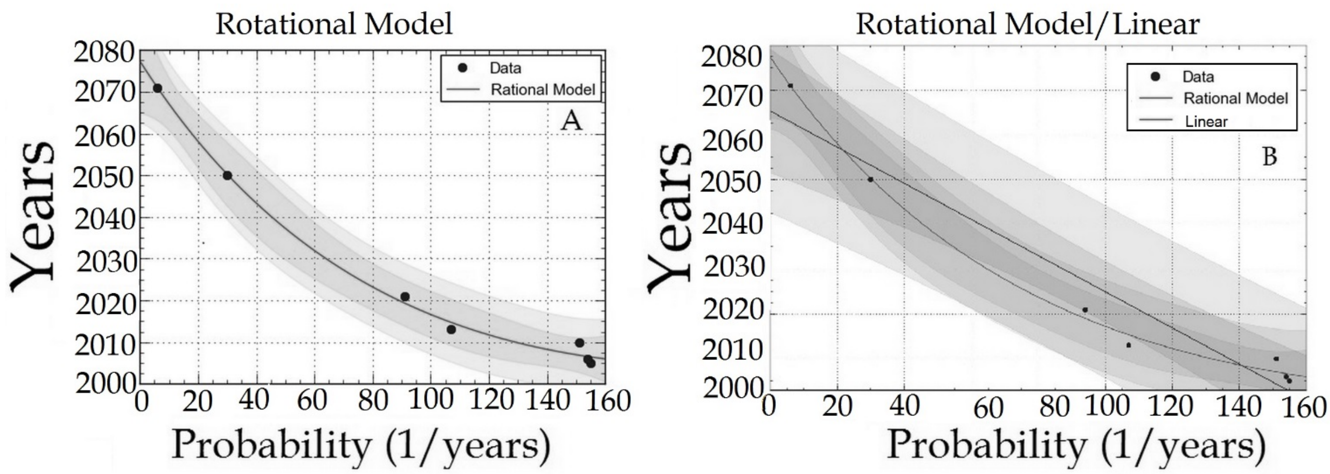


Fig. 84: Graph of the correlation function for the high susceptibility class (II) (A) and the graphic comparison of the first two correlation curves (B)

- the Linear Fit curve was used for the medium susceptibility class, defined by the formula:

Y = a + bx, a = 25609.2, b = -12.08, x = year of the prediction, y = probability (years).

All three functions which were used to create the prediction fulfil statistical standards, as they have a close-to-unit correlation coefficient and a low maximum residue. For a better accuracy of the prediction results and in order to select the best equation, the graphical comparison of the correlation curves was performed (Fig. 83.B, 84.B., 85.B.) using the AIC statistical criterion and the visual interpretation of the probability values fitting in the confidence and prediction interval of 95%.

The analysis of the criteria mentioned above emphasises the impossibility to use a linear correlation (although it is used in the majority of studies) for the first two susceptibility classes – high and very high (fig. 85), as the probability values which were statistically determined do not fit into the confidence interval and the AIC value of the linear correlation is much higher than that of the selected functions (Akaike 1974). For the medium susceptibility class (fig. 85) the linear correlation of the prediction is visibly validated, both graphically and numerically.

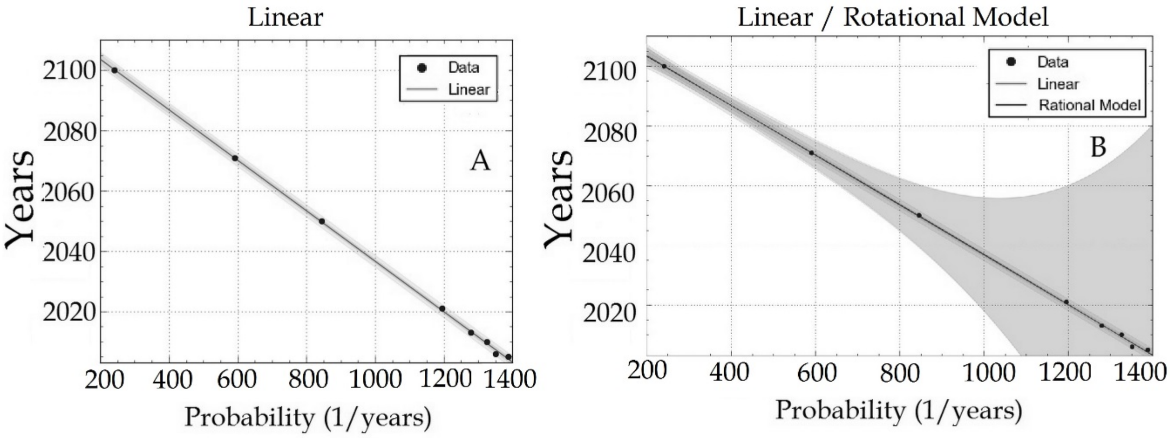


Fig. 85: Graph of the correlation function for the medium susceptibility class (III) (A) and the graphic comparison of the first two correlation curves (B)

The analysis of the landslide probability results for the three susceptibility classes and the four characteristic years evidences an acceleration tendency of landslide events, starting from the probability of 1:33 years in 2013 and reaching a probability of 1:7 years, for a total period of 87 years in the very high susceptibility class. The highest probability of landslide occurrence was calculated for the high susceptibility class, both for short (8 years, 2005-2013) and long (87 years, 2013-2100) time intervals, with significant variations between the characteristic years.

Medium and small susceptibility classes are characterised by small variations of probability, for short time intervals 2005 (1:1388 years) - 2013 (1:1278 years), as well as for the entire time interval, mainly due to the low landslide incidence in these areas.

Prediction is the main aim of GIS spatial analysis models. The scenarios for modelling the prediction of landslide occurrence highlights through predictive mapping the surfaces included in susceptibility classes in relation to their temporal probability. The use of statistical equations defining regression curves in the form of equations of spatial analysis and their integration in the GIS environment enabled the spatial identification of the probability of occurrence depending on the susceptibility degree. The four predictive scenarios illustrate the same exponential variation of the relationship between the recurrence interval and the landslide susceptibility class and of the variation per probability class in relationship with the annual variation.

7.2.7. LARGE-SCALE LANDSLIDE RISK ANALYSIS – CASE STUDY IN THE SMALL NIRAJ RIVER BASIN

The river basin of the Small Niraj was used to determine the landslide risk due to its high potential of landslide occurrence over the last seven years, in the time interval 2005-2012 (according to the reports of the Inspectorate for Emergency Situations, Mureș). The territory includes the administrative units of 10 settlements where landslide events have caused material damages to buildings and transport infrastructure. Thus, the study focused on the acquisition of the spatial attribute data, the initiation, processing and updating of the databases.

Table 15: Landslide Risc Matrix

		Hazard			
		H_1	**H_2**	**H_3**	**H_4**
Exposure	**E_0**	R_0	R_0	R_1	R_2
	E_1	R_0	R_1	R_2	R_3
	E_2	R_1	R_2	R_3	R_4
	E_3	R_2	R_3	R_4	R_4

In order to identify the risk classes from the river basin of the Small Niraj (Fig. 88), a first qualitative approach was based on a matrix encompassing the relationship between hazard classes and the vulnerability to landslides (Tabelul 15).

The current study used the number of persons affected by landslides according to the Plan of Risk Analysis and Mitigation from the Mureș County, 2011 and the approximate costs of real estates from the Mureș County, 2013. The approximate costs vary between 0.4 - 500 RON/m^2 (Fig. 87).

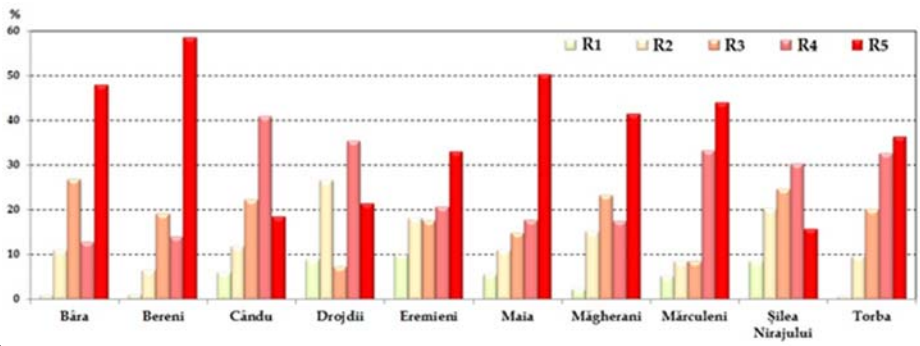


Fig. 86: Percentage of built up areas from the Niraj river basin in each landslide risk class

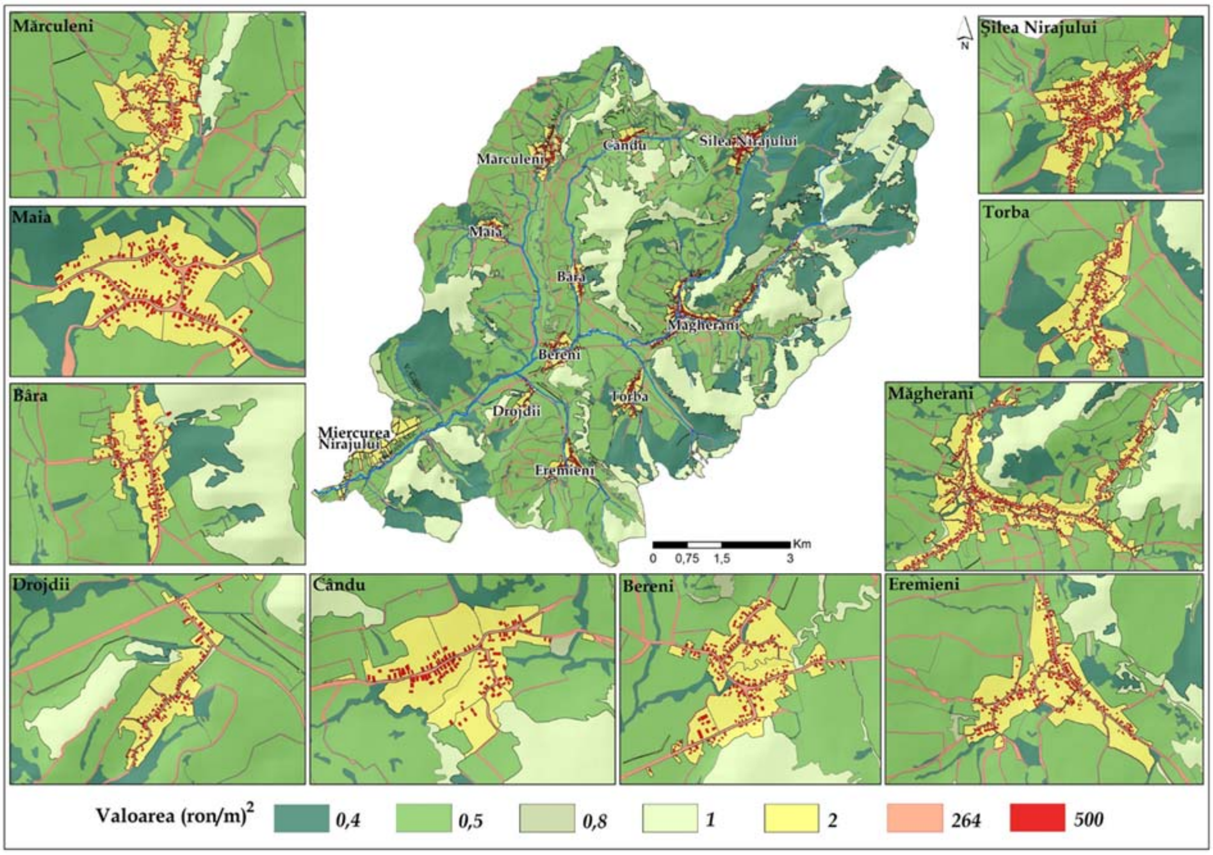


Fig. 87: The value of the infrastructure and terrains from the Small Niraj river basin

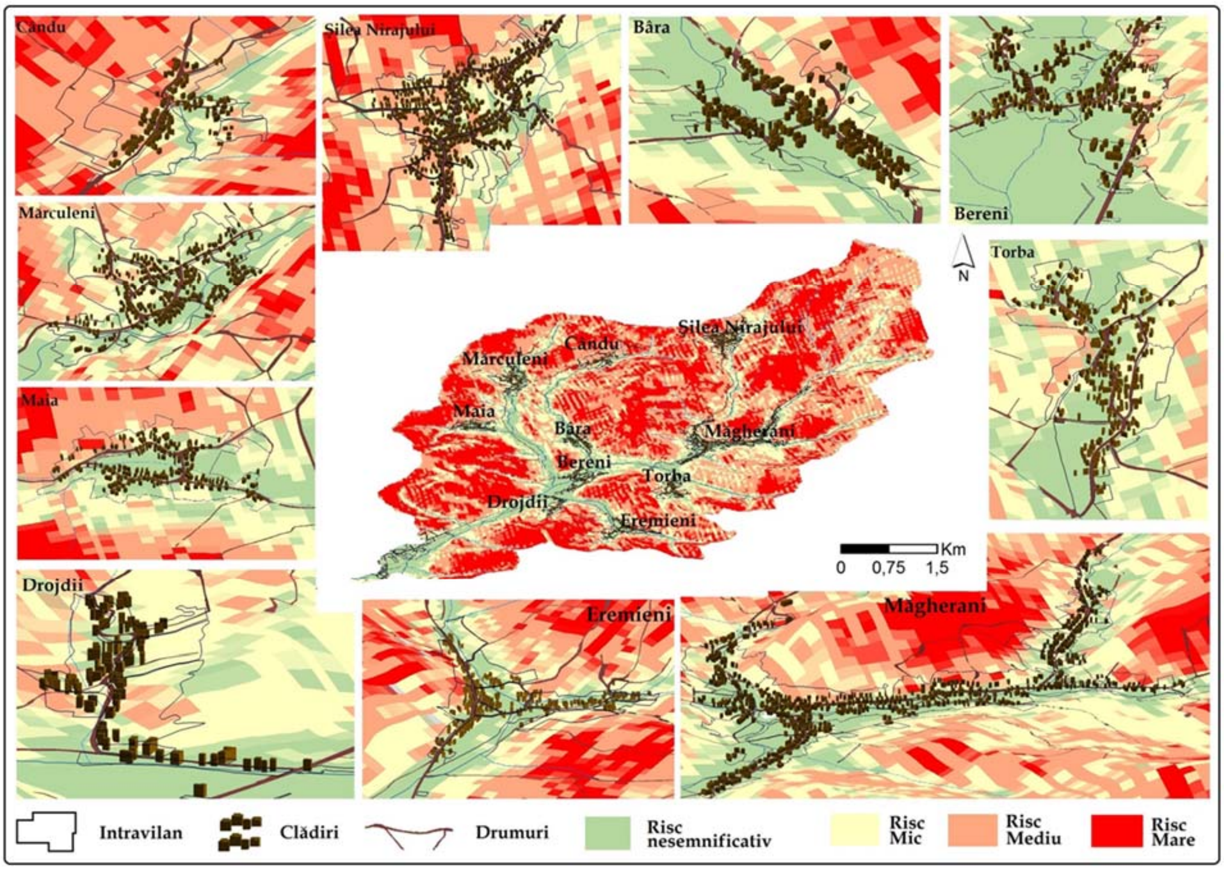


Fig. 88: Distribution of buildings and transport infrastructure on landslide risk classes

7.3. MEANDERING HAZARD AND RISK

The identification of the area with meandering potential highlighted territories with low, medium and high meandering potential (Fig. 89, 90), according to the average erosion rate and based on the presence of abandoned river beds and the proximity of geological sectors with a high resistance to erosion:

$$ZPM_{ridicată} = ZIM + 10 * RME$$

$$ZPM_{moderat} = ZPM_{Scăzut} + 10*RME$$

$$ZPM_{scăzută} = ZPM_{moderată} + 10*RME$$

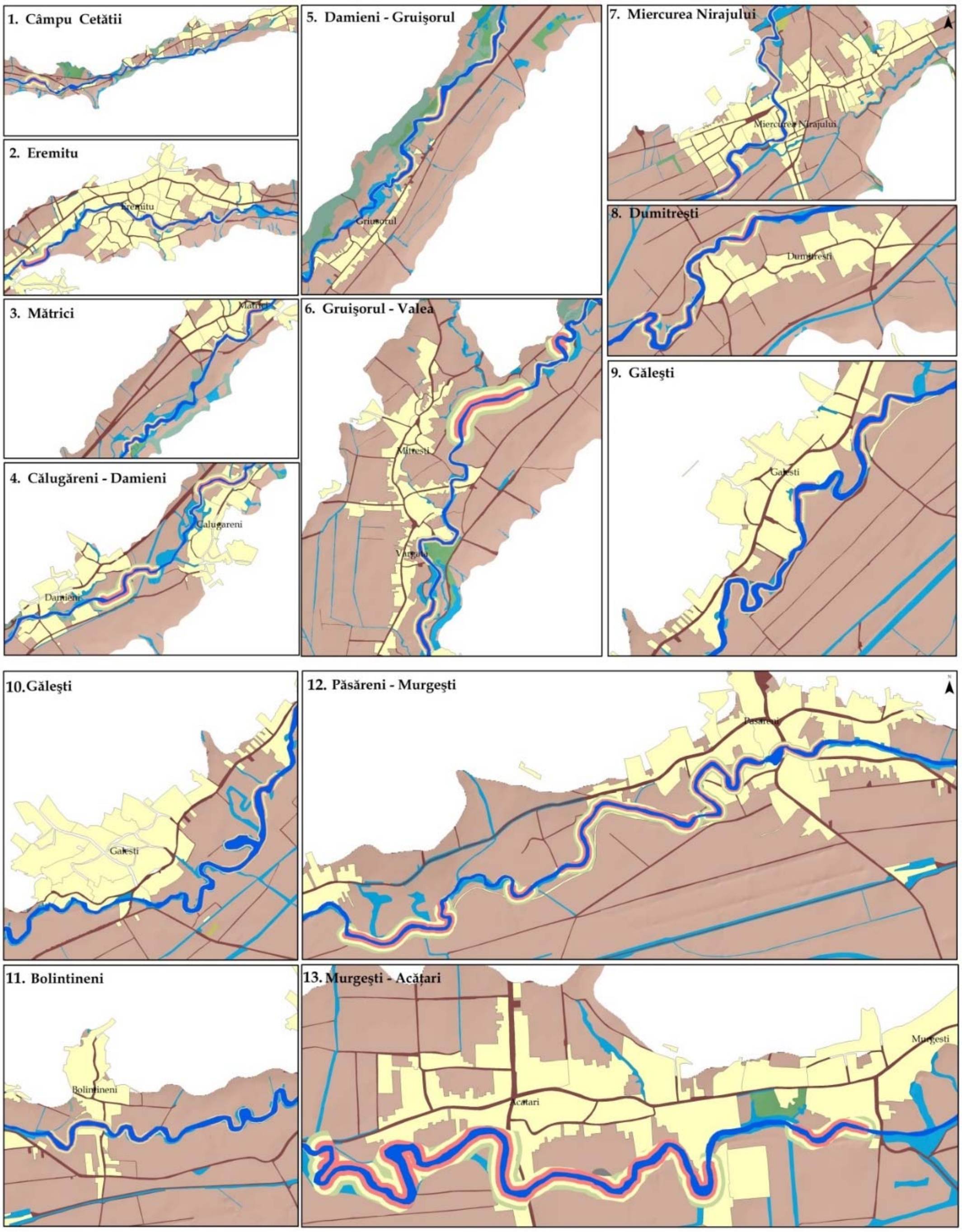


Fig. 89: Exposure of infrastructure to meandering of the Niraj in the Câmpu Cetății-Acățari sector

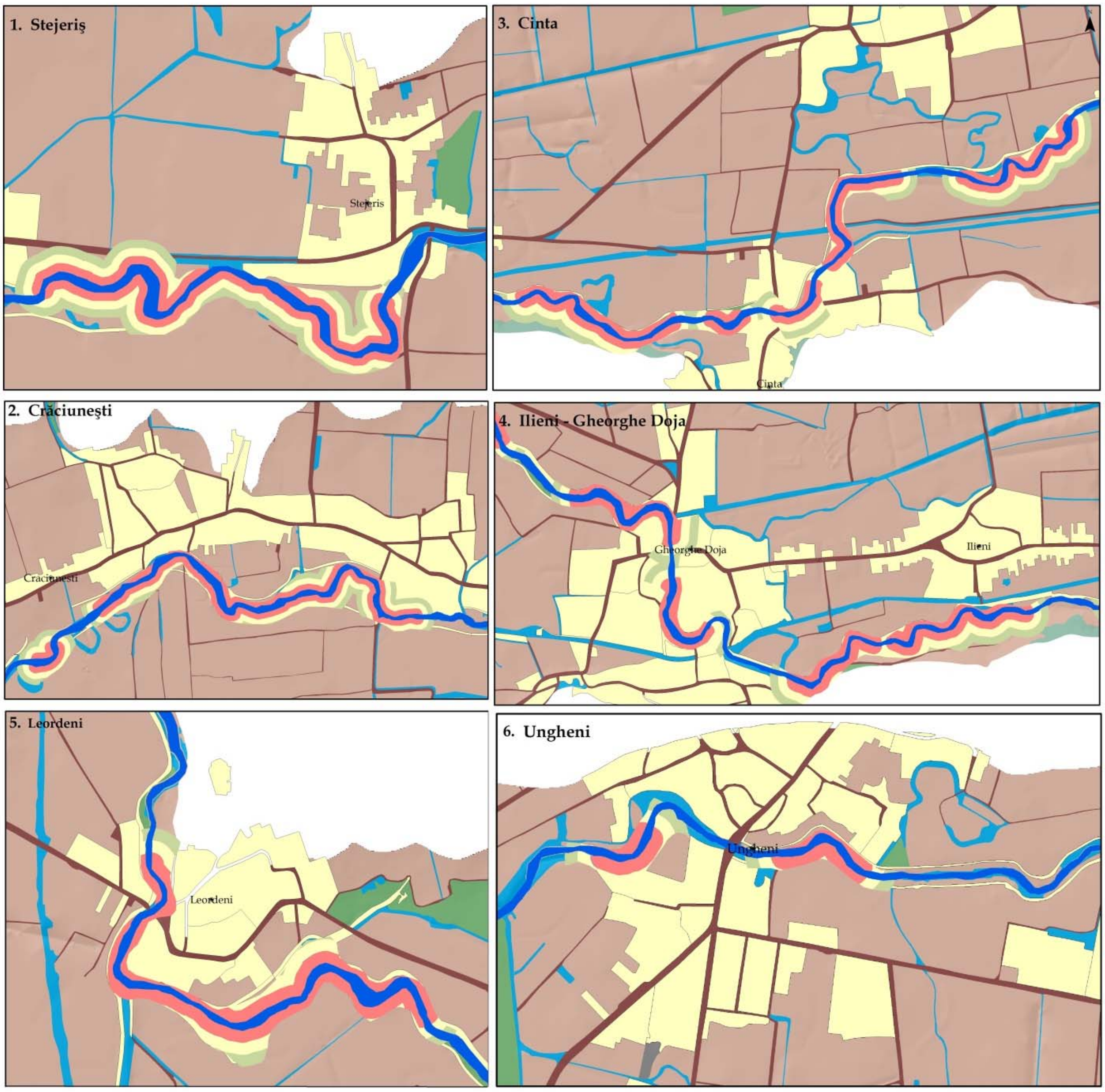


Fig. 90: Exposure of infrastructure to meandering of the Niraj in the Stejeriș - Ungheni sector

The detailed analysis highlights a series of meander bows with an increased dynamics which can lead to bank failures if the there are no natural or anthropical constraints (dams), determining losses in the agricultural lands from outside the built up areas: Câmpu Cetății , Mătrici, Dămieni, Gălești, Acățari, Dumitrești, Gruișorul, Mitrești și Murgești (Fig. 7.35), Stejeriș, Crăciunești, Cinta and Ilieni (Fig. 89).

In the built up areas the high meandering potential is limited to a small number of meander bows : Eremitu (4), Mătrici (1), Călugăreni (1), Gruișorul (1), Mitrești (1), Vărgata (2), Păsăreni (5), Acățari (5) (Fig. 89), Stejeriș (1), Crăciunești (2), Cinta (1), Gheorghe Doja (2), Leordeni (3) and Ungheni (1) (Fig. 90).

Applying this methodology one can provide a medium-scale image of the river bed dynamics which can enable the identification of medium to high risk areas in the next 50 years. This work scale is imposed by the detail level of the database and can lead to slight overestimations of the meandering potential for sectors with a certain stability (which do not show any effects of lateral erosion at the present moment of analysis, but which can be affected at the moment when the threshold level of the causing factors is reached and surpassed).

8. ASSESSMENT OF TERRAIN SUITABILITY TO VARIOUS AGRICULTURAL USES BY MEANS OF THE AGRICULTURAL BONITATION TECHNIQUE

In the present context, the research concerned with land suitability for certain types of agricultural use represents a very important stage in the decision process of the local and national authorities. The land capability classification includes the identification of land suitability for different agricultural uses as well as the restrictions determined by specific physicogeographical characteristics and is used as a study method for identifying the agricultural potential and the pedo-geographical identity of a territory. The suitability is expressed by means of land capability values in natural conditions and after their enhancement through land improvement measures (according to the Cadastre of Agricultural Fund).

Starting from the analysis of the qualitative soil parameters included in databases, a GIS spatial analysis model was created to identify the areas in the territory of the Niraj river basin which have the maximum suitability for the creation of fruit tree plantations. The model is developed on primary databases which were modelled and structurally derived according to the classical methods of land capability classification into 6 categories (fig. 91).

Table 16: Databases used for the modelling process

Database	Structure type	Attributes	Database type
DEM	raster	Elevation (m)	primary
Slope angle	raster	%	modelled
Aspect	raster	Aspect type	modelled
Soils	vector	Type, texture	primary
Permeability	raster	measure	modelled
Gleying	raster	Gleying classes	modelled
Edaphic volume	raster	%	modelled
Texture	raster	Texture type	primary
Average multiannual precipitation	raster (grid)	Precipitation (mm)	modelled
Average multiannual temperature	raster (grid)	Temperature (°C)	modelled
Pseudogleying	raster	pseudogleying degree	modelled
Humidity at the surface	raster	Humidity degree	modelled
Landslides	vector	Activity stage	modelled
Flood zones	vector	Inundability classes	modelled

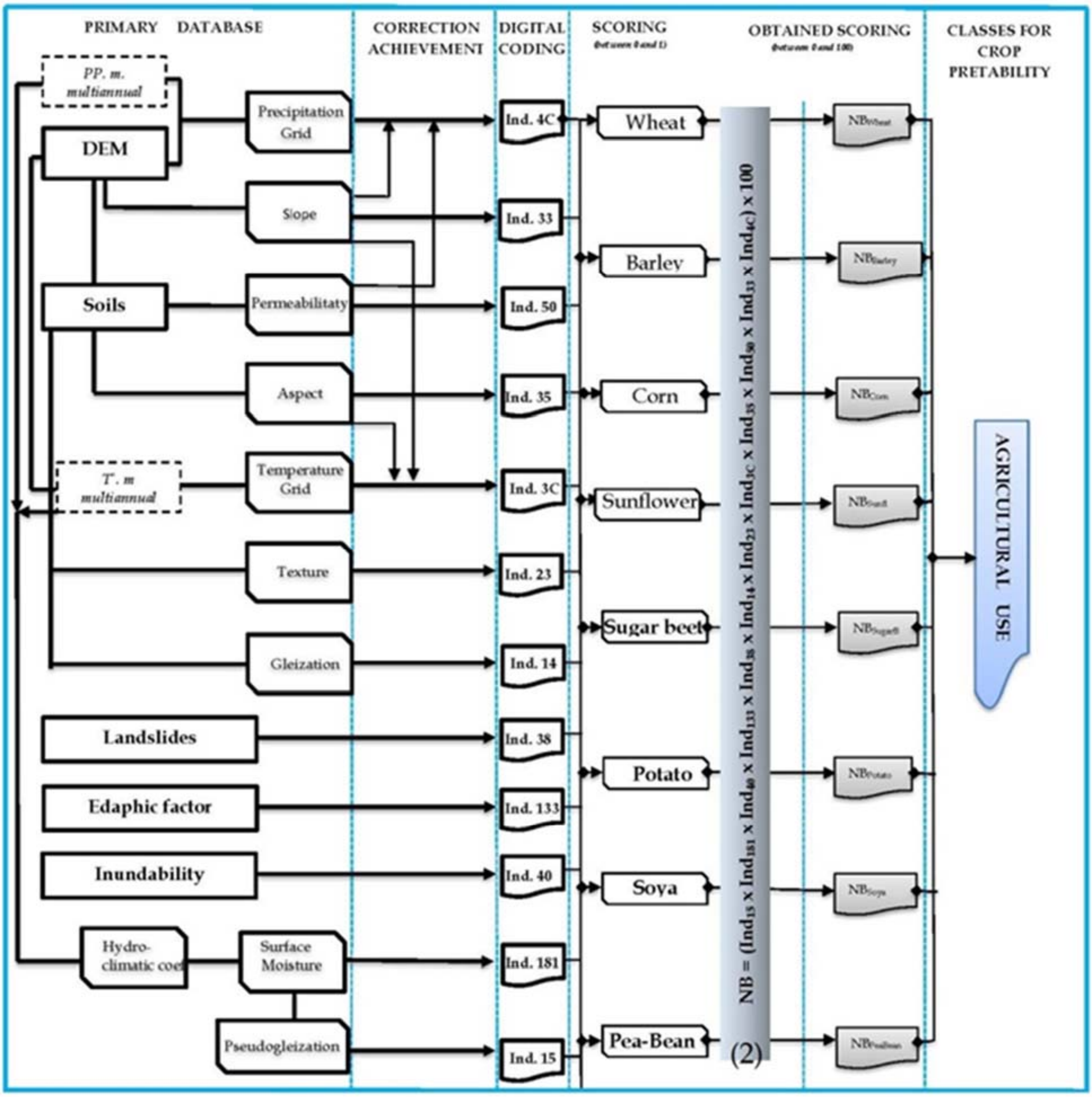


Fig. 91: Conceptual flow chart of the bonitation model for determining the suitability to different uses

As a result, the maps of each corresponding coefficients for the afore-mentioned indicators were generated in order to obtain the bonitation marks for each of the 24 uses: pastures (PS), grasslands (FN), apple tree (MR), pear tree (PR), plum tree (PN), cherry/sour cherry tree (CV), apricot tree (CS), peach tree (PC), wine vineyard (VV), grape-vineyard (VM), wheat (GR), barley (OR), corn (PB), sun flower (FS), autumn potato (CT), sugar beet (SF), soy (SO), green peas-beans (MF), oil flax (IU), fiber flax (IN), hemp (CN), lucerne (LU), clover (TR), vegetables (LG) and arable land (AR).

The result is represented by suitability maps for various uses and agricultural crops in the form of spatial databases with bonitation marks for certain measurable and significant indicators which were mapped at a local and regional level (Fig. 92, Table 17).

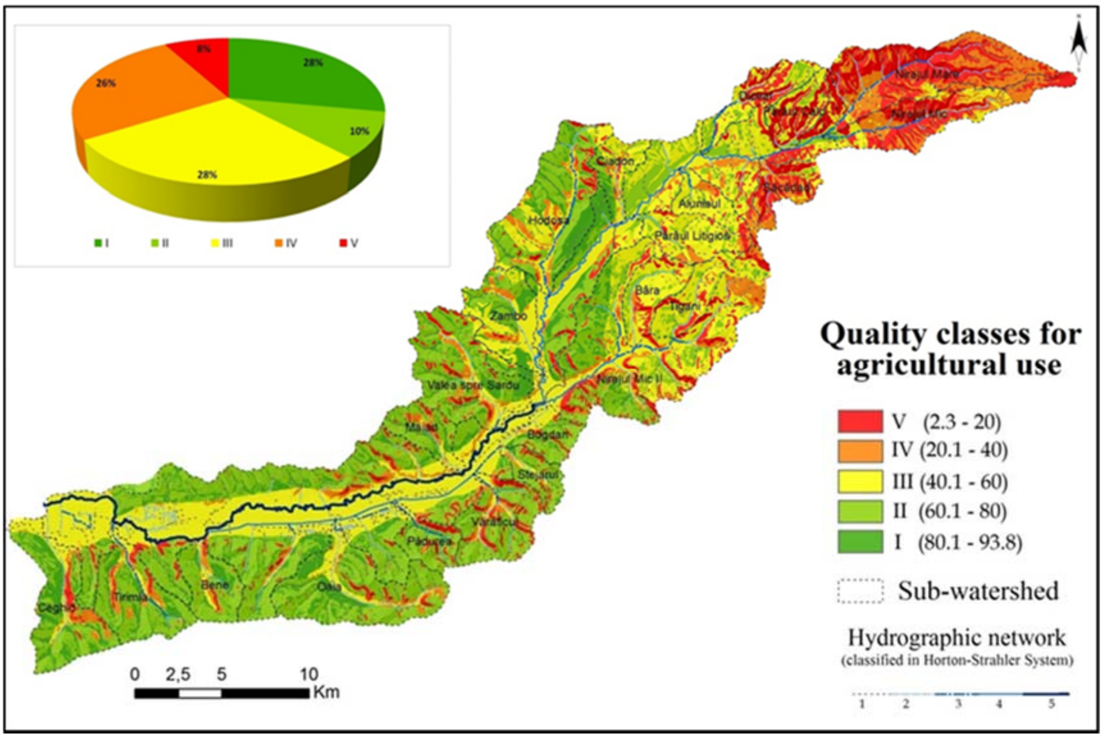


Fig. 92: Quality classes for agricultural use at the basin level

Table 17: Quality classes for agricultural land use at the basin and commune level

COMMUNE	Quality classes for agricultural use									
	I		II		III		IV		V	
	m²	%	m²	%	m²	%	m²	%	m²	%
HODOŞA	6850400	21.34	12128300	37.78	8656500	26.97	2556200	7.96	1907500	5.94
EREMITU	2349500	2.95	17687700	22.24	**37340500**	46.94	**6623900**	8.33	**15543800**	19.54
MĂGHERANI	0	0.00	8399800	17.61	**26605600**	55.79	**5905200**	12.38	**6776100**	14.21
VĂRGATA	**7543800**	19.73	12267100	32.08	14035500	36.70	2777100	7.26	1617000	4.23
MIERCUREA NIRAJULUI	**8502000**	16.49	**22710000**	44.04	12431700	24.11	3486800	6.76	4430700	8.59
CHIHERU DE JOS	0	0.00	1443400	2.18	9085100	13.71	**23178700**	34.98	**32548700**	49.13
BERENI	3748100	9.50	13512400	34.25	15719900	39.85	2099400	5.32	4369300	11.08
GĂLEŞTI	5428100	10.08	**27184600**	50.46	13047600	24.22	3583100	6.65	4633200	8.60
PĂSĂRENI	2929100	10.17	13147800	45.64	8637200	29.98	1504500	5.22	2590300	8.99
UNGHENI	6607500	20.89	9397200	29.71	12413700	39.24	1964700	6.21	1249400	3.95
GHEORGHE DOJA	6121700	16.59	15336500	41.57	11908500	32.28	1800800	4.88	1722400	4.67
ACĂȚARI	**12653900**	18.49	33121900	48.40	**17447900**	25.50	3051300	4.46	2158800	3.15
SUPLAC	3484600	30.37	6966200	60.72	208200	1.81	782400	6.82	31000	0.27
CRĂCIUNEŞTI	6111900	14.74	**20283700**	48.92	12848700	30.99	1303100	3.14	917300	2.21

8.4.1. Application of Soil Loss Scenarios using the Romsem Model Depending on Maximum Land Use Pretability. In order to identify the erosion according to the corresponding land uses and the highest degree of favourability resulted from the local soil, climate and topographic conditions, three scenarios have been applied. They contain variants of the correction coefficient (Fig.8A, B, C and D) for crop management applied on the sub-basins with the highest rates of surface erosion: Nirajul Mic, Bâra, Țigani and Pârâul Litigios, that will be subsequently described.

For the first scenario the modelling of the present situation was undertaken and the databases previously listed were used. Hence it can be observed that some important percentages of 58.17% of the Bâra sub-basin, 43.42% for the Nirajul Mic and 40.7% for Țigan correspond to the high rates of surface erosion. Class 0 that indicates accentuated stability of the analyzed territories is represented by low percentages (8%) (table 18).

For the IInd scenario the first two classes have been kept according to their pretability for agricultural land, the rest of the terrains keeping their land use criteria specific to the present moment. By eliminating the last two favourability classes occupied by forested areas, it can be observed with respect to the agricultural areas an increase of the surfaces.

The IIIrd scenario is based on the use of the first classes of pretability to arable land and on that of the IInd class for pretability to orchards. At the level of the Bâra and Țigani sub-basins, having introduced the class with favourability for orchards, the percentages characterised by the maximum values of the C coefficient are constant. Some modifications can be seen however as there is an increase in the Nirajul Mic and Pârâul Litigios sub-basins.

By applying the ROMSEM model and by the use of the three variants of the C coefficient according to the three scenarios while maintaining constant the other factors that contribute to the modelling, major modifications can be observed when it comes to the level of erosion class distribution in the studied sub-basins. (Tabelul 18, Fig. 93).

Table 18: Relative spatial expansion of erosion classes in river sub-basins

Sub-basin	Erosion Classes (t/ha/an)				Moment
	0 - 0,5	**0,5 - 3**	**3 - 9**	**>9**	
Nirajul Mic	77,387	20,661	3,678	0,423	Scenario I
	60,010	36,972	3,476	0,350	Scenario II
	65,486	31,858	2,417	0,239	Scenario III
Bâra	75,705	21,902	4,448	0,715	Scenario I
	59,431	36,760	2,700	0,353	Scenario II
	73,689	24,013	2,035	0,263	Scenario III
Țigani	67,835	29,080	6,133	1,204	Scenario I
	52,587	43,338	3,628	0,585	Scenario II
	64,714	32,511	2,391	0,383	Scenario III
P. Litigios	83,131	15,360	1,827	0,692	Scenario I
	72,735	25,312	1,467	0,374	Scenario II
	78,570	19,981	1,153	0,296	Scenario III

.

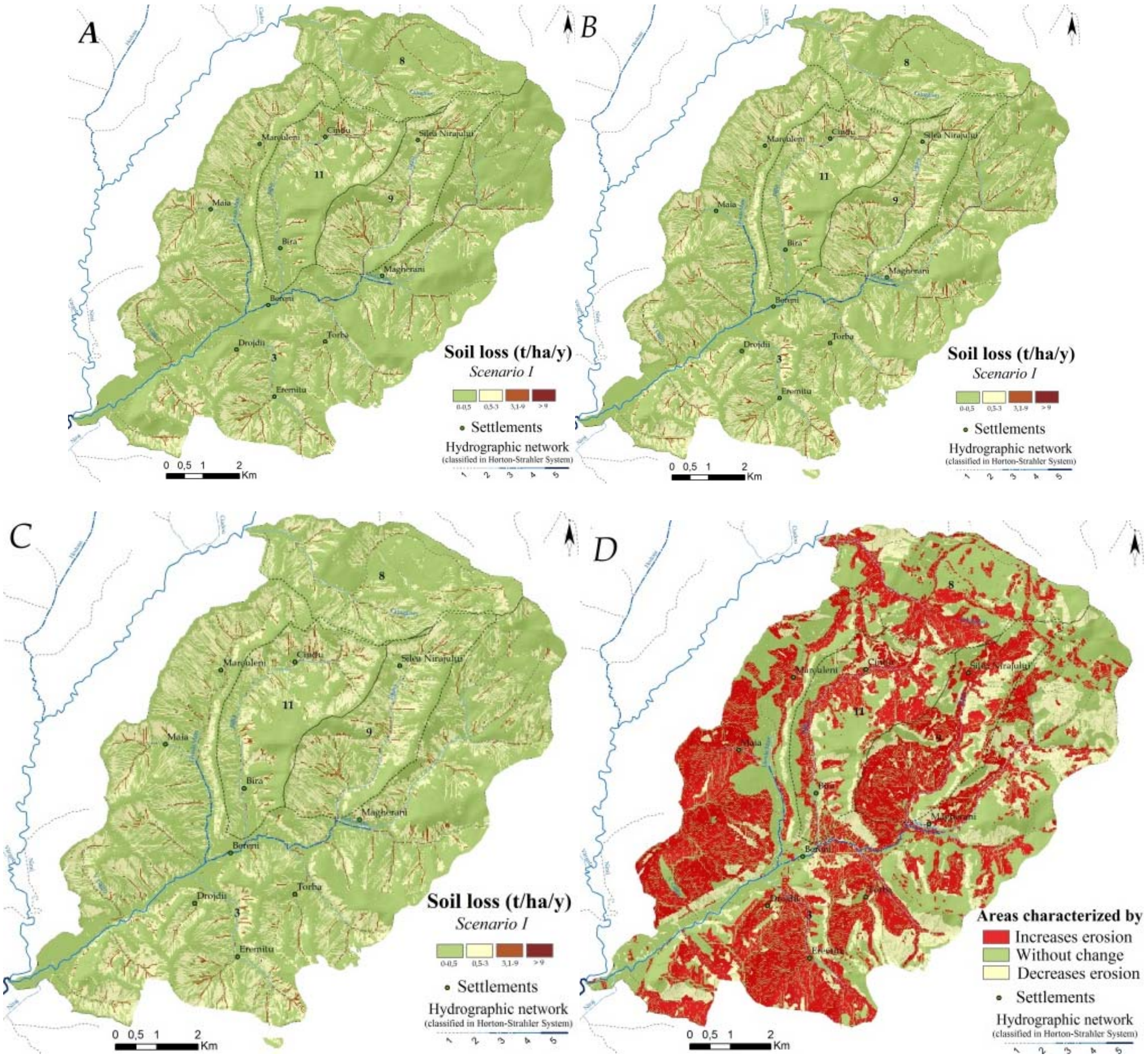


Fig. 93: Soil loss estimation according to scenario 1 (A), scenario 2 (B) and scenario 3 (C) with highlighted differences (D) at the level of the Nirajul Mic, Bâra, Țigani and Pârâul Litigios sub-basins.

The quantitative analysis of results indicates an increase of the surface percentages where low levels of erosion occur (0-0.5 t/ha/yr) in the Niraj river basin, when scenario II is put in application, namely for the first two maximum favourability categories. As a comparison, the results of scenario I, where classes IV and V were proposed for forest as a land use, show a decrease in percentage of the surfaces with mean erosion (21.8%). The results of scenario III offer the best results in the entire river basin, namely when the first classes are used as arable land and the IInd class as orchards.

9. MULTI-HAZARD AND MULTI-RISK ANALYSIS AT COMMUNE LEVEL

The applied character of the present study requires an estimation of the cumulated geomorphological risks from the analysed territory. This estimation creates an overview on the geomorphological potential and the risk-generating geographical phenomena. This type of approach facilitates the identification of a realist solution for these problems.

The multi-hazard map was created using the previous results of assessing: the landslide probability of occurrence, the potential of fluvial erosion, the map of the exposure to areolar erosion as well as the flood potential map.

A matrix approach was used in order to determine the multi-risk classes, which captures the relationship between hazard and consequence classes (Table 19).

Table 19: Risk classes determination using the hazard and consequence class correspondence

		CONSEQUENCES				
HAZARD		Very High	High	Medium	Low	Insignifiant
	High	R_1	R_1	R_2	R_3	R_4
	Medium	R_1	R_2	R_3	R_3	R_5
	Low	R_2	R_3	R_4	R_5	R_5

where R1 – Risk Very High, R2 – High, R3 – Medium, R4 – Low, R5 – Insignfiant

In order to improve the value of the results, qualitative classes were employed as suggested by AGR, 2000, but their limits are based on a monetary classification.

The challenge of this approach consisted of obtaining a building database for the 63 settlements (included in the 16 administrative territories from the river basin) which eventually included after the digitisation from recent satellite images a total of 12.531 buildings.

Nevertheless, the focus was placed on the three administrative territories which are entirely represented in the Niraj watershed.

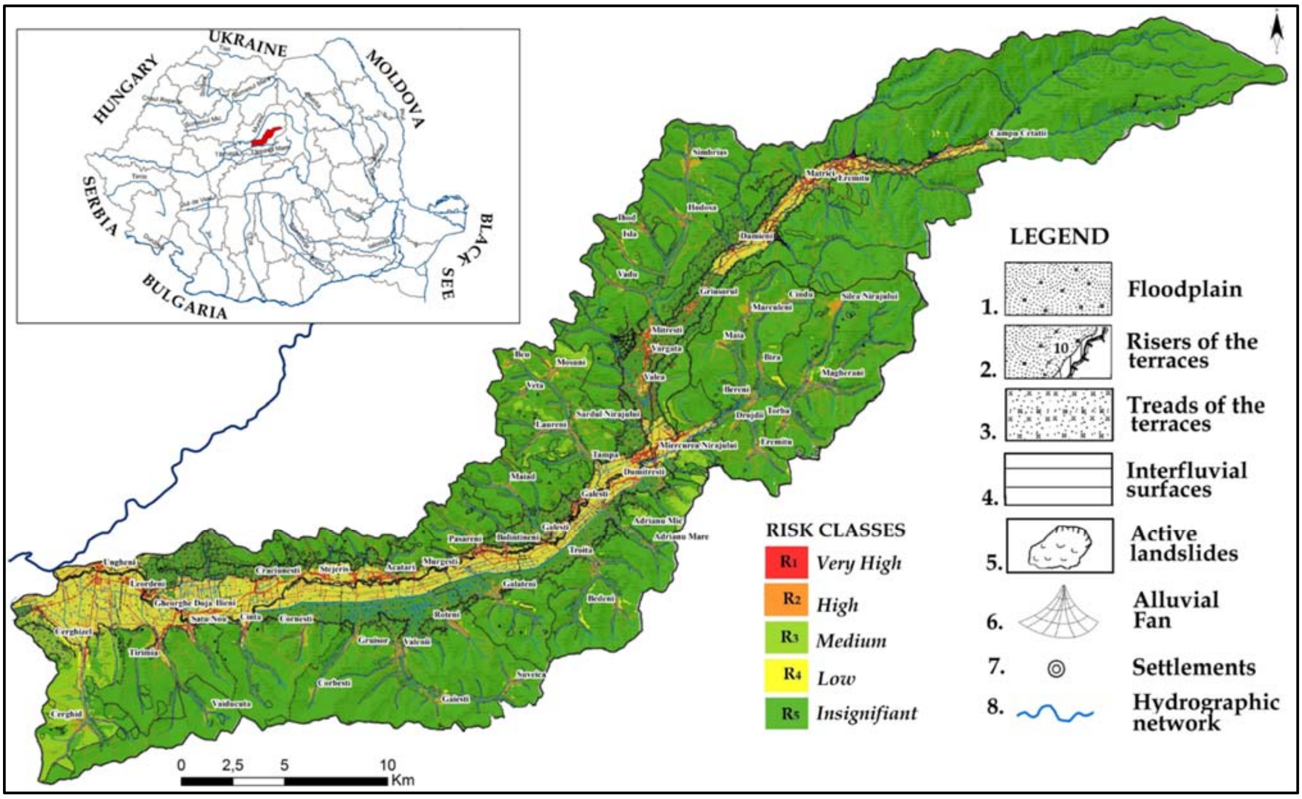


Fig. 94: Basin level multi-risk map

Analysing the spatial distribution of the administrative territories on each risk class, with the exception of the R5 class which corresponds to the insignificant risk, one can notice the administrative territories of Gheorghe Doja, Ungheni and Eremitu in the very high risk class, the administrative territories of Bereni, Crăciuneşti, Păsăreni, Găleşti, Miercurea Nirajului, Măgherani, in the high risk class and the administrative territories of Ungheni, Gheorghe Doja, Crăciuneşti and Păsăreni, in the medium risk class

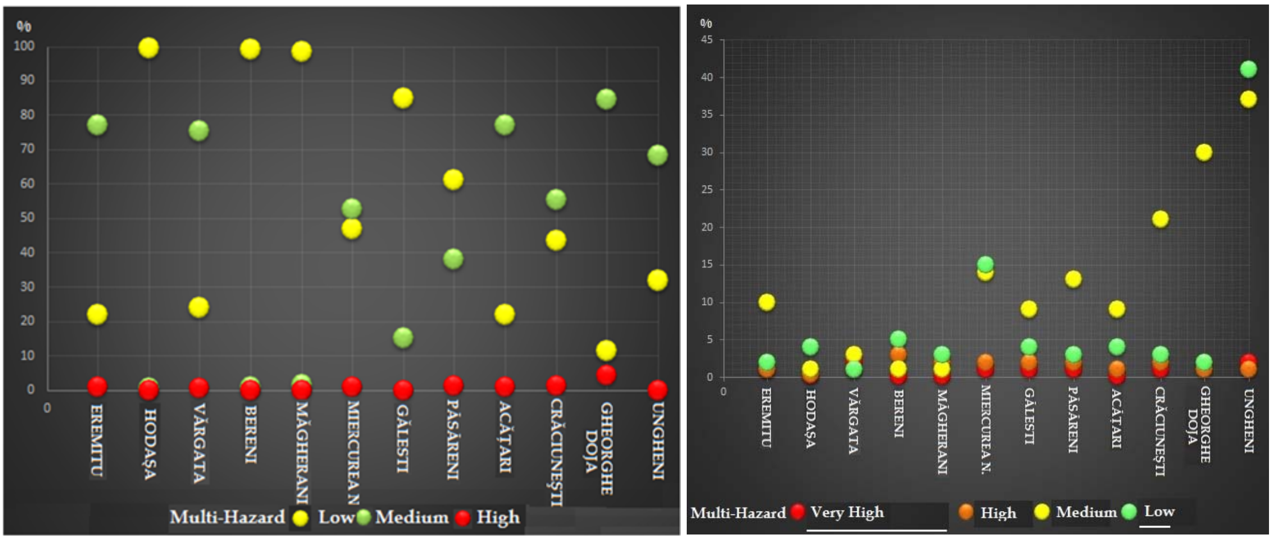


Fig. 95: Percentage of the Niraj administrative units in each multi-hazard (left) multi-risk class (right)

By applying the multi-hazard and multi-risk model through the mediation method, a distribution of the analysed territory was performed in a first stage using specific multi-hazard classes. In order to determine the risk classes in a quantitative manner the matrix method was used, which highlights the relationship between the classes of the cumulated hazard and the expected negative effects (by classifying the actual values of the terrain in land use classes and costs of the built area correspondent to each settlement from each commune of the river basin).

Specialised studies highlight the advantages of a multi-hazard analysis as compared to singular, individual approaches, the results being better used in planning mitigation measures of negative effects (Bell and Glade, 2012). However, the main objective remains the application of multiple scenarios where the analysis of a triggering threshold is done in respect to all local transformations. Thus, the results could be used as cumulated predictions. For the Niraj river basin this type of approach and the results of the multi-hazard and multi-risk model provide useful information in research studies from the stage of the territory analysis used in the creation of General Urban Plans.

The resulting maps represent work instruments which the authorities can use in order to restrict the building process in areas characterised by a high probability of occurrence of risk-generating processes. This measure would decrease the potential effects of their enactment.

In the process of creating the cartographic database one focused on a simple and easy-to use form which also follows the legislative precepts so that it may be used in future local studies. Thus, urban planning and risk strategies can receive precious information from the applied multi-hazard analyses, the results being easily included in a complex applied model of organising the Niraj river basin in respect to the risk factors.

The assessment of landslide, flood and river bed migration hazards through their spatial and temporal dimensions, using scenarios assisted by geomorphological mapping, offers optimum solutions to the development and organisation of the areas affected by the analysed geomorphological processes. This is possible due to the favourable topography and general physical-geographical characteristics of the analysed territory and due to the use of models which synthesise the geomorphological complexity.

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